CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Plug Loads and Lighting Modeling

Measure Number: 2016-RES-ACM-D

Residential Modeling

2016 CALIFORNIA BUILDING ENERGY EFFICIENCY STANDARDS

California Utilities Statewide Codes and Standards Team June 2016

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EXECUTIVE SUMMARY

Introduction

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

The overall goal of this CASE Report is to present the Statewide CASE Team's recommended rulesets (or "algorithms") to model the per-household annual energy consumption (AEC) of plug loads and lighting in newly constructed residential buildings. Plug loads include white good appliances—such as refrigerators and freezers, dishwashers, clothes washers and dryers, and ovens and ranges—as well as consumer electronics and other miscellaneous electric loads (MELs). The report contains pertinent information that justifies the proposed revisions to the modeling approach including:

- Description of the code change proposal, the measure history, and existing standards (Section 2);
- Methodology and assumption used to develop the proposed AEC algorithms (Sections 3 and 4);
- Results of the analysis, recommended algorithm for each product category, and how recommended the algorithms compare to existing field studies and energy models (Section 4);
- Methodology, results and recommendations for allowing compliance credit for the installation of appliances that are more efficient than is estimated in the default AEC algorithms (Section 5);
- Methodology, results, and recommendations regarding the recommended load profiles for all product categories (Section 6);
- Summary of all proposed default AEC equations and load profiles (Section 7);
- Recommended future work (Section 8); and
- Proposed language for the Residential ACM Reference Manual (Section 9).

Scope of Code Change Proposal

The plug loads and lighting modeling measure will affect the following code documents listed in Table 1.

Table 1: Scope of code change proposal

Standards Requirements (see note below)	Compliance Option	Appendix	Modeling Algorithms	Simulation Engine	Forms
N/A	N/A	N/A	Pm	Pm	N/A

Note: An (M) indicates mandatory requirements, (Ps) prescriptive, (Pm) performance.

Measure Description

This CASE Report proposes updated rulesets to use in the Title 24 residential compliance software to estimate annual energy use of plug loads and lighting in residential buildings. Plug loads are defined as appliances or electronic devices that are generally plugged into a receptacle, such as white goods, consumer electronics, and other miscellaneous electric loads (MELs); lighting includes all portable and hardwired interior, exterior, and garage lighting. These end uses collectively represent the purchase and usage decisions made by building occupants that have the greatest impact on its subsequent electricity use.

As California strives to achieve ZNE goals, it is critical that the Title 24 compliance software estimates energy use from MELs and lightings appropriately. Although the energy use of MELs and lighting loads only indirectly impact how much heating and cooling energy is included in the energy budget when verifying compliance with Part 6 of Title 24, energy use from these product categories is included directly in calculations of the energy design rating (EDR) used to demonstrate compliance with the energy efficiency requirements in Part 11 of Title 24, California's Green Buildings Standards (CALGreen). The 2016 CALGreen Standards include a zero net energy design designation (ZNE Tier) for newly constructed, low-rise residential buildings. To comply with the ZNE Tier, the applicant must use the Title 24 compliance software to demonstrate that the building achieves an EDR of zero. The EDR is based on the calculated annual time dependent valuation (TDV) energy use of the building. To receive an EDR of zero, all energy used within the building, including energy from plug loads and lighting, must be offset by energy generated at the site. Since plug loads and lighting account for over half the electricity use within a newly constructed residential building, it is important that the Title 24 compliance software estimate plug loads and lighting energy use correctly so that the on-site renewable energy system can be sized appropriately.

This CASE Report proposes changes to modify the current calculation procedures and assumptions used in estimating energy use from MELs and lighting in newly constructed residential buildings for compliance with the Title 24 Standards. The resulting revisions will be presented in the Residential Alternative Calculation Method (ACM) Reference Manual. These changes would not add a compliance options or new code requirements to Part 6 of Title 24; they would add an option to receive credit for the installation of high efficiency clothes washers, clothes dryers, and primary refrigerators when calculating the building's EDR. As previously mentioned, the EDR is not used for Part 6 compliance, but it is used for compliance with the ZNE Tier in CALGreen.

Section 2.2 provides descriptions of the proposed changes to the standards, appendices, Residential ACM Reference Manual and other documents that will be modified by the proposed revisions. See the following tables for an inventory of sections of each document that will be modified:

- Table 2: Scope of code change proposal
- Table 5: Sections of ACM impacted by proposed code change

Detailed proposed changes to the rulesets are provided in Section 9 of this report. This section proposes modifications to language with additions identified with underlined text and deletions identified with ~~struck out~~ text.

Methodology

The Statewide CASE Team followed the same general methodology to develop the rulesets for all of the individually-modeled appliances and lighting end uses. Data from a variety of existing data sources were used to inform assumptions about the types of products found in California homes, product usage patterns, and product age distributions[1]. Based on the estimated age of devices in new homes, energy efficiency standards and market trends, the Statewide CASE Team determined the likely efficiency of products that would be in use in homes built during the 2016 code cycle. The Statewide CASE Team applied the updated product efficiency assumptions to inventory and usage data from large saturation surveys that included results from a wide variety of homes in California, namely the Residential Appliance Saturation Study (RASS) and the California Lighting and Appliance Saturation Survey (CLASS). Finally, the Statewide CASE Team conducted linear regression analyses on the efficiency-adjusted RASS and CLASS data to develop algorithms that describe how the average energy use of each product category varies with home size.[2] See Section 4 for detailed information on the methodology used to develop the algorithms for each product category.

The diverse nature of the remaining electric loads—modeled in aggregate as "residual MELs"—necessitated unique methodology. The Statewide CASE Team combined data from several recent meta-analyses and energy models of residual MELs[3] to estimate the AEC of 114 product categories, detailed in Appendix C: List of Residual MELs. The resulting energy use estimates, which were based on historical data, were adjusted to account for recent observations that energy use from the residual MEL product category is growing. The Statewide CASE Team used the annual growth rate of "miscellaneous" residential end use energy estimated in CEC's Demand Forecast to account for growth and more accurately estimate likely energy use in building that are constructed during the 2016 Title 24 code cycle. Finally, the Statewide CASE Team assumed the AEC of residual MELs scales with home size in the same way as the three major consumer electronics product categories (televisions, set-top boxes, computers and monitors). See Section 4.9 for detailed information on the methodology used to develop the algorithms for the residual MEL category.

[1] Surveys, building audits, metering studies, DOE rulemaking documents, and the usage assumptions underlying CEC's water heating model.

[2] Statewide CASE Team did not need to perform regression analyses for dishwashers or clothes washers/dryers; these product categories scale with home size according to usage assumptions in CEC's water heating model.

[3] In particular a 2014 SCE meta-analysis, the technical support documents from the 2012 DOE rulemaking battery chargers and external power supplies, and the 2014 Building America House Simulation Protocols models (SCE 2014, DOE 2012f,Wilson et al. 2014).

The Statewide CASE Team proposes updated hourly schedules and seasonal multipliers for all MEL and lighting product categories. It is recommended that dishwashers, clothes washers, and clothes dryers use same load profiles as are used in the Title 24 domestic water heating rulesets used in the compliance software, which will align the plug load and water heating models. The Statewide CASE Team used data from recent submetering studies conducted in Florida and the Pacific Northwest to update the load profiles for most of the other modeled product categories. The methodology used to develop the recommended load profiles is discussed in Section 60.

To help verify that the rulesets presented in this report yield reasonable AEC estimates, the Statewide CASE Team compared the proposed rulesets against various reference points and benchmarks. The benchmarking methodology is discussed in Section 3.5.

Results

The Statewide CASE Team has recommended update rulesets for all plug load and lighting end uses. The rulesets were developed using a transparent and repeatable processes, and can be updated relatively easily as new data becomes available. Some of the key results of the analysis include:

- Residual MELs have the highest estimated AEC by a wide margin, followed by electric clothes dryers (if present), and primary refrigerators;
- For average sized homes, the two greatest recommended changes from the 2013 algorithms are a substantial decrease in interior lighting AEC and an increase in the estimated AEC of residual MELs;
- The recommended algorithms estimate lower AEC of large homes as compared to the 2013 rulesets; and
- The pronounced differences between the recommended daily load profiles for each end use underscore the need for granular load profile assumptions.

Figure 1and Figure 2 show the proposed AEC of all modeled plug loads and lighting for average-sized (three bedroom) single-family homes.

Figure 3 and Figure 4 show the recommended load profiles (hourly schedules and seasonal multipliers) for the product categories that will employ this framework to adjust energy use on a daily and monthly basis.[4]

[4] Refrigerators/freezers and the product categories that are harmonized with CEC's water heating (WH) model are not shown, because they will be using separate methodologies to adjust and distribute energy use over time. (See Section 6 for further discussion).

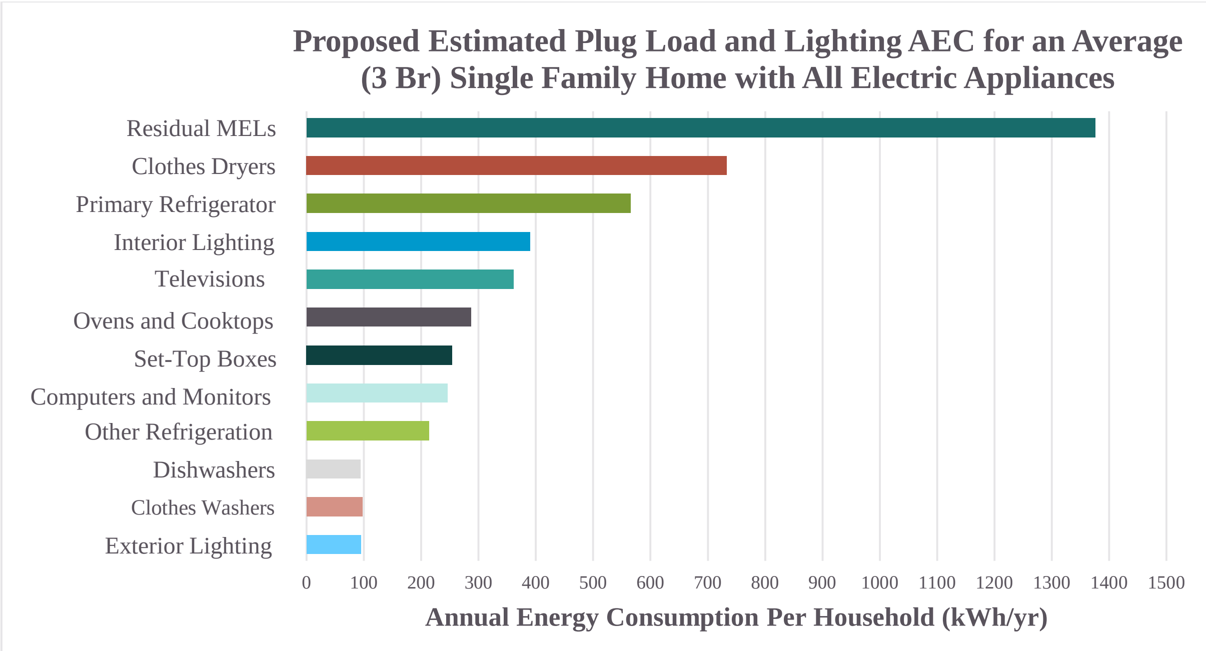

Figure 1: Estimated AEC of all electric end uses in an average-sized single-family home

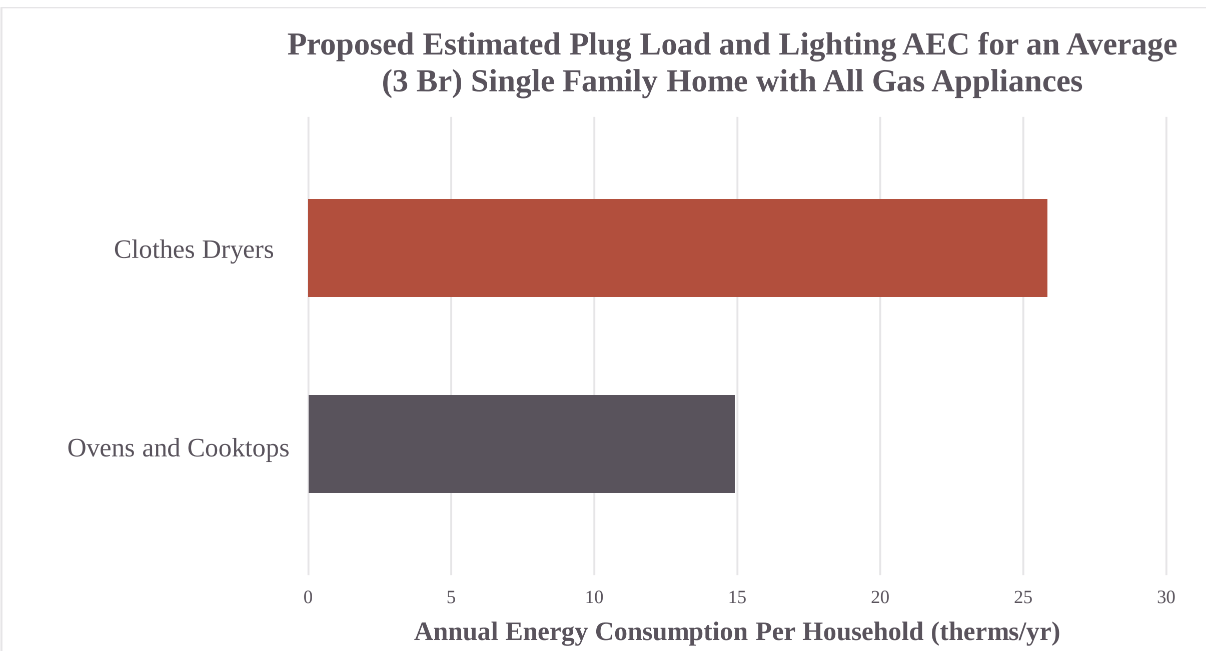

Figure 2: Estimated AEC of all gas end uses in an average-sized single-family home

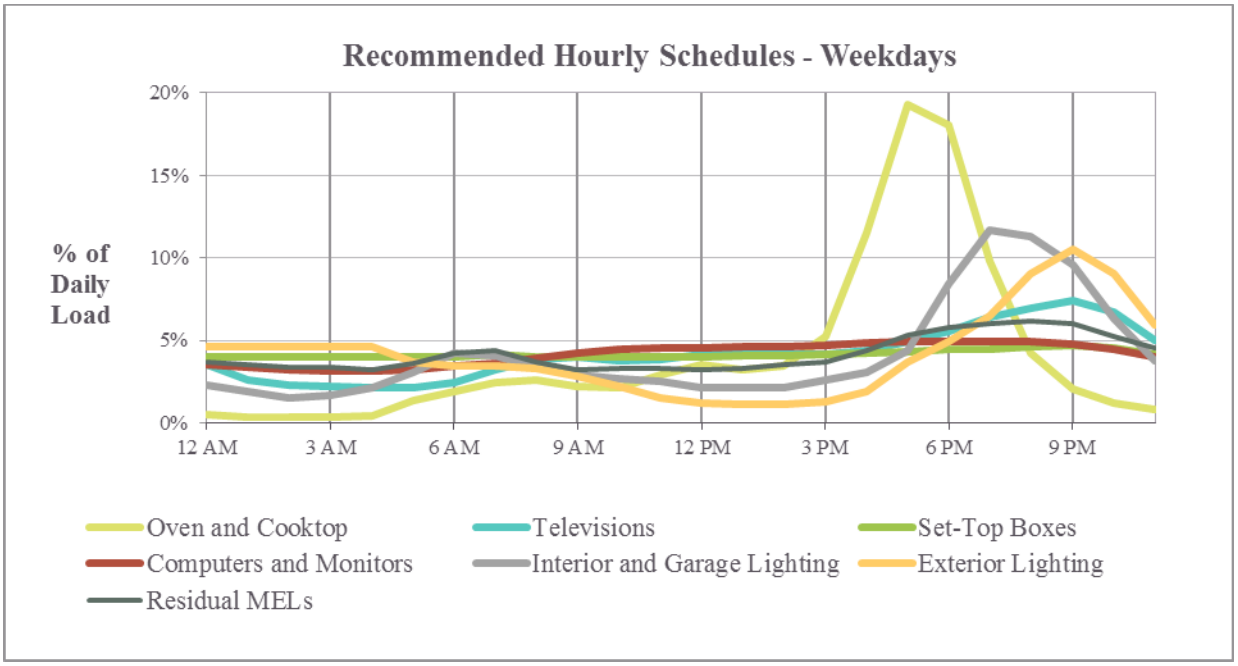

Figure 3: Recommended hourly schedules for weekdays

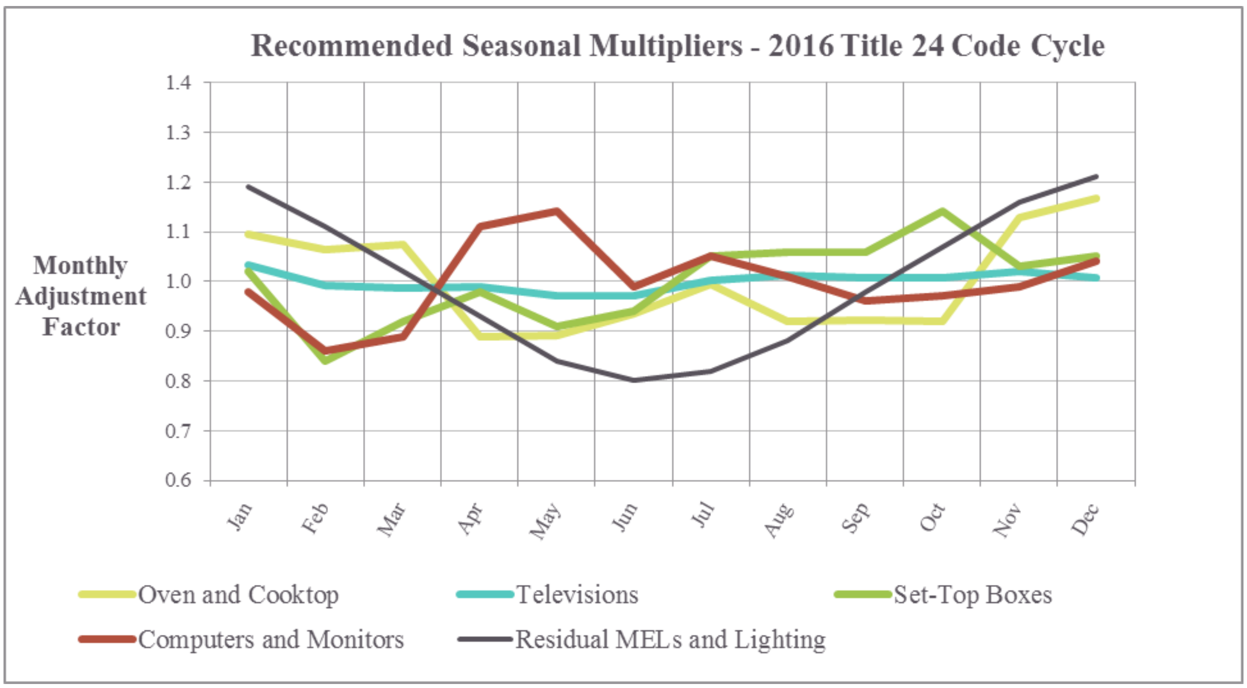

Figure 4: Recommended seasonal multipliers

See Section 4.11 for figures that summarize the results of the effort to update the AEC algorithms for all modeled product categories and how the recommended AEC algorithms compare to the 2013 rulesets.

See Section 6.3 and 0 for results of the load profile analysis and how the recommended hourly schedules and seasonal multipliers for each end use compare to the 2013 load profiles.

Market Analysis and Regulatory Impact Assessment

The Statewide CASE Team did not perform a market analysis for this proposal, which is not recommending revisions to the standards and therefore does not require a market analysis. Although market analysis is not required, the Statewide CASE Team used market information to inform the proposed rulesets. Section 3 of this report includes a detailed description of the methodology used to develop the proposed rulesets, including how information about the current market was used.

The proposed revisions to the rulesets do not directly impact costs of goods or services to consumers in California. This measure is not expected to result in any advantages or disadvantages to California businesses or an increase or decrease of investments in California. This measure is not expected to have a significant impact on any of the following:

- Builders
- Building designers
- Occupational safety and health
- Building owners and occupants
- Equipment retailers (including manufacturers and distributors)
- Energy consultants
- Building inspectors
- Statewide employment
- Creation or elimination of businesses in California
- Incentives for innovations in products, materials or processes
- State General Fund, special funds and local government funds
- Cost of enforcement to State Government and local governments
- Migrant workers; persons by age group, race, or religion
- Homeowners (including potential first time home owners)
- Renters
- Commuters

Statewide Energy Impacts

This measure is not expected to have any direct impact on statewide energy use.

Cost-effectiveness

This measure is not proposing changes to the mandatory or prescriptive standards and a cost-effectiveness analysis is not required to revise the methodology used in the Title 24 compliance software. Revising the MEL and lighting rulesets is not expected to have any direct impact on the costs of any goods or services. The revisions may influence designers' decisions as they strive to achieve a ZNE rating. The revised modeling approach may also impact how savings are calculated and measured for incentive programs.

Greenhouse Gas and Water-Related Impacts

This measure is not expected to have any direct impact on greenhouse gas emissions, water use or water quality.

Field Verification and Diagnostic Testing

This measure does not currently require field verification or diagnostic testing to verify compliance with Part 6 or Part 11 of the Title 24 Standards. The Statewide CASE Team has not recommended adding field verification as part of the compliance process at this time. In future code cycles, the CEC may want to consider how building officials should verify that higher-efficiency appliances that receive EDR credit have actually been installed in the building.

The Statewide CASE Team is recommending rulesets that can be updated relatively easily as new data becomes available. The rulesets could be further improved with more data; data collected during the 2016 code cycle could be used to verify evaluate the accuracy of the existing rulesets and be used to make improvements to the rulesets in the future.

Future Updates

The recommended rulesets were developed using the best data available at this time with the expectation that more robust and updated data will become available in the future. Given data gaps still exist and the scope of this effort did not include a deep analysis of all factors that impact plug load and lighting energy use. The Statewide CASE Team acknowledges the inherent shortcomings in some assumptions used in the analysis and recommends the following work be completed in the future to increase the efficacy and usefulness of the rulesets:

- Use more recent survey data as well as data from a modern, California-specific building stock assessment and submetering study;
- Separately model single-family and multi-family units;
- Further develop the residual MELs methodology;
- Provide builders with further options to receive credit for more efficient appliances;
- Expand the scope of the algorithms to cover existing homes;
- Explicitly model per-household AEC from standby loads;
- Account for trends in energy use over time; and
- Update the people loads rulesets.

See Section 8 for a full discussion of recommended future work.

1. INTRODUCTION

The Codes and Standards Enhancement (CASE) initiative presents recommendations to support California Energy Commission's (CEC) efforts to update California's Building Energy Efficiency Standards (Part 6 of Title 24) to include new requirements or to upgrade existing requirements for various technologies. The four California Investor Owned Utilities (IOUs) – Pacific Gas and Electric Company (PG&E), San Diego Gas and Electric (SDG&E), Southern California Edison (SCE) and Southern California Gas Company (SCG) – and Los Angeles Department of Water and Power (LADWP) sponsored this effort. The program goal is to prepare and submit proposals that will result in cost-effective enhancements to energy efficiency in buildings. This report and the code change proposal presented herein is a part of the effort to develop technical and cost-effectiveness information for proposed regulations on building energy efficient design practices and technologies.

The overall goal of this CASE Report is to present the Statewide CASE Team's recommended rulesets for modeling the annual energy use of plug loads and lighting in newly constructed residential buildings. This report recommends revisions to the rulesets for the following product categories:

- Major appliances (refrigerators and freezers, dishwashers, clothes washers, gas and electric dryers, gas and electric ovens and cooktops);
- Major consumer electronics (televisions, set-top boxes, computers, and monitors)
- Interior, exterior, and garage lighting; and
- Residual MELs (all other plug loads that were not modeled individually).

Section 2 of this CASE Report provides a description of the measure, how the measure came about, and how the measure helps achieve the state's zero net energy (ZNE) goals.

Section 3 presents the general methodology used to develop the proposed rulesets for all product categories. This section provides an overview of key data sources and a description of global assumptions and modeling practices.

Section 4 describes the specific analytical steps used to develop the ruleset for each product category. For each product category, the Statewide CASE Team introduces the technology, presents information on existing energy standards and other market data, discusses key variables used in the proposed ruleset, reviews each step of the ruleset development process, presents the resulting rulesets, and compares the results to various benchmarks. Section 4 concludes with a presentation of whole-home results from the recommended rulesets and whole-home benchmarking analysis.

Section 5 presents a proposed approach to allow compliance credit for the installation primary refrigerators, clothes washers, and clothes dryers that are more efficient than is assumed in the default annual energy consumption (AEC) algorithms presented in Section 4. (The default algorithms for these product categories assume that devices are minimally compliant with federal efficiency standards and have an average age distribution.) Section 5 also discusses the methodology used to develop the proposed approach.

Section 6 presents the methodology, results, and proposed load profiles for each product category. The Statewide CASE Team presents recommended hourly schedules and seasonal multipliers for most product categories.

The results of all of the recommended default AEC algorithms and load profiles are summarized in Section 7.

Section 8 contains a discussion of future modeling needs and data gaps related to this measure.

The report concludes with recommended language to include in the Residential ACM Reference Manual in Section 9.

2. MEASURE DESCRIPTION

2.1 Measure Overview

2.1.1 Measure Description

This CASE Report proposes updated rulesets to use in the Title 24 residential compliance software to estimate annual energy use of plug loads and lighting in residential buildings. Plug loads are defined as appliances or electronic devices that are generally plugged in to a receptacle, such as white goods, consumer electronics, and other miscellaneous electric loads (MELs), while lighting includes all portable and hardwired interior, exterior, and garage lighting. These end uses collectively represent the purchase and usage decisions made by building occupants that have the greatest impact on its subsequent electricity use.

As California strives to achieve ZNE goals, it is critical that the Title 24 compliance software estimates energy use from MELs and lightings appropriately. Although the energy use of MELs and lighting loads only indirectly impact how much heating and cooling energy is included in the energy budget when verifying compliance with Part 6 of Title 24, energy use from these product categories is included directly in calculations of the energy design rating (EDR) used to demonstrate compliance with the energy efficiency requirements in Part 11 of Title 24, California's Green Buildings Standards (CALGreen). The 2016 CALGreen Standards include a zero net energy design designation (ZNE Tier) for newly constructed, low-rise residential buildings. To comply with the ZNE Tier, the applicant must use the Title 24 compliance software to demonstrate that the building achieves an EDR of zero. The EDR is based on the calculated annual time dependent valuation (TDV) energy use of the building. To receive an EDR of zero, all energy used within the building, including energy from plug loads and lighting, must be offset by energy generated on-site. Since plug loads and lighting account for over half the electricity use within a newly constructed residential building, it is important that the Title 24 compliance software estimate plug loads and lighting energy use correctly so that the on-site renewable energy system can be sized appropriately.

Energy use from plug loads and lighting is constantly changing over time as new technologies and loads enter the market, existing product efficiencies improve, user preferences and behaviors evolve, and new energy codes are adopted. Developing effective rulesets for these loads is challenging due to the variety of products under consideration, the speed at which changes are expected to impact different markets, and general uncertainty around future trends in technology, innovation, and consumer behavior. To address these challenges, the Statewide CASE Team specifically defined the scope of this effort in order to simplify the modeling objectives, which are listed as follows:

- Estimate AEC of each product or product category to be appropriate for newly constructed buildings built during the 2016 Title 24 code cycle;
- Develop rulesets that appropriately scale estimated product AEC with home characteristics that are known during the design phase, such as conditioned floor area (CFA) and number of bedrooms (NBr);
- Propose revised hourly and seasonal load profiles for each product or product category to allow for more accurate estimates of TDV energy use and energy costs;
- Maximize consistency with the recently updated Title 24 domestic water heating rulesets used in the compliance software;
- Provide builders with a straightforward method of receiving credit for installing appliances that are more efficient than appliances that are minimally compliant with state or federal energy codes requirements;
- Use data sources that will be updated on a regular basis, so the rulesets can be updated using the same methodology when new data becomes available; and
- Create a methodology that is repeatable, so that new data can be easily integrated to improve model efficacy in future update cycles.

The Statewide CASE Team did not address several related aspects of residential plug load and lighting energy use modeling. The following modeling tasks were considered out of scope for this measure:

- Account for trends in energy use over time beyond 2017;
- Allow for the full suite of possible adjustments to baseline product performance; and
- Model energy use of existing homes.

These additional tasks have been identified as useful next steps for enhancing the rulesets proposed in this CASE Report.

The proposed changes would modify the calculation procedures and assumptions used in estimating energy use from plug loads and lighting in newly constructed residential buildings. The resulting revision will be presented in the Residential ACM Reference Manual. These changes would not add new compliance options or code requirements to Part 6 of Title 24. The changes would add an option to receive credit for the installation of high efficiency clothes washers, clothes dryers, and primary refrigerators when calculating the building's EDR. As previously mentioned, the EDR is not used for compliance, but it is used for compliance with the ZNE Tier in CALGreen.

2.1.2 Measure History

To demonstrate compliance with Part 6 of Title 24 through the performance approach, the proposed building must achieve an equivalent or lower energy budget than the standard building design when using Title 24 compliance software that has been approved by CEC. The approved software tool must also be used to demonstrate compliance with the energy efficiency tiers in CALGreen.

In determining compliance with Part 6 of Title 24, plug load and lighting energy use is not directly included in the calculation of the building's energy budget, but it is used to determine the internal heat gains assumptions that are used in calculated heating, ventilation, and air conditioning (HVAC) loads, which do contribute to the energy budget. Since plug loads and lighting are not directly factored into energy budget calculations, they are considered non-regulated loads. Although they are "non-regulated" in the context of Title 24, there are existing standards that regulate the efficiency of most plug loads and lighting loads, including requirements within Title 24 itself for lighting loads. The current Residential ACM Reference Manual requires that Title 24 software tools have the capability to calculate and report the energy use from non-regulated loads. Although energy use from the non-regulated loads is not used to demonstrate compliance with the Part 6 of Title 24, energy use from these loads is used to determine the building's EDR, which impacts compliance with the energy efficiency requirements in CALGreen.

For compliance with CALGreen, plug load and lighting energy use is included in whole-building EDR as a metric to evaluate ZNE buildings. As Title 24 requirements improve all other aspects of residential building energy efficiency, it is predicted that plug loads will represent an increased share of the overall building energy use. Plug loads are becoming an increasingly important component of total building energy use and must be properly accounted for in building energy models. The need for an accurate methodology to estimate plug load and lighting energy use was accelerated when the CEC adopted a ZNE Tier into the 2016 CALGreen requirements (CEC 2015a). As mentioned, to comply with the ZNE Tier in CALGreen the building must receive an EDR of zero, which means all energy used within the building (scaled using TDV), including energy from plug loads and lighting, must be counterbalanced by energy generated at the site. Incorporating the proposed changes into the Residential ACM Reference Manual will ensure that the Title 24 compliance software has the ability to more accurately model total energy use of entire residential buildings, not just the regulated loads. This will in turn help ensure that the on-site renewable system can be sized appropriately.

There are no preemption concerns associated with the proposed measure. As discussed in Section 5, the recommended ruleset for appliances that have federal efficiency standards and are preempted uses a default assumption that the appliance is minimally compliant with the federal standard. The Statewide CASE Team has recommended a methodology to allow for EDR credit if more efficient appliances are installed (see Section 6).

2.1.3 Existing Standards

The current methodology is defined in the 2013 Residential ACM Reference Manual, which in turn references the rulesets in the 2008 California Home Energy Rating System (HERS) Technical Manual. The ruleset accounts for energy use from appliances (refrigerators and freezers, dishwashers, clothes washers and dryers, and stoves/ovens), other miscellaneous electric loads, interior lighting, and exterior lighting [5]. However, there are many ways in which the existing rulesets could be improved.

The existing rulesets do not account for the significant changes in the market that have occurred in recent years. Technology advances and updates to state and federal energy efficiency standards have led to improved energy efficiency. For example, homes built during the 2016 Title 24 code cycle will have to install high-efficiency, hard-wired luminaires, which will substantially reduce interior lighting AEC. The rulesets could be improved to account for recent advancements in efficiency, as well as energy efficiency codes, which impact the modeled annual energy use plug loads and lighting.

Moreover, the existing rulesets do not account for trends in technology and consumer preferences since the equations were last updated in 2008. For example, television and computer energy use have been impacted by the increase in average television screen size and the number of notebook computers per home, as well as the increasing use of much more efficient display technologies. It is important to update the rulesets to estimate the impact of such trends, as discussed in Section 8.1.6.

The existing rulesets do not sufficiently disaggregate end uses. The “miscellaneous” category in the current rulesets includes all plug load electricity end uses other than the major white goods and lighting. A large volume of data exists to support the individual modeling of major consumer electronics loads, such as televisions, computers, and set-top boxes. One of the key proposed changes is to disaggregate these end uses to more accurately approximate their contributions to home energy use. Individually modeling more product categories also facilitates updates to the models for these loads to reflect changes in the prevalence, usage, and efficiency of these loads over time (both naturally occurring and from updated appliance and building standards).

Finally, there have been concerns that the existing rulesets do not scale energy use with building size appropriately. There is a particular concern that the existing ruleset overestimates energy use from plug loads and lighting in large residential buildings. As discussed in the previous section, if plug load and lighting load energy use is overestimated, it could result in the on-site solar photovoltaic (PV) system being oversized to achieve an EDR of zero, and it is not desirable for the building code to be encouraging oversized solar PV systems.

2.1.4 Alignment with Zero Net Energy Goals

The Statewide CASE Team and the CEC are committed to achieving California’s ZNE goals. As Title 24 requirements improve all other aspects of energy use within residential buildings, plug loads will represent an increased share of the overall energy use. This measure will help achieve ZNE goals by improving estimated energy use from plug loads and lighting, which will allow for more accurate assessments of home energy usage and allow builders to size on-

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[5] The California HERS Technical Manual groups all loads that are not covered elsewhere into the “miscellaneous” category. This category includes plug-in equipment such as televisions, set-top boxes, computers, toasters, microwaves, etc.

site renewable energy generation systems more appropriately. These proposed changes to the modeling rulesets will set the foundation for future code updates that will help ensure ZNE goals are achievable.

In the immediate term, the updated rulesets will allow for a more accurate approximation of a building's EDR for compliance with the ZNE Tier in the 2016 CALGreen Standards.

2.1.5 Relationship to Other Title 24 Measures

The proposed rulesets will enable compliance with the ZNE Tier in the 2016 CALGreen Standards.

Residential lighting efficiency standards that were adopted for the 2016 Title 24 Standards were used as the basis for developing the lighting rulesets presented in this report.

Since this measure proposes changes to modeling assumptions contained in the Residential ACM Reference Manual, this measure may impact how other Title 24 measures are implemented and evaluated, particularly as they relate to meeting ZNE goals.

2.2 Summary of Changes to Code Documents

The sections below provide a summary of how Title 24 documents will be modified by the proposed change. See Section 9 of this report for detailed proposed revisions to code language.

2.2.1 Catalogue of Proposed Changes

Scope

Table 2 identifies the scope of the code change proposal. This measure will impact the following areas (marked by a "Yes").

Table 2: Scope of code change proposal

Mandatory	Prescriptive	Performance	Compliance Option	Trade-Off	Modeling Algorithms	Forms
No	No	Yes, CALGreen Only	Yes, CALGreen Only	No	Yes	No

Standards

The proposed code change will not modify the California Building Energy Efficiency Standards (Title 24, Part 6).

Appendices

The proposed code change will not modify any sections of the reference appendices.

Residential ACM Reference Manual

The proposed code change will modify the sections of the Residential ACM Reference Manual identified in Table 3.

Table 3: Sections of ACM impacted by proposed code change

Residential Alternative Calculation Method Reference		
Section Number	**Section Title**	**Modify Existing (E) New Section (N)**
3.5	Appliances, Miscellaneous Energy Use and Internal Gains	E

Simulation Engine Adaptations

The proposed revisions are relatively simple engineering calculations. Title 24 software tools will need to be updated, but doing so will not require major revisions to the simulation engine.

2.2.2 Standards Change Summary

The proposed code change will not modify the standards.

2.2.3 Standards Reference Appendices Change Summary

The proposed code change will not modify the appendices of the standards.

2.2.4 Residential Alternative Calculation Method ACM Reference Manual Change Summary

This proposal would modify the sections of the Residential ACM Reference Manual as shown below. See Section 9 of this report for proposed language for the Residential ACM Reference Manual.

SECTION 3.5 Appliances, Miscellaneous Energy Use and Internal Gains: The Statewide CASE Team is proposing changes to the rulesets used by the compliance software for MELs and lighting and internal gains from these loads.

SECTION 3.5.1 Background: The Statewide CASE Team proposes modifications to this text to reflect the data sources and methods used to develop the proposed rulesets.

SECTION 3.5.2 Approach: The Statewide CASE Team proposes modifications to the description of the methodology and problems to reflect the proposed rulesets.

SECTION 3.5.3 Inputs: The Statewide CASE Team proposes changes to the inputs and rulesets defined in this section to match the goals of this measure.

2.2.5 Compliance Forms Change Summary

There will be an option to receive credit on the calculated EDR for installing high-efficiency clothes washers, clothes dryers, and primary refrigerator. The EDR credit will not be used for compliance with Part 6, but it can be used for compliance with the energy efficiency tiers in CALGreen. As such, revisions to the compliance forms are not recommended. It is outside of the scope of this CASE effort to recommend revisions to compliance documents for CALGreen, though it may be advantageous to develop a mechanism to verify that the higher efficiency appliances used in calculations of the EDR have been installed.

2.2.6 Simulation Engine Adaptations

The proposed revisions are relatively simple engineering calculations. Title 24 software tools will need to be updated, but doing so will not require major revisions to the simulation engine.

2.2.7 Other Areas Affected

No other areas will be affected.

3. Annual Energy Consumption – General Methodology

This section summarizes of general methodology that the Statewide CASE Team used to create new rulesets for each product category: refrigerators and freezers, dishwashers, clothes washers and dryers, ranges and ovens, televisions, set-top boxes, computers and monitors, residual MELs, and lighting. This section describes the methodology used to develop the proposed rulesets for estimating AEC. The methodology used to develop the proposed load profiles for each product category is discussed in Section 6.

The following sections present a high-level summary of the Statewide CASE Team's key data sources, methodology used to create equations that predict AEC based on home size, and an expanded discussion of the Statewide CASE Team's approach to the regression analysis used to create many of the AEC equations.

3.1 Data Sources

The Statewide CASE Team used a variety of data sources to accomplish the modeling objectives. Key data sources and each source's primary use in the development of the proposed rulesets are presented in the following subsections. This group of data sources does not represent the full set of resources that the Statewide CASE Team used in developing the proposed rulesets. Several other product-specific resources were necessary for individual products; however, the data sources presented below are the most commonly cited resources throughout the model development process for all products. If product-specific data sources were used, those sources and their uses are discussed in the appropriate sub-section in Section 4 of this report.

3.1.1 Residential Appliance Saturation Survey 2009

The 2009 California Residential Appliance Saturation Study (RASS) collected information from five California utility service territories: PG&E, SCE, SDG&E, SCG, and LADWP (KEMA 2010b). RASS requested that survey respondents provide information on household appliances, equipment, and general consumption patterns. The survey included data from about 25,000 residential customers. Survey results were self-reported by survey participants and were not independently verified by field auditors. Survey results were combined with electric and gas billing data provided by each of the participating utilities to model end uses within each household and to calculate estimated unit energy consumption for each end use. Data in this survey was collected in 2009 (KEMA 2010b).

This resource is referenced throughout this report as "RASS" or "RASS 2009." CEC provided the Statewide CASE Team with access to the RASS microdata—an Excel spreadsheet that contained the survey responses of all 25,000 surveyed households, as well as statistically derived sample weights that allowed the Statewide CASE Team to calculate statewide averages based on responses of the sampled households.[6]

The Statewide CASE Team used RASS microdata to relate the information about products (e.g. typical number of products per household, type of product, and usage data) to the NBr in a home. These relationships are the foundation upon which the Statewide CASE Team was able to relate estimated AEC to NBr for most of the product categories.

In addition to the survey itself, the analysts that implemented the survey also conducted a Conditional Demand Analysis (CDA)—statistically-adjusted engineering approach to estimating the AEC of the various residential end uses in the surveyed homes. The Statewide CASE Team primarily referenced the 2009 RASS CDA as a benchmark for comparison. For a description of the RASS CDA see Section 3.5.2.1.

3.1.2 California Lighting and Appliance Saturation Study 2012

The 2012 California Lighting and Appliance Saturation Survey (CLASS) updates and augments saturation and efficiency characteristics from previous CLASS studies that were conducted in 2005 and 2000 (DNV GL 2012). The 2012 CLASS study conducted on-site observations at a sample of single-family, multi-family and mobile home residences with individually-metered electric accounts. Field surveyors recorded energy use data at 1,987 homes across the service territories of PG&E, SCE and SDG&E. The data includes a detailed inventory of lighting at each home in the study (DNV GL 2012). This resource is referenced through this report as "CLASS 2012."

The Statewide CASE Team relied on CLASS 2012 to create the lighting AEC models, which draw on the lighting inventories collected in the survey for homes of varying sizes (floor areas). CLASS data was also used to augment RASS data in cases where the RASS survey was insufficiently detailed. For example, the Statewide CASE Team used CLASS data on average television age and screen size because this information was not reported in RASS. Although the CLASS data on device characteristics has the distinct advantage of being recorded by a third party investigator as opposed to self-reported by the building occupant, it also has several drawbacks relative to RASS. Namely, the survey has a smaller sample size, only targets

[6] The sample weights in RASS account for the fact that some demographics were over-represented in sampled households and other were under-represented. The RASS analysts calculated the sample weights to be inversely proportional to the likelihood that a given household would be sampled, given factors such as geographical location and self-reported demographics.

households with individually-metered electric accounts, covers homes within fewer utility service territories, and the Statewide CASE Team is not able to access the raw microdata.[7]

3.1.3 2013 CE Usage Surveys

As a part of the larger Energy Consumption of Consumer Electronics in U.S. Homes in 2013 study (Urban et al. 2014), the Consumer Electronics Association (CEA) funded a series of phone surveys to gather information about the installed base of consumer electronics their usage. These surveys are referenced in the report as "CE Usage Survey." The surveys adhere to the Marketing Research Association's Code of Marketing Research Standards. Five independent surveys covered five categories of consumer electronics—video game consoles, home audio devices, desktops and portable computers, mobile devices, and televisions—with a sample size of close to 1,000 respondents per product category. The data was weighted by the survey-reported demographics of the study population to extrapolate to the entire U.S. adult population. Questions varied by product category, but in general gathered information such as number of devices plugged in at a given time, how long the device is in active use in a day, what mode the device is left in when not in use (e.g. on, off, standby), charging habits, and device characteristics.

Generally, the Statewide CASE Team used CE Usage Survey data to develop factors used to scale RASS or CLASS data. For example, the Statewide CASE Team referenced the CE Usage Survey data to determine the average number of monitors per computer, the relative screen size of a household's primary television compared to the less-watched televisions, and the average number of computers per household in 2013 relative to the average as reported in RASS.

3.1.4 ENERGY STAR™

The Environmental Protection Agency (EPA) and the Department of Energy (DOE) jointly administer the ENERGY STAR™ program to help consumers and businesses identify energy efficient products and practices. ENERGY STAR creates specifications and guidelines addressing energy efficiency across a wide range of products. ENERGY STAR also collects and shares data on models that qualify for each specification, in the form of Qualified Products Lists (QPLs).

The Statewide CASE Team utilized both technical specifications and data from ENERGY STAR QPLs to analyze certain product characteristics (i.e. product size) that impact energy use, and to aid in the development of estimates for market average product efficiency for the individually-modeled consumer electronics.

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7 The Statewide CASE Team used the CLASS WebTool (https://webtools.dnvgl.com/projects62/Default.aspx?tabid=190) to analyze the CLASS data. Although the CLASS Web Tool allows for some degree of filtering and conditional averages, the Statewide CASE Team was not able to analyze data with nearly the degree of granularity as the RASS microdata.

3.1.5 Federal and State Appliance Standards Rulemaking Documents

For federal rulemakings, DOE releases technical analyses used to support the adoption of new or revised federal energy efficiency requirements. These technical support documents contain detailed information on the energy efficiency of the regulated product collected throughout the rulemaking process, including manufacturer data requests, teardown analyses, testing and other related research activities.

The CEC releases similar rulemaking documentation for products regulated under state appliance energy efficiency regulations. Additionally, the Statewide Utility Codes and Standards Program produces CASE Reports that detail energy performance analyses. These CASE Reports include a variety of information, including testing results, market research findings, and other data useful for conducting analyses of product energy performance.

The Statewide CASE Team utilized DOE and CEC rulemaking documents as well as CASE Reports, to help determine energy performance for federally and state regulated products.

3.2 General Methodology for Individually-Modeled Product Categories

The Statewide CASE Team followed the same generalized methodology to develop the AEC rulesets for all of the individually-modeled appliances and lighting end uses. Existing data sources (primarily RASS and CLASS) were used to inform assumptions about the types of products found in California homes, product usage patterns, product age distributions. Based on product attributes, the Statewide CASE Team assessed the likely efficiency of products that would be in use in homes that are newly constructed during the 2016 code cycle. Product efficiency assumptions for newly constructed homes were then applied to the inventory and usage data from RASS and CLASS. Finally, the Statewide CASE Team conducted linear regression analyses on the efficiency-adjusted RASS and CLASS data to develop algorithms that describe how the average energy use of each product category varies with home size.

The fundamental steps of the methodology for individually-modeled appliances and lighting end uses are described below, along with information on the data sources that the Statewide CASE Team typically used for each step. Residual MELs necessitated a unique approach, described in Section 3.3.

1. **Determine product inventory and usage patterns:** The Statewide CASE Team used the 2009 RASS to determine the number and type of devices that are typically used in California homes and how residents use these devices. This step also included collecting information about the quantity of each device within the home (e.g. number of refrigerators, televisions, computers, etc.) and characteristics of each device that impact energy use (e.g. the size of refrigerators and freezers).

   The Statewide CASE Team primarily used RASS to determine product inventory, but deviated from using RASS when other data sources were substantially more accurate or when there was a desire to harmonize with the data sources used in other Title 24 compliance software rulesets. For example, the Statewide CASE Team did not base the lighting inventory on RASS due to residents' limited ability to self-report all of the different light sources in their homes. Instead, the Statewide CASE team used CLASS data. Similarly, the Statewide CASE Team did not rely on RASS self-reported hours of use for television or lighting, but instead used California-specific metering studies. To guard against using problematically outdated inventory data, the Statewide CASE Team used more recent data sources to estimate values such as television screen size, number of computers per home, and the relative share of different lighting technology types. To achieve consistency with the water heating (WH) rulesets, the annual usage assumptions for dishwashers, clothes washers, and clothes dryers were based on the hot water usage assumptions that CEC developed during the 2016 code cycle for use in the water heating rulesets—currently in draft form at the time of this writing.[8] While clothes dryers do not use hot water, the use assumption for clothes dryers is linked to the use assumption for clothes washers.

The proposed rulesets for dishwashers, ovens, cooktops, clothes washers and clothes dryers do not rely on the average number of devices per household as reported in RASS. Instead, the rulesets ask users if the devices will be installed. If a device is going to be present in the new home, the ruleset assumes that only one device will be present. If a device is not going to be present, energy use from the device is excluded from calculations.

Similarly, the proposed rulesets do not use RASS data regarding the average proportions of gas and electric devices. Instead, the rulesets ask users if ovens, cooktops, and clothes dryers will use gas or electricity in order to determine whether the gas or electric equations should be applied.

2. **Estimate product age in new buildings:** Ovens, cooktops, and dishwashers, and hard-wired luminaires were assumed to be new in newly constructed homes. The Statewide CASE Team calculated an age distribution for non-builder supplied white goods in new homes (clothes washers/dryers, refrigerators/freezers) based on RASS data, as described in Appendix A: Age of Non-Builder Supplied White Goods. It was assumed that residents would bring their existing televisions, computers, and monitors to their new home, and thus the Statewide CASE Team estimated the age of these devices as equivalent to the average age of devices in the existing building stock. Set-top boxes and portable luminaires were assumed to be a mix of new and old; the CASE Team was not able to precisely quantify their likely age distribution in new homes and thus made simplifying assumptions, as discussed in Sections 4.7 and 4.10.
3. **Estimate product efficiency in 2017:** The Statewide CASE Team generally based product efficiency estimates on the likely product age when the building is new. Federally covered products were assumed to be minimally compliant with the federal efficiency requirements that would have been in place when the product was manufactured. Similarly, for major consumer electronics (televisions, set-top boxes, computers and monitors), the Statewide CASE Team estimated the average manufacture year of products in 2017 homes and then used the ENERGY STAR specification that was

[8] The Statewide CASE Team recommends that the plug load and lighting rulesets be updated to remain aligned with any updates to the WH rulesets, incorporating the latest draw schedule and annual usage assumptions.

met by most products manufactured during that year to determine efficiency. Lighting efficiency was estimated based on the likely market share of different lighting technology types (e.g. LED, CFL, or halogen) and the efficiency of each of those technology types. See Section 4.10 for a description of the sources used to determine the efficiency of each type of lighting technology.

4. **Calculate "2017 per-household AEC" for surveyed homes of varying size:** The Statewide CASE Team used information about product inventory, usage patterns, age and efficiency to calculate the 2017 per-household AEC of each individually-modeled product category. These AEC values represent the annual energy consumption of all products within the specified product category (i.e. all computers within the home, not just one computer) in newly constructed homes built during the 2016 code cycle. For most individually-modeled products, the Statewide CASE Team applied efficiency assumptions for products in newly constructed homes to the self-reported device inventory data for every household surveyed in RASS. This calculation results in an estimate of the per-household AEC of each product category if the building were built during the 2016 code cycle.

   For the products that share usage assumptions with CEC's water heating rulesets – dishwashers, clothes washers, and clothes dryers – per-household AEC was calculated by multiplying assumed estimated efficiency(as energy consumption per use) by the annual uses, which are consistent with use assumptions used in the water heating ruleset.

   For lighting, the Statewide CASE Team applied efficacy assumptions (in lumens per watt) to estimated light output estimates calculated from the CLASS building audit data. This calculation resulted in an approximation of the assumed wattage in a newly constructed home to achieve the same lighting levels that were found in CLASS field studies. The Statewide CASE Team then multiplied wattage estimates by the assumed annual hours of operation to arrive at 2017 per-household AEC.

5. **Develop equations that predict 2017 per-household AEC from NBr or CFA:** The final step was to create equations that predict per-household AEC of a new home a given NBr or conditioned floor area (CFA). For most individually-modeled end uses, the Statewide CASE Team conducted a linear regression analysis to capture the trend in how the 2017 per-household AEC calculated for each home in RASS varies with the households' self-reported NBr.

   This final step was not necessary for the end uses that are harmonized with the WH rulesets (dishwashers, clothes washers, clothes dryers). The WH rulesets already define the predicted annual uses based on NBr, so for these end uses the Statewide CASE Team simply multiplied the assumed uses per yr from the WH ruleset by an estimated amount of energy per use. Because the WH rulesets have different assumptions about how usage varies with NBr for single-family and multi-family housing, this procedure yielded separate single-family and multi-family algorithms.

   For lighting, the Statewide CASE Team conducted a linear regression analysis to capture the trend in how average 2017 per-household AEC varies with CFA.

See Section 3.4 for a full discussion of the modeling choices involved in the regression analyses, including the choice of NBr or CFA, the use of linear equations, and why AEC is not modeled as increasing indefinitely with home size.

Table 4 summarizes the major inputs used to develop the proposed rulesets. Data sources are provided in parentheses. A more detailed table of variables used to create algorithms for each end use and associated data sources can be found in the “Key Variables” tables in Section 3.

Table 4: Key inputs and data sources for individually modeled end uses

Product Category	Age	Efficiency	Inventory	Usage	Home Size
Refrigerators and Freezers	Age distribution in new homes[1] (RASS 2003, 2009)	Code minimum (2001, 2014 fed stds)	Size, type, saturation (RASS 2009)	N/A	NBr (RASS 2009)
Dishwashers	Assumed new	Code minimum (2015 fed stds)	N/A: saturation reflects what is installed	Uses/yr (WH rulesets)	NBr (RASS 2009)
Clothes Washers	Age distribution in new homes[1] (RASS 2003, 2009)	Code minimum (2007, 2015 fed stds)	Type (RASS 2009) saturation reflects what is installed	Uses/yr (WH rulesets)	NBr (RASS 2009)
Clothes Dryers	Age distribution in new homes[1] (RASS 2003, 2009)	Code minimum (1994, 2015 fed stds)	N/A: saturation and fuel type reflects what is installed	Uses/yr (WH rulesets)	NBr (RASS 2009)
Ovens and Cooktops	Assumed new	Code minimum (2009 fed stds)[3]	N/A: saturation and fuel type reflects what is installed	Uses/yr (RASS 2009)	NBr (RASS 2009)
Televisions	Average age in existing buildings (CLASS 2012)	Market average power by mode (ENERGY STAR specification)	Saturation (RASS 2009); screen area (CLASS 2012)	Hrs/year (Nielson 2012 metering study)	NBr (RASS 2009)
Set-Top Boxes	Assumed to be a mix of new and old[4]	Market average power draw (ENERGY STAR QPL)	Saturation, type (RASS 2009)	Duty cycle (DOE rulemaking documents)	NBr (RASS 2009)
Computers	Average age in existing buildings (CEC Staff Report)	Market average AEC[6] (ENERGY STAR QPL)	Saturation,[4] type (RASS 2009)	Real-World Adjustment Factor[6] (Title 20 rulemaking documents)	NBr (RASS 2009)
Monitors	Average age in existing buildings (CEC Staff Report)	Market average power by mode (ENERGY STAR QPL)	Average monitors per desktop/notebook (2013 CE Usage Survey)	Duty cycle (2013 CE Usage Survey)	NBr (RASS 2009)
Lighting	Hard-wired luminaires assumed to be new, portable assumed to be a mix of new and old[7]	Most likely code compliant (Title 24, other sources) [8]	Number and type of lights (CLASS 2012), used to estimate lumens per room	Hrs/day by room type (2010 DEER metering study)	CFA (CLASS 2012)

1. See Appendix A for a description of this methodology.

2. Dryer uses adjusted to account for fraction of clothes washer loads that are line dried.
3. Adjusted the federal standard using CA-specific data.
4. The Statewide CASE Team was unable to precisely estimate the average age of set-top boxes in new homes, but presents evidence that the 2017 stock of set-top boxes is likely to generally meet the ENERGY STAR version 3.0 specification.
5. Survey-reported desktop and notebook saturation was upward to reflect increased market penetration from 2008-2017.
6. Used to TEC values from ENERGY STAR to reflect field data on actual usage patterns.
7. Due to a lack of data on the age of portable lighting in new homes, Statewide CASE Team made the simplifying assumption that half of portable lighting in new homes is newly purchased and half is the average age of the light type in existing buildings.
8. For interior and exterior lighting, the Statewide CASE Team consulted with the Title 24 Residential Lighting Statewide CASE Team to determine the mix of lighting technologies that would be the most likely path to code compliance in 2017. For example, even though Title 24 will require that hard-wired lighting have an luminous efficacy of ≥45 lumens per watt, the three primary light source types that could fulfill this requirement for residential hard-wired lighting (linear fluorescent, CFL, and LED) all have typical efficacies well over 45 lumens per watt, and the Statewide CASE Team reflected this in its lighting model.

3.3 Residual MELs Methodology Overview

The diverse nature of the remaining electric loads—modeled in aggregate as "residual MELs"—necessitated a unique methodology. The Statewide CASE Team took a bottom-up approach to modeling residual MELs by constructing a comprehensive list of over a hundred end uses from several data sources.[9] The Statewide CASE Team estimated the AEC of each of these products for a reference year (2013) and then projected the total residual MELs AEC forward using CEC's assumed annual growth rate for miscellaneous residential AEC.

There are no existing studies that have empirically evaluated how residual MEL energy use scales with building size, nor are there adequate data sources available to derive the relationship with reasonable accuracy.[10] In the absence of existing studies or data sources, the Statewide CASE Team assumed that AEC of residual MELs scale with home size in the same way that consumer electronics scale with home size. This assumption was made in part because many of the residual MELs that use the most energy (e.g. DVD players, video game consoles, audio devices) have the same general usage patterns as the individually-modeled non-white goods (televisions, computers and monitors, and set-top boxes). The resulting equation that describe AEC based on NBr appear reasonable in magnitude and slope when benchmarked against other models of whole-building energy use and MEL energy use, as

[9] The data sources considered for the list of residual MELs are discussed in Section 4.9.4. The most prominent data sources were a 2014 meta-analysis of consumer electronics and residual MELs AEC by SCE (SCE 2014), DOE rulemaking documents for the battery chargers and external power supplies (DOE 2012f), and the Building America House Simulation Protocols energy models (Wilson et al. 2014).

[10] For example, the RESNET 2013 equations assume a constant energy per square foot based on the average residual MELs AEC and average floor area (RESNET 2013). The 2014 Building America House Simulation Protocols also take a theoretical approach, generally assuming that half of residual MELs AEC is fixed for all home sizes, a quarter scales based on kWh/bedroom, and a quarter scales based on kWh/square foot (Wilson et al. 2014). The RASS 2009 Conditional Demand Analysis uses a statistically-adjusted engineering approach to estimate miscellaneous electricity use for homes of varying NBr (based on whole-home metered data and survey responses), but the analysts were not able to separate residual MELs from lighting (KEMA 2010b)

shown in Section 4.9.5 (Parker et al. 2011; Wilson et al. 2014). A more complete description of the residual MELs methodology and results can be found in Section4.9.

Given the diversity and constant evolution of residual MELs AEC and the fact that the AEC of residual MELs is larger than that of any other product considered in this report, the need to better characterize residual MELs AEC is one of the most important data gaps highlighted in this report (see Section 8.1.2 for further discussion).

3.4 Regression Analysis to Relate Per-Household AEC to Home Size

With the exception of the rulesets that are derived from CEC's HWH ruleset,[11] the proposed AEC rulesets are linear equations that estimate AEC as a function of NBr or CFA. Scaling MEL and lighting energy use with NBr or CFA is a common approach in building energy simulations. The 2013 Title 24 rulesets (which use the equations in the 2008 HERS Technical Manual) are all linear equations that predict AEC based on NBr or CFA, as are the equations in Residential Energy Services Network (RESNET), the Building America House Simulation Protocols, and the 2011 Florida Solar Energy Center (FSEC) study that informed both the RESNET and BA HSP energy models (RESNET 2013, Wilson et al. 2014, Parker et al. 2011).[12] This section examines the logic and data underlying the convention of scaling AEC with NBr and/or CFA and discusses the choices the Statewide CASE Team made when conducting regression analyses to develop AEC equations. In particular, this section presents the Statewide CASE Team's rationale for choosing to model MELs as a function of NBr and lighting as a function of CFA, the choice of a linear functional form for the regression analysis, and why estimated AEC in the proposed rulesets does not increase indefinitely with home size.

3.4.1 Scaling Per-Household AEC Based on Home Size

There are several intuitive reasons why larger homes would have greater plug load and lighting AEC. Larger homes tend to have more physical space for more devices (and larger devices), more occupants consuming energy services, and the occupants tend to have more household income to spend on increased amenity, such as additional devices or devices with premium features. As shown in Table 5, these intuitions are supported with data from RASS 2009, showing the increase in average number of occupants and household income with greater CFA. Furthermore, Table 5 shows that occupants, income, and CFA all tend to increase with NBr. Based on the averages, the occupancy and income trends do not appear to continue for homes with more than seven bedrooms, but these averages are far less certain, as only seven 8-bedroom households were surveyed.

[11] The dishwasher, clothes washer, and clothes dryer rulesets scale with NBr according to the modeled annual uses in the HWH model, not based on the results of a regression equation built on survey data.

[12] Exceptions are that primary refrigerator AEC is constant in some models and residual MELs are modeled in the form of AEC = a + b(NBr) + c(CFA) in the Building America House Simulation Protocols.

Table 5: Average CFA, number of occupants, and total household income by NBr (RASS 200)

NBr	Average CFA	Average Occupants	Average Household Income	Number of Households Sampled	% of CA Households[1]
0	400	1.5	$ 34,000	362	2%
1	600	1.8	$ 41,000	2873	13%
2	900	2.5	$ 49,000	7377	27%
3	1600	2.9	$ 71,000	8475	34%
4	2200	3.4	$ 93,000	4286	19%
5	2800	4.1	$ 97,000	959	4%
6	3600	4.0	$ 102,000	141	1%
7	4000	6.4	$ 139,000	27	0%
8	4400	4.5	$ 80,000	7	0%

1. Fraction of California households living in dwelling units with the specified NBr. The Statewide CASE Team used the RASS sample weights to estimate population statistics from the responses of the households sampled in RASS. These sample weights correct for the over-sampling and under-sampling of different demographics.

These trends are plausible reasons to explain why plug load and lighting energy use has been shown to increase with NBr. For example, Figure 5 presents the Statewide CASE Team's analysis of RASS microdata,[13] which shows the average AEC of all plug loads and lighting

[13] The AEC values in

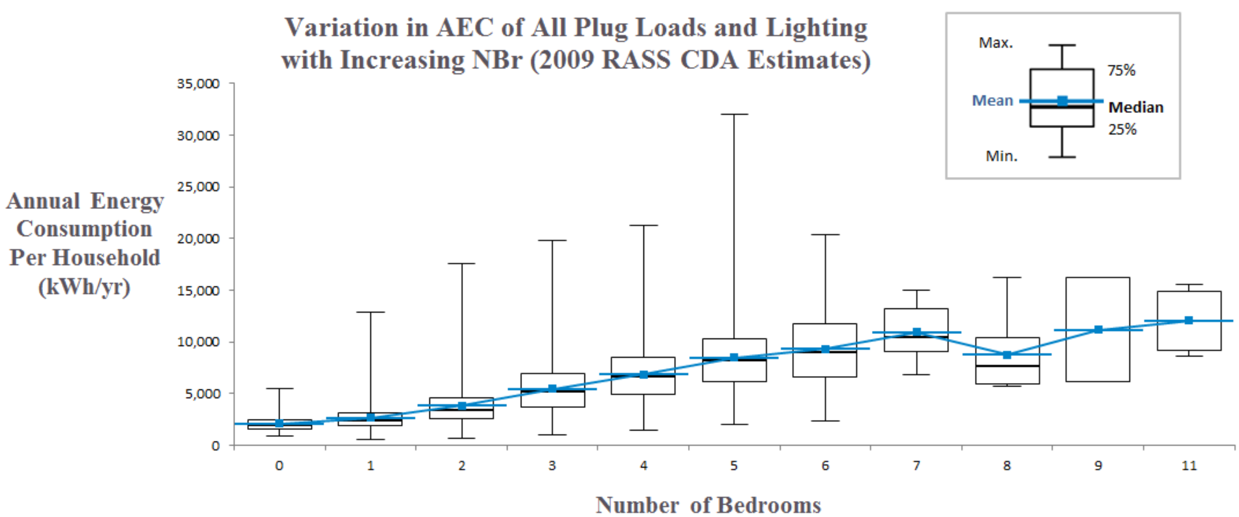

Figure 5: Variation in annual electricity use from all plug loads and lighting with increasing NBr (RASS 2009 CDA)

are derived from the RASS Conditional Demand Analysis (CDA), which is described in further detail in Section 3.5.2.1.

tends to increase approximately linearly with NBr through seven bedrooms, similar to the trends in average occupancy and income. Plots showing generally similar trends for the constituent end uses can be found in the benchmarking portions of Section 3. Note that while the average per-household AEC tends to increase linearly with NBr, there is substantial variation in AEC between households of the same NBr, as shown by the distance between the minimum and maximum AEC.[14]

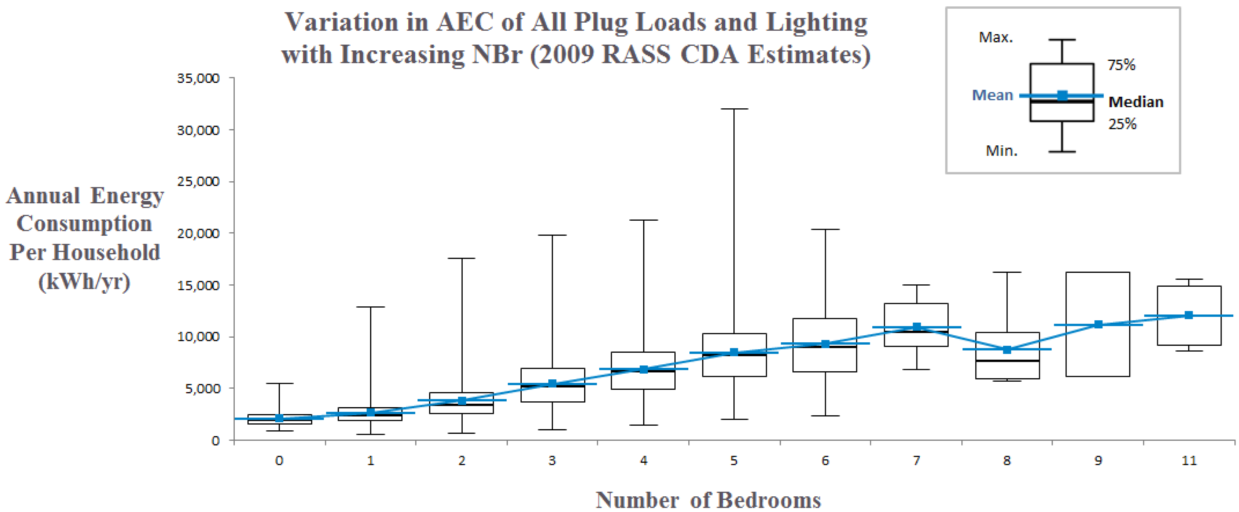

Figure 5: Variation in annual electricity use from all plug loads and lighting with increasing NBr (RASS 2009 CDA)

3.4.2 Choice of NBr or CFA as Metrics of Home Size

There are other variables that could be used to predict AEC of newly constructed homes, but not nearly as many variables as could be used for existing buildings. In existing buildings, a model could be based on information about the house and its occupants, a detailed inventory of devices, or even historic billing data. For new construction, AEC must be predicted based only on information that the builder supplies about devices that will be present in the home, and information about the house itself.

Information about builder-supplied devices includes which white goods will be present, their fuel type, and in certain cases their rated efficiency. The Statewide CASE Team aimed to incorporate available information about the builder-supplied devices into the models, as summarized in the inventory and usage columns of

Table 4 and described in more detail in Section 4.11.3, which discusses the proposed energy efficiency credit system.

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[14] A linear regression between the AEC and NBr values presented in Figure 1 yields an R^2 of 0.35, indicating that most of the variation in total plug load and lighting AEC is not explained by NBr.

Information about the house includes house type (e.g. single-family or multi-family), geographic location, NBr, CFA, number of stories, and presence of gas/electric hook-ups.

The Statewide CASE Team did not use all of the possible house characteristics to predict AEC by home size, but instead based the regression on NBr for plug loads and CFA for lighting. Taking certain additional characteristics into account may be a valuable expansion to the rulesets in future code cycles. For example, the Statewide CASE Team recommends that future updates to the rulesets fully account for house type—at least when making the distinction between single-family and multi-family housing. The recommended algorithms for the 2016 code cycle only depend on house type for non-primary refrigerators and separate freezers and the end uses that were harmonized with CEC's WH ruleset.[15]

When developing the rulesets, the Statewide CASE Team determined that either NBr or CFA could be used to scale AEC with home size with a comparable level of accuracy. Given the desire to simplify the rulesets, the Statewide CASE Team proposes rulesets that use NBr for all plug loads and CFA for lighting. Table 6 presents the home size metrics that other modeling approaches use to scale energy use by home size. The shift to using NBr for plug loads and CFA for lighting harmonizes the Title 24 modeling approach with other modeling approaches, such as RESNET. The Statewide CASE Team modeled lighting measures as a function of CFA for consistency with other models because the number of light fixtures most directly scales with floor area and, due to the practical limitation that the CLASS WebTool does not provide conditional averages based on NBr.

[15] Multi-family residences are assumed to have no non-primary refrigerators or separate freezers, as explained in Section 4.1.5. Because the CEC's WH models have different usage assumptions for single-family and multi-family residences, the recommended algorithms for dishwashers, clothes washers, and dyers also depend on house type.

Table 6: Home size metrics used in different models of plug load and lighting energy use

End Use	FSEC[1] 2011	RESNET [2] 2013	BA HSP[3] 2014	TITLE 24 WH[4] Model	2013 Title 24 Rulesets	Proposed 2016 Title 24 Rulesets
Primary Refrigerators	NBr	NBr	Constant	N/A	Constant	NBr
Non-Primary Refrigerators and Separate Freezers	N/A	N/A	NBr + CFA	N/A	Constant	NBr
Dishwashers	NBr	NBr	NBr	NBr	NBr	NBr
Clothes Washers	NBr	NBr	NBr	NBr	CFA	NBr
Clothes Dryers	NBr	NBr	NBr	NBr	CFA	NBr
Ovens and Cooktops	NBr	NBr	NBr	N/A	CFA	NBr
Televisions	NBr	NBr	NBr + CFA	N/A	N/A	NBr
Set-Top Boxes	N/A	N/A	NBr + CFA	N/A	N/A	NBr
Computers and Monitors	N/A	N/A	NBr + CFA	N/A	N/A	NBr
Residual MELs	CFA	CFA	NBr + CFA	N/A	CFA	NBr
Lighting	CFA	CFA	CFA	N/A	CFA	CFA

1. Updated Miscellaneous Electricity Loads and Appliance Energy Usage Profiles for Use in Home Energy Ratings, the Building America Benchmark Procedures and Related Calculations (Parker et al. 2011)
2. Residential Energy Services Network National Home Energy Rating Systems Standards (RESNET 2013)
3. 2014 Building America House Simulation Protocols (Wilson et al. 2014)
4. Domestic Water Heating Ruleset used in the Title 24 compliance software

A further benefit of the standardized approach in choosing NBr or CFA is that it can facilitate updates to the model. Updates can focus on providing more recent and reliable data rather than re-running statistical tests to determine the ideal predictor variables of home size. Being easy to update is also an important benefit to using a single-variable approach, as opposed to a multiple regression analysis that predicts AEC based on NBr and CFA. With a multivariate approach it would be more difficult for analysts updating the model to: 1) present results and compare results to other benchmarks, 2) verify the assumption of linear, additive effects across all homes sizes, and 3) check that the predicted AEC is reasonable for all combinations of NBr and AEC.

Although using a multiple regression analysis or selecting CFA for some plug loads could result in more accurate results, the level of accuracy that is lost by using NBr for all plug loads is minimal. Table 7 presents the fit (R^2) of the linear models that predict AEC of each household in RASS based on NBr, CFA, or both. The NBr models are equivalent to the regression equations underlying the proposed rulesets. The CFA models are what the algorithms would have been if the Statewide CASE Team had based the RASS equations on CFA. The combined model represents a multivariate approach. Overall, none of the models can explain most of the variation in per-household AEC; the R^2 of the models when applied to the RASS data is always less than 0.22. Moreover, the R^2 for the CFA models is very similar to that of the NBr models for every product category, indicating that the choice of NBr or CFA does not bear a large predictive cost. A multivariate approach only yields marginal gains in R^2, largely because NBr and CFA are correlated with each other.

Table 7: Fit (R^2) values for linear models that estimate "2017 per-household AEC" based on NBr, CFA, or both

Product Category	R^2 of Per-Household AEC[1] by Home Size Using Various Metrics for Home Size		
	NBr	CFA	NBr + CFA
Primary Refrigerators	0.19	0.18	0.22
Non-Primary Refrigerators and Separate Freezers	0.12	0.14	0.16
Dishwashers	No regression results: these measures are scaled with home size using the projected uses/year from CECs WH ruleset		
Clothes Washers			
Clothes Dryers			
Ovens	0.01	0.02	0.02
Cooktops	0.02	0.01	0.03
Televisions	0.09	0.10	0.14
Set-Top Boxes	0.07	0.07	0.09
Computers and Monitors	0.14	0.11	0.15
Residual MELs	No R^2 values: residual MELs were scaled in proportion to the total estimated AEC of the individually modeled consumer electronics		
Lighting	No R^2 values: lighting measures were derived from the CLASS WebTool, which only provides conditional averages, not raw data		

1. R2 values are based on the relationship between NBr and the "2017 per-household AEC" calculated for each home in RASS—not metered AEC.

Although most of the variation in per-household AEC cannot be explained by home size (measured by NBr, CFA, or both), there are statistically significant trends in how AEC tends to increase with home size. This is clear from the results of statistical tests—all of the models in Table 7 are highly statistically significant (with a p-value less than 0.001). Figure 6 illustrates this pattern: although the unexplained variation in per-household AEC of computers and monitors is very high ($R^2 = 0.17$), there is a clear trend that average per-household AEC increases with NBr, and the NBr-based model is highly statistically significant (p-value < 0.001). In general, the algorithms presented in this report can be expected to predict the average AEC of a given home size, but are unlikely to accurately predict AEC of a given home. There are simply too many other factors that affect AEC other than home size, such as individual variation in consumer and behavioral preferences.

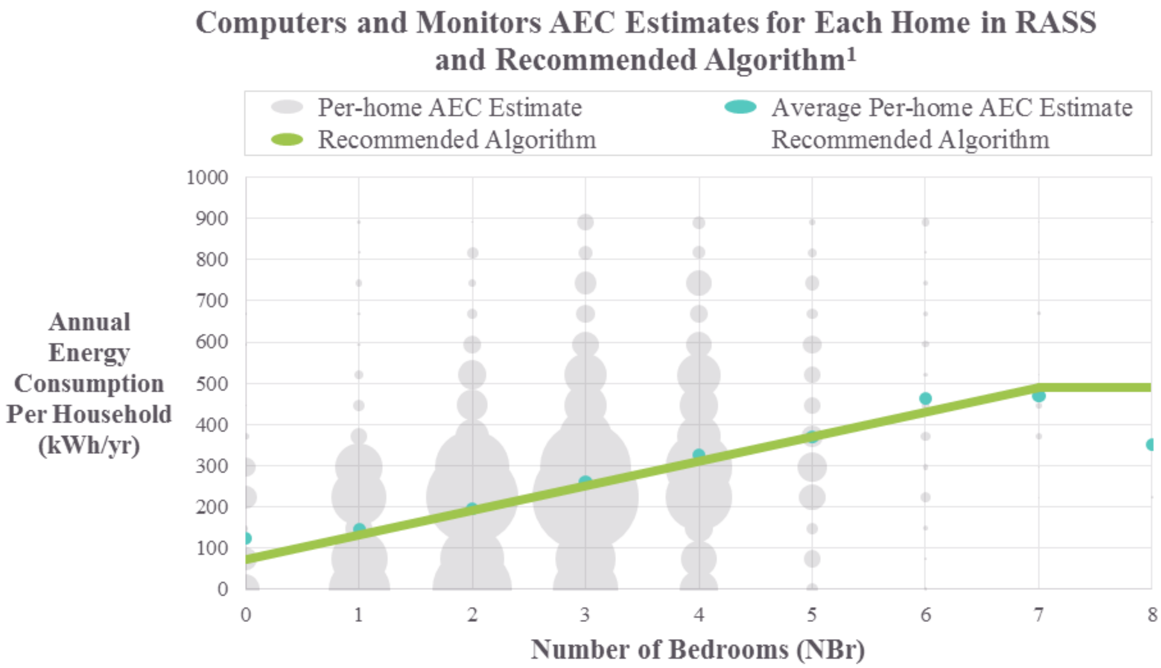

Figure 6: Variation in per-household AEC of computers and monitors and average AEC estimates by NBr

1. Bubbles represent the per-household AEC estimates for every home in RASS. The size of the bubble is proportional the number of households with a given combination of AEC and NBr. There are only a discrete set of estimated per-household AEC values, because AEC is calculated based on RASS survey responses.

3.4.3 Assumption of Linearity

The Statewide CASE Team considered alternatives to linear equations, including logarithmic, exponential, quadratic, and sigmoidal functional forms, but ultimately chose to use linear equations. The Statewide CASE Team's estimated AEC values and the AEC values from the RASS CDA follow an approximately linear trend with NBr (at least through seven bedrooms), so linearity was a reasonable approximation. Although more advanced curve-fitting approaches could have marginally increased the R^2, the potential improvement in accuracy from using more complex curve-fitting is limited since the correlation between NBr and per-household AEC is not strong.

Moreover, the substantial benefit of simplifying the rulesets by using linear regressions for all produce categories outweighs the small improvement in model accuracy. Using linear regression makes updates to the rulesets much easier. Rather than choosing a new functional form for the equations every time the data is updated, analysts can follow a set procedure for capturing the trend in how AEC generally varies with home size.

One potential limitation to scaling AEC linearly with NBr is that it may under-predict the AEC of studio apartments, which are coded as "0 bedrooms" in the RASS data. For some product categories, it appears that the difference in per-household AEC between 0-bedroom and 1-bedroom homes may not be as great as the difference between successively higher-bedroom homes. The Statewide CASE Team suggests that the potential underestimation of AEC of studios should be re-examined in updates to the rulesets, after accounting for the difference between single and multi-family housing and analyzing trends in metered AEC data.

3.4.4 Capping AEC Scaling for Large Homes

All of the proposed rulesets have a maximum AEC value that applies to homes above a certain size. The end uses that are harmonized with the Title 24 WH rulesets are capped at five bedrooms, because the Title 24 WH rulesets assume a constant number of annual uses for home with five or more bedrooms.

The other plug load models are capped at seven bedrooms, in part because the estimated AEC values appear to plateau at seven bedrooms for most end uses, as do the RASS CDA results for most end uses. In addition, as shown in Table 7, the average number of occupants and household income do not continue to increase after seven bedrooms. It is possible that these trends are an artifact of the low sample size in RASS for extremely large homes. The Statewide CASE Team suggests that the cap on these plug load equations be re-evaluated in updates to the model after analyzing any submetered data for very large homes that becomes available in the interim. Given the fact that homes with eight or more bedrooms represent less than 0.1 percent of the existing building stock (as determined through the sample-weighted RASS data), the cap at seven bedrooms is not likely to have an impact on new construction during the 2016 Title 24 code cycle.

The Statewide CASE Team capped the lighting models at 4,150 square feet—the estimated average size of the largest home size bin reported by the CLASS WebTool.[16] Although the total number of luminaires is likely to increase indefinitely with CFA, the Statewide CASE Team recognizes that the amount of lighting services consumed by a household is likely to plateau due to decreasing occupant densities. The Statewide CASE Team suggests that the cap for lighting equations be re-evaluated in updates to the model after analyzing data from light-logging studies that establish how average hours of use vary with home size. Alternately, submetering studies could provide an empirical basis for the relationship between CFA and lighting AEC of large homes.

3.5 Comparisons against Various Reference Points and Benchmarks

3.5.1 Benchmarking Approach Overview

To help verify the relative accuracy of the rulesets presented in this report, the Statewide CASE Team compared the proposed rulesets against various reference points and benchmarks. These resources are summarized in Table 8 and described in more detail in Section 3.5.2.

[16] The Statewide CASE Team calculated this value using square footage data from RECS 2009, which was measured on-site by trained auditors.

Table 8: Resources used to benchmark modeling results

Data Source	Data Type	Most Representative of Which Building Stock?
RASS 2009 CDA Estimates, Average AEC by NBr	Energy model	2008, existing CA homes
2013 Title 24 Code Cycle Algorithms	Energy model	2008, existing CA homes
RESNET 2013 Standards for the Reference Home	Energy model	2011, existing US homes
Building America 2014 House Simulation Protocols	Energy model	2010, existing US homes
NEEA Residential Building Stock Assessment 2014	Submetering study	2011-2012, existing single-family homes in the Pacific Northwest
Energy Consumption of Consumer Electronics in U.S. Homes in 2013 meta-analysis (Urban et al. 2014)	Meta-analysis of consumer electronics AEC	2013, existing US homes
Other (Includes: CLASS 2012, HMG 1999, REU 2016, Redwood Energy Cooking Study, etc.)	Generally submetering studies	Varies

These resources are useful for high level comparative analysis of proposed rulesets' accuracy, but there are important reasons why none of the reference points are directly comparable to the Statewide CASE Team's proposed rulesets. The most crucial difference is that the Statewide CASE Team's objective is to estimate energy use of new California homes constructed during the 2016 code cycle, whereas the other data sources are most representative of different time periods, geographic regions, and/or building vintages. It can be challenging to determine whether these differences would cause the referenced data sources to overestimate or underestimate AEC in modern, newly built California homes, and more difficult still to quantify the magnitude of that bias.[17] Rather than introduce an additional set of errors into the benchmarking analysis by developing numerical correction factors that aim to make all data sources fully comparable, the Statewide CASE Team has provided a brief qualitative analysis at the end of each results section, discussing similarities and differences between the proposed algorithms and the various reference points and benchmarks.

Another important consideration when analyzing the benchmarking results is that there may be errors associated with both the proposed rulesets and the reference points. Due to a lack of recent, California-specific submetering data, the majority of data sources for comparison are energy models, which may not accurately estimate the magnitude of AEC of the year and region they represent, nor how AEC actually scales with home size. The Statewide CASE Team generally considers submetering studies to be more reliable representations of their target building stock and time period.

[17] For example, older data sources will tend to overestimate energy use in modern, newly built California homes to the extent that the efficiency of that product category is improving but will tend to underestimate energy use to the extent that the number or size of devices is increasing over time. Similarly, it can be challenging to determine whether energy use estimates from other regions will tend to biased high or low relative to California-specific data.

3.5.2 Data Sources for Benchmarking

3.5.2.1 RASS 2009 CDA

The RASS Conditional Demand Analysis (CDA) employs a statistically-adjusted engineering method to disaggregate the metered energy use of the homes surveyed in the 2009 RASS. The analysts developed engineering equations to estimate the AEC of all the major end uses in the home as a function of the survey-reported data. For some end uses, such as lighting and HVAC, the analysts also based AEC estimates on daylight hours and climatic variables. The AEC values were then linearly scaled to minimize the difference between the sum of the estimated AEC values and the metered, whole-home energy use of each home (KEMA 2010b).

The RASS microdata provided to the Statewide CASE Team contains AEC estimates for each surveyed household. Although these estimates are not reliable on a per-household basis—many households have unrealistic or even negative estimated AEC values—they are a useful benchmark when averaged over many homes. The Statewide CASE Team compared the recommended algorithms for the 2016 Title 24 code cycle to the average AEC estimated by the RASS CDA for homes of varying NBr. These average AEC estimates are most reliable for the most common home sizes.

For dishwashers, ovens, cooktops, clothes washers and clothes dryers, the Statewide CASE Team filtered the RASS CDA microdata to analyze the households that reported owning a particular device.

3.5.2.2 2013 Title 24 Code Cycle Algorithms

The current algorithms in the Title 24 Residential ACM Reference Manual use the equations from the 2008 California HERS Technical Manual to estimate AEC of new construction (CEC 2013, 2008a). In general, the magnitude and scaling of the current algorithms are based on a regression analysis that captures the trends in how the AEC estimates from the RASS CDA vary with CFA or NBr. A more detailed explanation of the assumptions and methods underlying the 2013 algorithms can be found in the California HERS Consultant Report, which generally aligns with the adopted HERS rulesets (CEC 2008a).

Because many of the current MEL algorithms use CFA as the predictor variable (see Table 6), the Statewide CASE Team had to convert from CFA to NBr in order to visually compare the current algorithms to the proposed algorithms. The Statewide CASE Team did so by determining the average CFA for each NBr and inputting these values in the CFA-based algorithms. Table 5 presents the average CFA by NBr that the Statewide CASE Team used, calculated from the RASS microdata.

3.5.2.3 RESNET 2013 Standards for the Reference Home

The Statewide CASE Team compared the proposed algorithms to energy models defined in the National HERS Standards, published by RESNET. These algorithms estimate the AEC of the Reference Home as a function of NBr or CFA (see Table 6) (RESNET 2013). The source of the RESNET algorithms is a 2009 Florida Solar Energy Center (FSEC) analysis (last updated 2011), which scales AEC to home size based on survey-reported saturation, size, and usage in the national survey RECS 2005 (Parker et al. 2011)[18]. The lighting AEC equations in RESNET, which are also taken from the 200 FSEC study, were ultimately derived from the 2002 DOE Lighting Market Characterization, conducted by Navigant (Parker et al. 2011).

3.5.2.4 Building America 2014 House Simulation Protocols

Sponsored by DOE, the Building America House Simulation Protocols (Wilson et al. 2014) provides builders with AEC benchmarks as a function of NBr, CFA, or both (see Table 6) (Wilson et al. 2014). The benchmark home is defined as one that is constructed according to the 2009 International Energy Conservation Code (IECC), as well as the federal appliance standards in effect as of 2010, lighting characteristics and MELs most common in 2010 (Wilson et al. 2014). The general relationship between appliance loads, NBr, and house size was based on regression analysis of data from the national survey RECS 2001, in a similar fashion to the FSEC analysis that informs the RESNET 2013 standards Wilson et al. 2014).

3.5.2.5 Northwest Energy Efficiency Alliance (NEEA) Residential Building Stock Assessment (RBSA) 2014

From 2012-2013, the NEEA submetered 101 single-family, all-electric homes in the Pacific Northwest as part of their RBSA (NEEA 2014). Each home was submetered at a device level at 15-minute intervals for a full year, and light loggers were installed to measure hours of on-time in interior and exterior spaces (NEEA 2014). Submetered appliances include all of the individually modeled plug load product categories in this CASE Report.

The Statewide CASE Team multiplied the metered AEC per device listed in the NEEA RBSA Report by the number of devices per household reported in RASS 2009 by families living in the newest stock of homes (built from 2005-2008). The strengths of the resulting per-household AEC estimates are that they reflect a California-specific saturation and a relatively recent estimate of unit energy consumption. On the other hand, the limitations of this benchmark are that it reflects 2009 saturation and Pacific Northwest usage and efficiency patterns. Furthermore, the NEEA submetering data is only a point estimate, plotted at the average NBr value of the sampled homes.

3.5.2.6 Energy Consumption of Consumer Electronics in U.S. Homes in 2013 Meta-Analysis (Urban et al. 2014)

The CE Usage Survey described in Section 3.1.3 was one component of *The Energy Consumption of Consumer Electronics in U.S. Homes in 2013* meta-analysis (Urban et al. 2014). This meta-analysis, conducted by Fraunhofer CES, employed a bottom-up approach to develop AEC estimates for 49 CE product categories, including televisions, set-top boxes, computers, and monitors, based on a wide variety of data sources. The authors estimated the

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[18] Updated Miscellaneous Electricity Loads and Appliance Energy Usage Profiles for Use in Home Energy Ratings, the Building America Benchmark Procedures and Related Calculations (Parker et al. 2011)

power draw by mode, duty cycle, and installed base (total number of devices actively used in American homes) for each product category. The authors calculated the AEC per device for different product classes (as well as the per-household AEC of all products in each category) by multiplying these factors together.

The Statewide CASE Team multiplied the AEC per device reported in the meta-analysis by the number of devices per household reported in RASS 2009 by families living in the newest stock of homes (built from 2005-2008). The strengths and weaknesses of this benchmark are similar to the RASS saturation-adjusted NEEA RBSA; per-household AEC estimates reflect a California-specific saturation and a relatively recent estimate of unit energy consumption, but not California-specific usage and efficiency patterns. The data from the Urban et al. 2014 study is represented as a point estimate, plotted at the average NBr value for U.S. homes, according to microdata from the national survey RECS 2009.

3.5.2.7 Other

In addition to the standardized set of data sources listed above, the Statewide CASE Team compared the proposed algorithms to supplementary benchmarks. For example, the Statewide CASE Team compared CLASS 2012 and data sources that were more specific to certain product categories, such as HMG's 1999 *Lighting Efficiency Technology Report*, the recent update to the residential end uses of water submetering study, and recent submetering of 81 low-income, multi-family, California homes by Redwood Energy (HMG 1999; WRF 2016; Redwood Energy Cooking Study 2015).

4. Annual Energy Consumption Calculation and Results Summaries

This section discusses the methodologies used to develop the rulesets for each product category, the resulting AEC algorithms, and benchmarking against a selection of studies and models. The final section (Section 4.11) contains plots that provide a summary and benchmarking analysis of the results (i.e. recommended algorithms) for all product categories combined.

4.1 Refrigerators and Freezers

4.1.1 Technology Introduction

Residential refrigeration products include refrigerators, refrigerator-freezers, and freezers. The DOE defines refrigeration products as “appliances that cool and/or freeze food and beverages and which may also provide ice and chilled water” (DOE 2014c).

Standard-size refrigerator-freezers—that is, refrigeration products that are roughly 5.5 feet tall that include both a refrigerator and a freezer—constitute approximately two thirds of the market share of refrigeration products used in the residential sector. The remaining one third of refrigeration products is almost entirely comprised of standard-size freezers (about one sixth of the market) and compact refrigerators (the remaining sixth), as shown in detail in Table 9 (DOE 2011a).

Table 9: 2008 market share for residential refrigeration products

Product Type	**Market share (2008)**
Standard-Size Refrigerator-Freezers	67%
Standard-Size Freezers	16%
Compact Refrigeration Products	16%
Built-in Refrigeration Products	2%
Total	**100%**

Source: (DOE 2011a)

Refrigerators and freezers have steadily increased in efficiency for decades. For example, the AEC of a new refrigerator has decreased from approximately 1,800 kWh/yr in 1972 to less than 500 kWh/yr for a modern refrigerator (DiMasco et al. 2014).

The AEC of miscellaneous refrigeration products, such as wine coolers, is accounted for in the residual MELs model.

4.1.2 Existing Energy Efficiency Standards

The dramatic progress in refrigeration efficiency has been driven in part by a series of efficiency standards, beginning with standards that California adopted in the 1970s and updated twice in the 1980s and further propelled through three iterations of federal standards (DiMasco et al. 2014).

The most recent federal efficiency standards for residential refrigerators and freezers were adopted in 2011 and took effect in 2014, as codified in 10 CFR 430.32(a) of the standards. These standards prescribe minimum energy efficiency requirements for 42 different refrigerator and freezer product classes, which are defined by a unique combination of configuration and features.[19] For each product class, the efficiency requirement is a function of its internal volume of refrigerator capacity and freezer capacity.

The Statewide CASE Team assumed that some refrigerators and freezers in new homes would be newly purchased and some would be older models. The default rulesets assume the weighted average efficiency of new and existing models. The Statewide CASE Team therefore considered an older set of federal efficiency standards for the existing models. The previous federal efficiency standards for residential refrigerators and freezers were adopted in 1997 and took effect in 2001. The structure of the previous standards is similar to the 2014 standards, but with less granular product classes.

[19] For example, product class “3I. Refrigerator-freezers—automatic defrost with top-mounted freezer with an automatic icemaker without through-the-door ice service.”

4.1.3 Key Variables Impacting Energy Use

The Statewide CASE Team accounted for the following factors in the refrigeration products AEC algorithm:

- Number of devices per household (saturation);
- Internal volume of refrigerator capacity and freezer capacity (cubic feet);
- Product type (refrigerator, freezer, or refrigerator-freezer);
- Configuration (e.g. top-mounted, bottom-mounted, or side-mounted freezer and chest or upright freezer);
- The presence or absence of features self-reported in RASS (specifically, whether products have automatic defrost and a through-the-door ice dispenser); and
- Device age.

Other factors that affect real-world AEC of refrigeration devices include occupant behavior (e.g. how frequently the doors are opened and coils are cleaned and whether energy efficiency features are disabled) and additional product characteristics not reported in RASS (e.g. presence of automatic icemaker and whether the refrigerator is built-in or standalone). Although the Statewide CASE Team was not able to fully account for these variables with available data, future updates to the model may be able to do so through use of real-world adjustment factors or by relying on more detailed or empirical data sources. Although the proposed AEC algorithms do not account for the effect of indoor temperature on refrigerator and freezer energy use, the proposed load profile algorithm does, as discussed in Section 6.

The variables that the Statewide CASE Team used to develop the refrigerator algorithms are presented in Table 10, along with how the variable was used when developing the ruleset and the data source used to obtain them.

Table 10: Key variables and their functions within the refrigerators/freezers methodology

Variable	Function	Source
Configuration	Assign devices reported in RASS to DOE product classes	RASS 2009; DOE rulemaking documents
Features		
Adjusted Volume	Determine maximum allowable AEC of each device in RASS	RASS 2009; ENERGY STAR QPL
Age Assumption	Determine age-weighted AEC	RASS 2009[1]
Saturation	Convert AEC to per-household AEC	RASS 2009

1. Method explained in Appendix A: Age of Non-Builder Supplied White Goods.

4.1.4 Methodology

4.1.4.1 Methodology Overview

The Statewide CASE Team used RASS data to inform the inventory of refrigerators and freezers found in California homes, including information about refrigerator types, ages, common design features, configuration, and the number of refrigerators per home.

As mentioned, it was assumed that some refrigerators in newly constructed homes would be new and therefore meet the 2014 federal efficiency standards and some would be old and therefore meet the 2001 federal efficiency standards. For all survey-reported refrigerators and freezer in RASS 2009, the Statewide CASE Team calculated the estimated AEC if the device was minimally complaint with the current federal standards, which took effect in 2014. Refrigerator size, configuration, and features were taken into account in the calculation. The efficiency adjustment process was repeated assuming all devices were minimally compliant with the previous federal efficiency standards, which took effect in 2001. Next, data on the average age of refrigerators in newly constructed homes was used to develop an age-weighted average AEC of all refrigerators and freezers in the RASS database.

For each home in RASS, the Statewide CASE Team calculated two categories of per-household AEC of refrigeration: 1) AEC of the primary refrigerator and the combined AEC of any non-primary refrigerators and 2) any separate freezers.

The Statewide CASE Team developed two separate algorithms to describe how refrigerator and freezer energy use varies with home size: one for primary refrigerators and one for all other refrigerators and freezers. Both algorithms were developed using a linear regression comparing per-household AEC and NBr. The per-household AEC of other refrigerators and freezers reflects tendency for the average number of non-primary refrigerators and separate freezers to increase with NBr.

As discussed in Section 5.2, builders can receive credit for installing a primary refrigerator that is more efficient than minimally compliant with the current 2014 federal standards.

4.1.4.2 Translating RASS 2009 Size Data into Adjusted Volume

The 2001 and 2014 federal efficiency standards are defined as a linear function of the adjusted volume (AV) of a refrigeration product, which is its internal capacity in cubic feet with an adjustment factor that weighs freezer capacity more heavily than refrigeration capacity. See Equation 1 for DOE's definition of adjusted volume.

Equation 1: Definition of AV as used in DOE refrigeration efficiency standards

$$Refrigerator.AV = Refrigerator.Capacity + 1.63 \times Freezer.Capacity$$

$$Freezer.AV = 1.73 \times Freezer.Capacity$$

RASS respondents reported the size of their refrigerators and freezers by selecting from pre-determined size bins rather than providing a precise capacity in cubic feet. The Statewide CASE Team used capacity and adjusted volume data listed on the ENERGY STAR QPLs for residential refrigerators and freezers to convert the survey-reported refrigerator and freezer size bins to average adjusted volume values (ENERGY STAR 2015a; ENERGY STAR 2015b).[20] Table 11 and Table 12 present the Statewide CASE Team's estimates of the average adjusted

[20] For example, the Statewide CASE Team estimated the average adjusted volume of refrigerators that are 20 to 23 cubic feet to be 25.5 cubic feet. This is the model-weighted average adjusted volume of the 165 refrigerators on the ENERGY STAR QPL that have a capacity between 20 and 23 cubic feet.

volume values corresponding to each of the RASS size bins for refrigerators and freezers. Average internal volume is also provided for reference.

Table 11: RASS 2009 refrigerator size bins and estimated average adjusted volume

RASS Size Bin (cu. ft.)	ENERGY STAR QPL Average (cu. ft.)	
	Capacity	Adjusted Volume
<13	4.7	5.2
13-16	14.5	17.1
17-19	17.8	21.0
20-23	21.1	25.5
>23	26.5	33.2

Table 12: RASS 2009 freezer size bins and estimated average adjusted volume

RASS Size Bin (cu. ft.)	ENERGY STAR QPL Average (cu. ft.)	
	Capacity	Adjusted Volume
<13	4.7	5.2
13-16	14.5	17.1
>16	22.4	27.4

4.1.4.3 Assigning DOE Refrigeration Product Classes

The efficiency requirements in the 2001 and 2014 federal standards for refrigerators and freezers depend not only on the adjusted volume of the products, but also on their product class. For each home in RASS 2009, the Statewide CASE Team mapped all of the self-reported refrigerators and freezers to the nearest DOE product class, first using the product classes in the 2014 standards and then using the product classes in the 2001 standards. For example, if RASS 2009 indicated that refrigerator had automatic defrost, through-the-door ice, and a side-by-side configuration, the Statewide CASE Team assigned it to the DOE product class seven, "Refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service," which is both a 2014 and 2001 DOE product class. Full details on the Statewide CASE Team's classification of RASS refrigerators and freezers into DOE 2014 and 2001 product classes can be found in Appendix B: Refrigerator and Freezer DOE Product Class Assignment. Table 13 and Table 14 summarize the Statewide CASE Team's assignment of 2014 DOE product classes to the refrigerators and freezers in RASS. The 2001 product classes are parallel to the 2014 product classes but with fewer categories.[21]

[21] For example, the 2001 standards do not subdivide product classes according to whether the refrigerator is built-in or if it has an automatic icemaker.

Table 13: Distribution of DOE product classes assigned to refrigerators reported in RASS

2014 DOE Product Class	Fraction of Refrigerators (%)
3I. Refrigerator-freezers—automatic defrost with top-mounted freezer with an automatic icemaker without through-the-door ice service.	36.8
7. Refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service.	25.7
4I. Refrigerator-freezers—automatic defrost with side-mounted freezer with an automatic icemaker without through-the-door ice service.	9.9
5I. Refrigerator-freezers—automatic defrost with bottom-mounted freezer with an automatic icemaker without through-the-door ice service.	8.7
1. Refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.	4.9
3A. All-refrigerators—automatic defrost.	4.7
11. Compact refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.	3.0
11A.Compact all-refrigerators—manual defrost.	2.3
5A. Refrigerator-freezer—automatic defrost with bottom-mounted freezer with through-the-door ice service.	1.7
6. Refrigerator-freezers—automatic defrost with top-mounted freezer with through-the-door ice service.	1.2
1A. All-refrigerators—manual defrost.	1.1
15. Compact refrigerator-freezers—automatic defrost with bottom-mounted freezer.	0.1
Total:	**100**

Table 14: Distribution of DOE product classes assigned to freezers reported in RASS

2014 DOE Product Class	Fraction of Freezers (%)
9. Upright freezers with automatic defrost without an automatic icemaker.	33.1
8. Upright freezers with manual defrost.	20.0
18. Compact chest freezers.	16.0
10. Chest freezers and all other freezers except compact freezers.	8.4
16. Compact upright freezers with manual defrost.	8.0
17. Compact upright freezers with automatic defrost.	8.0
10A. Chest freezers with automatic defrost.	6.4
Total:	**100**

4.1.4.4 Adjusting Efficiency to Reflect Likely Products in Newly Constructed Homes

The Statewide CASE Team calculated the expected energy use if all refrigerators in the RASS database met the 2014 federal standards, then re-calculated assuming all refrigerators met the 2001 federal standards. It was assumed that products would be minimally compliant with the relevant efficiency standard. This assumption may result in the AEC estimates being somewhat high because a portion of the products will exceed minimum efficiency requirements. The Statewide CASE Team estimated then developed an age-weighted AEC value for each refrigerator in the RASS data set. RASS 2009 data was used to predict that 42.5 percent of refrigerators and freezers in 2017 would comply with the 2014 standards, and 57.5 percent would comply with only the 2001 standards. The method for this prediction is discussed in Appendix A: Age of Non-Builder Supplied White Goods.

4.1.4.5 Determining Per-Household AEC as a Function of NBr

Using the age-weighted per-household AEC for all homes in RASS 2009, the Statewide CASE Team performed linear regression analyses to capture the relationship between per-household AEC and NBr, both for the primary refrigerator and for the all other refrigerators and freezers. The Statewide CASE Team recommends capping the resulting equation at seven bedrooms for the reasons discussed in Section 3.4.4.

4.1.5 Results

The following figures present the recommended algorithms for estimating the per-household AEC of primary refrigerators (Figure 7) and other refrigerators and freezers (Figure 8) based on NBr. The points in the graph represent the average per-household AEC calculated for RASS homes with a given NBr.

Multi-family residences are assumed to have no non-primary refrigerators or separate freezers. Although the saturation of these devices is non-zero in multi-family housing, there are technical barriers to estimating non-primary refrigeration AEC of multi-family residences, because the software assumes that non-primary refrigeration will be installed in the garage of the dwelling unit.

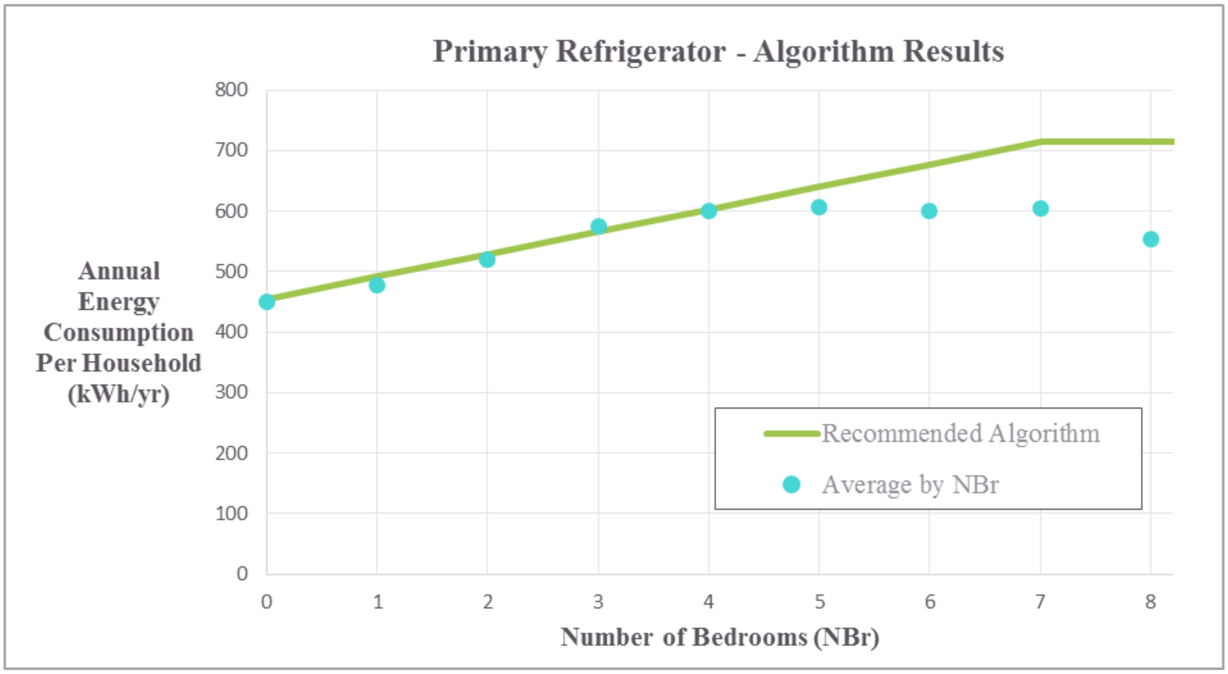

Figure 7: Per-household primary refrigerator AEC as a function of NBr

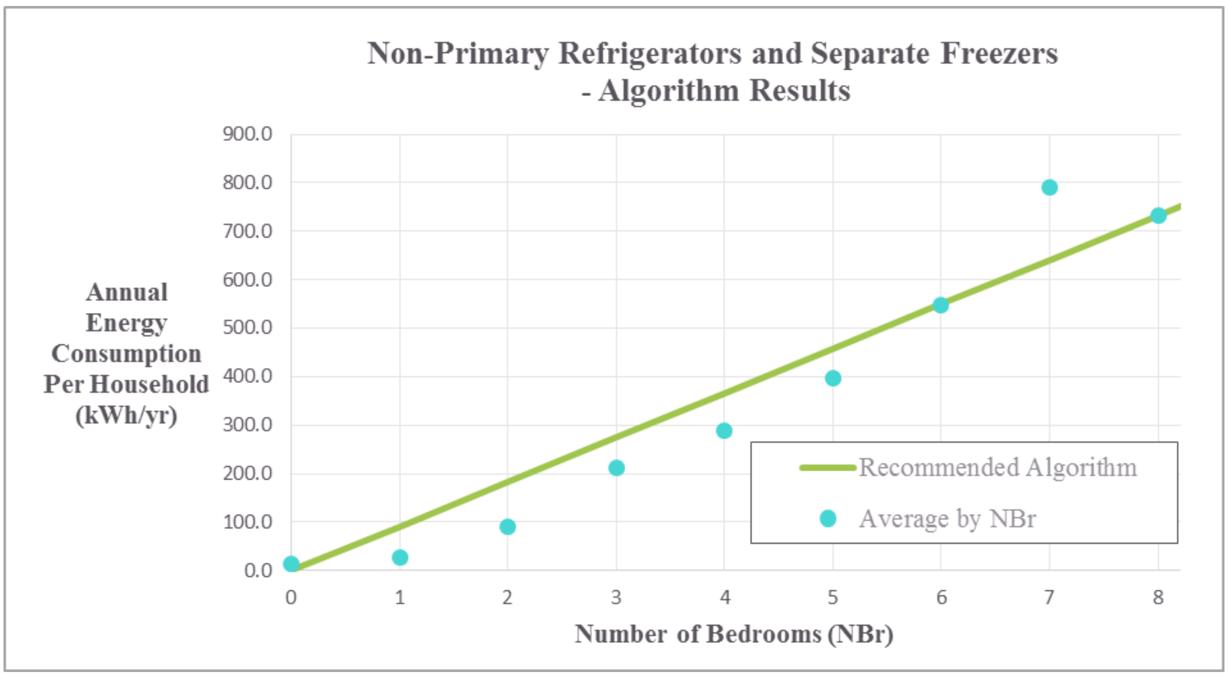

Figure 8: Per-household non-primary refrigerator and separate freezer AEC as a function of NBr

Primary refrigerator AEC tends to increase with NBr because the homes with more bedrooms tend to have larger primary refrigerators and are more likely to have more energy-intensive product classes.[22] The estimated AEC of non-primary refrigerators and freezers increases with NBr for the same reasons, but even more so because the average saturation of these devices rises with NBr.

Table 15 presents the results of the algorithm by NBr, for single-family and multi-family residences.

Table 15: Per-household AEC of refrigerators and freezers, estimated based on NBr

NBr	Annual Energy Consumption (kWh)		
	Primary Refrigerator	Non-Primary Refrigerators and Separate Freezers	
		Single-Family	Multi-Family
0	454	0	0
1	491	71	0
2	528	142	0
3	565	213	0
4	602	284	0
5	639	355	0
6	676	426	0
7+	713	497	0

Figure 9 and Figure 10 compare the refrigerators and freezers algorithms to various benchmarks, described in Section 3.5.2. Both algorithms are close in magnitude to the most empirical data sources—the 2014 NEEA RBSA and the 2012 CLASS building audits. The primary refrigeration algorithm generally scales more steeply than the other data sources for the reasons discussed above. The non-primary refrigerators algorithm has comparable scaling to the 2014 Building America House Simulation Protocols.

[22] For example, top-mounted and single-door primary refrigerators are less common and side-by-side primary refrigerators are more common in homes with more bedrooms. Additionally, through-the-door ice is more common for primary refrigerators in homes with more bedrooms.

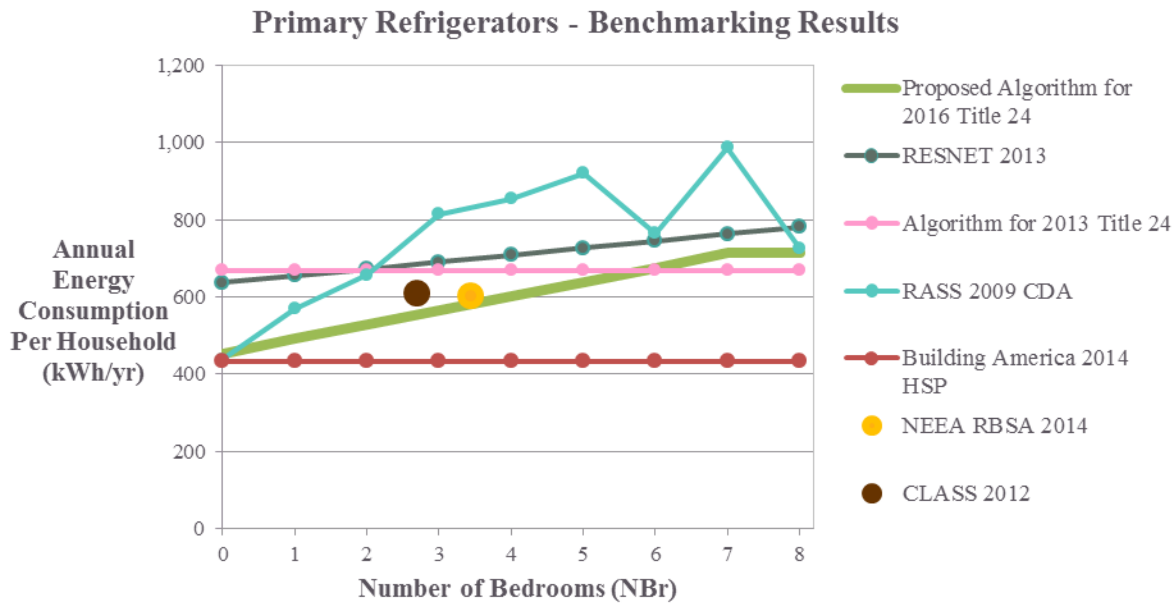

Figure 9: Comparison of primary refrigerators AEC algorithm against various benchmarks

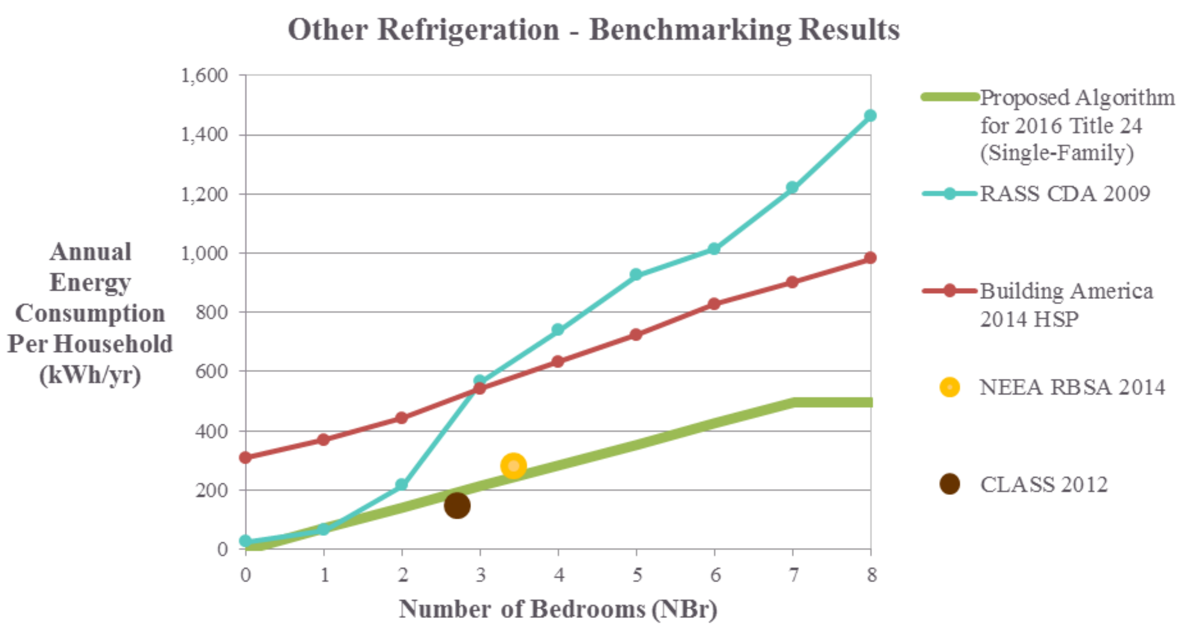

Figure 10: Comparison of non-primary refrigerators and separate freezers AEC algorithm against various benchmarks

4.2 Dishwashers

4.2.1 Technology Introduction

A dishwasher is defined by DOE as "a cabinet-like appliance which with the aid of water and detergent, washes, rinses, and dries (when a drying process is included) dishware, glassware, eating utensils, and most cooking utensils by chemical, mechanical and/or electrical means and discharges to the plumbing drainage system" (DOE 2012d). Dishwashers come in two primary size bins: 1) compact, with fewer than eight place settings, and 2) standard, with more than eight place settings. According to DOE rulemaking documents, standard dishwashers make up over 99 percent of the market (DOE 2012b).

4.2.2 Existing Energy Efficiency Standards

Dishwashers are regulated by federal energy efficiency standards. The most recent standards for dishwashers were adopted by DOE in 2012 and took effect on May 30, 2013 (DOE 2012d). Table 16 presents the standards defined in 10 CFR 430.32(f)(2), which apply to products manufactured on or after May 30, 2013. The maximum annual energy uses allowed for standard and compact dishwashers are 307 kWh/year and 222 kWh/yr, respectively.[23]

Table 16: Current federal standards for residential dishwashers, effective May 2013

Product Class	Maximum Annual Energy Use (kWh/year)	Water Consumption (gallons/cycle)
Standard Size	307	5.0
Compact	222	3.5

4.2.3 Key Variables Impacting Energy Use

Dishwashers impact home energy consumption in two ways. First, the dishwashing machine itself consumes energy in active mode and in standby mode. Second, during wash cycles, the dishwasher uses hot water, and energy is required to heat water. Both of these energy uses are accounted for in the federal efficiency standard, but the Statewide CASE Team included machine energy use in the proposed rulesets. Water heating energy use was omitted from the recommended MEL ruleset because the water heating ruleset already accounts for energy required to heat water that is used in dishwashers, and accounting for the water heating energy use in the MEL ruleset would double count the energy required to heat water that is used in dishwashers.

Other factors that affect real-world AEC of dishwashers include device characteristics such as size, premium functional capabilities, sensing technology, or temperature settings. In addition, some dishwashers heat water above the temperature delivered to the dishwasher from the water

[23] On December of 2014, DOE issued a Notice of Proposed Rulemaking to update these energy efficiency standards to 234 kWh/yr and 203 kWh/yr for standard and compact dishwashers, respectively. However, this ruling will likely not take effect until 2019.

heater, which constitutes water heating that is not accounted for in the water heating rulesets. Although the Statewide CASE Team was not able to account for these other variables with available data, future updates to the model may be able to do so through use of real-world adjustment factors or by relying on more detailed or empirical data sources.

The energy consumption of the dishwasher also depends on the device age. In this report, the Statewide CASE Team assumed the dishwasher to be newly-purchased.

Annual energy use of dishwashers is directly related to the number of wash cycles in a year and the size of the unit. With a greater number of cycles, more time is spent in active mode, and more energy is used throughout the year.

Table 17 lists the key variables used to develop the rulesets for estimating annual clothes washer and dryer energy use, along with how the variables were used when developing the ruleset and the data source used to obtain them.

Table 17: Key variables and their functions within the dishwashers methodology

Variable	Function	Source
Saturation	Determine whether household will have a dishwasher, and thereby whether dishwasher AEC is included in whole-house energy use estimates	Reported by compliance software user
Age	Determining applicable federal standards	Assumed to be new in new homes
Size of Unit	Determining product class for DOE standard	Assumed to be Standard size
Annual Energy Use	Determining code baseline performance	DOE rulemaking documents
Per-Cycle Water Use	Separating machine energy use from water heating energy use	ENERGY STAR QPL
Cycles Per Year	Determining usage patterns as a function of home size	Title 24 WH ruleset

4.2.4 Methodology

4.2.4.1 Methodology Overview

The Statewide CASE Team determined a per-cycle energy use of an average dishwasher that is minimally compliant with the current federal standard. Per cycle energy use was then multiplied by the dishwasher uses per year assumptions from CEC's WH rulesets to arrive at AEC.

If the software user indicates a dishwasher will be installed by the builder before building permits are issued, the default ruleset assumes that the dishwasher will be minimally compliant with federal standards. If the user indicates a dishwasher will not be installed in the building, dishwasher energy use is not included in the whole-building energy use calculations.

4.2.4.2 Determining Per-Cycle Energy Use

The Statewide CASE Team used data from the DOE Compliance Certification Database and DOE's test procedure rules to calculate the portion of total reported AEC attributed to water heating and machine energy use for dishwashers that are minimally compliant with the federal standard. The DOE database includes data on AEC (kWh/yr) and water consumption (gallons/cycle). The reported AEC value includes energy use associated with machine and water heating energy uses where water heating energy use is reported in kWh, regardless of the water heater fuel (e.g. electric, natural gas, or other).[24] Figure 11 plots reported gallons per cycle and AEC of all standard sized dishwashers in the DOE database that meet the federal standards that will be in effect in 2017.

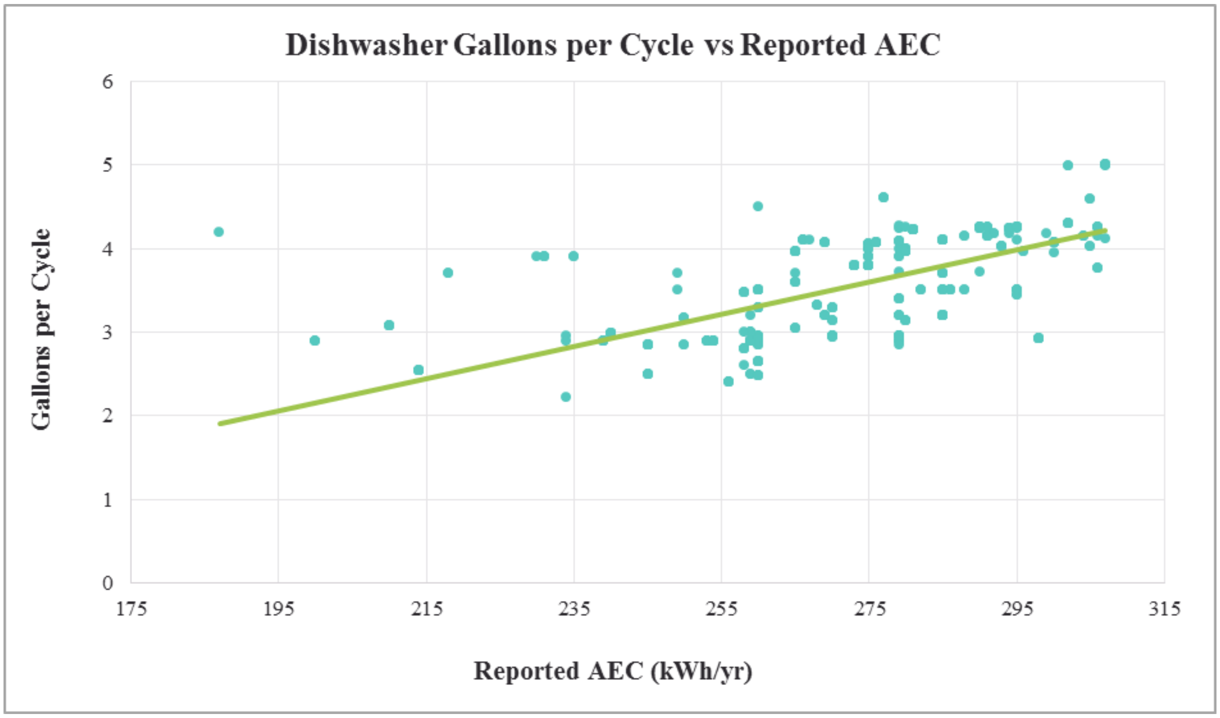

Figure 11: Gallons per cycle as a function of reported AEC of dishwashers in the DOE Compliance Certification Database

Source: (DOE 2015a)

Based on the linear trend line that best fits the data, a minimally compliant standard-sized dishwasher, which has an AEC of 307 kWh/year, consumes around 4.2 gallons of water per cycle.[25]

The DOE test procedure provides instruction for calculating water heating energy use, assuming a 70°F change in water temperature (50°F to an inlet temperature of 120°F) or 90°F change in water temperature (50°F to an inlet temperature of 140°F), depending on the dishwasher's hot water temperature settings. For the CASE Report's analyses, the Statewide

[24] In 2012, DOE updated its test procedure for dishwashers to include standby mode energy use. However, the existing standard does not include standby mode energy use, so the new test procedure is not currently in use when reporting energy use to DOE. The new test procedure will become mandatory once standards are updated in a future rulemaking cycle.

[25] An exponential trend line produces roughly the same R^2 value and AEC at 307 kWh/year.

CASE Team assumed heated temperature rise of 70°F due to the DOE recommendation that water heaters be set to 120°F. The DOE test procedure assumes 215 cycles per year and specific heat for water is assumed to be 0.0024 kWh/gal-F (DOE 2003).[26] Using these assumptions, a minimally compliant standard-sized dishwasher that uses 4.2 gallons of water per cycle requires 0.703 kWh/cycle or 151 kWh/yr to heat water. This accounts for about 49 percent of the total per cycle energy use of a standard-sized dishwasher (total energy use of 1.43 kWh/cycle or 307 kWh/yr). Accordingly, when considering machine energy use only, the typical dishwasher consuming 307 kWh/year is expected to consume 0.725 kWh/cycle on energy uses associated with machine operation, on average. These calculations are detailed below.

$$\begin{pmatrix}\text{Per-cycle}\\ \text{energy use}\end{pmatrix} = \frac{AEU}{Cycles\ per\ year}$$

$$= 307\frac{kWh}{year} \div 215\frac{cycles}{year} = \mathbf{1.43}\,\frac{\boldsymbol{kWh}}{\boldsymbol{cycle}}$$

$$\begin{pmatrix}\text{Per-cycle water}\\ \text{heating energy use}\end{pmatrix} = (\text{Volume}) \times \begin{pmatrix}\text{Temperature}\\ \text{Rise}\end{pmatrix} \times \begin{pmatrix}\text{Specific}\\ \text{heat of water}\end{pmatrix}$$

$$= 4.2\frac{gallons}{cycle} \times 70°F \times 0.0024\frac{kWh\cdot°F}{gal} = \mathbf{0.703}\,\frac{\boldsymbol{kWh}}{\boldsymbol{cycle}}$$

$$\begin{pmatrix}\text{Per-cycle}\\ \text{machine energy use}\end{pmatrix} = \begin{pmatrix}\text{Per-cycle}\\ \text{energy use}\end{pmatrix} - \begin{pmatrix}\text{per-cycle water}\\ \text{heating energy use}\end{pmatrix}$$

$$= 1.43\frac{kWh}{cycle} - 0.703\frac{kWh}{cycle} = \mathbf{0.725}\,\frac{\boldsymbol{kWh}}{\boldsymbol{cycle}}$$

4.2.4.3 Determining AEC as a Function of NBr

To estimate dishwasher AEC by NBr, the Statewide CASE Team multiplied estimated average per cycle machine energy use (0.725 kWh/cycle) by the Title 24 WH ruleset assumptions on dishwasher cycles per year by NBr. Table 18 presents the most recent data provided to the Statewide CASE Team on assumed cycles per year by NBr from the Title 24 WH rulesets.[27] Since the Title 24 WH rulesets have different usage assumptions for single-family and multi-family housing, this procedure yields separate single-family and multi-family algorithms. The usage assumptions in CEC's WH rulesets level off at five bedrooms, so the Statewide CASE Team's recommends that AEC algorithms also level off at five bedrooms. Algorithms for plug

[26] The DOE test procedure is meant to characterize the efficiency of the dishwasher, in terms of annual electrical energy use in kWh. For this measurement and reporting requirement, all dishwashers are assumed to be operated with an electric water heater, regardless of the likelihood of the product being used with a gas or oil-fired water heater in the field, which is generally much higher in California than nationally.

[27] In general, the Title 24 WH ruleset assumptions are current as of May 18, 2016. The assumptions of 0-Br and 1-Br single-family homes are from a slightly older iteration of the WH model (May 5, 2016). The Statewide CASE Team recommends that the algorithm for dishwasher machine energy use the most recent version of the Title WF rulesets.

load and lighting product categories that do not rely on usage data from CEC's WH rulesets level off at seven bedrooms.

Table 18: Assumed annual dishwasher cycles in the Title 24 WH ruleset

NBr	Average Annual Dishwasher Cycles	
	Single-Family	Multi-Family
0	115	77
1	115	94
2	125	132
3	138	130
4	137	167
5+	164	157

4.2.5 Results

Figure 12 presents the recommended algorithm for estimating the AEC of a dishwasher based on NBr. Because the CEC's WH rulesets have different usage assumptions for single-family and multi-family residences, the recommended algorithms for dishwashers also depend on house type. Dishwasher AEC is only assigned if the compliance software user reports that one will be present.

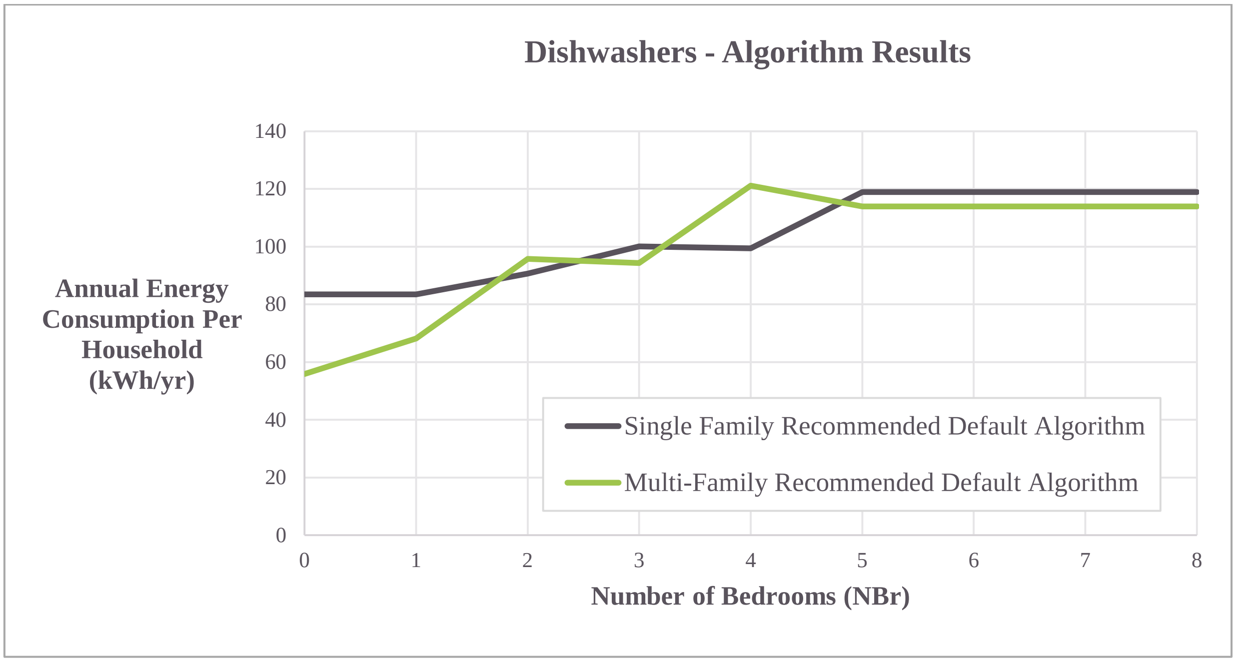

Figure 12: Estimated AEC of a dishwasher as a function of NBr

Table 19 presents the results of the algorithm by NBr, for single-family and multi-family residences.

Table 19: Estimated dishwasher AEC of single-family and multi-family homes by NBr

NBr	Annual Energy Consumption (kWh/yr)	
	Single-Family	Multi-Family
0	83	56
1	83	68
2	91	96
3	100	94
4	99	121
5+	119	114

Figure 13 compares the refrigerators and freezers algorithms to various benchmarks, described in Section 3.5.2. The recommended algorithms result in lower AEC than the existing Title 24 algorithms, the RESNET algorithms, the Building America House Simulation Protocols, or the NEEA RBSA. This may be due to the estimated efficiency of dishwashers installed in newly constructed homes. The recommended algorithms assume all dishwashers will be compliant with the 2015 federal efficiency standards, whereas other benchmark algorithms assume some dishwashers are less efficient. The proposed algorithms estimate higher AEC than was estimated by the 2009 RASS CDA. They also estimate higher AEC than what the Statewide CASE Team calculated by multiplying the metered average annual dishwasher uses from the 2016 *Residential End Uses of Water Study* by the 0.725 kWh/cycle value used in this report ((REUS 2016; WRF 2016).[28]

[28] $0.26\ dishwasher \frac{cycles}{day} \times 365 \frac{days}{yr} \times 0.725 \frac{kWh}{cycle} = 69 \frac{kWh}{yr}$ of machine AEC in an average household with a dishwasher.

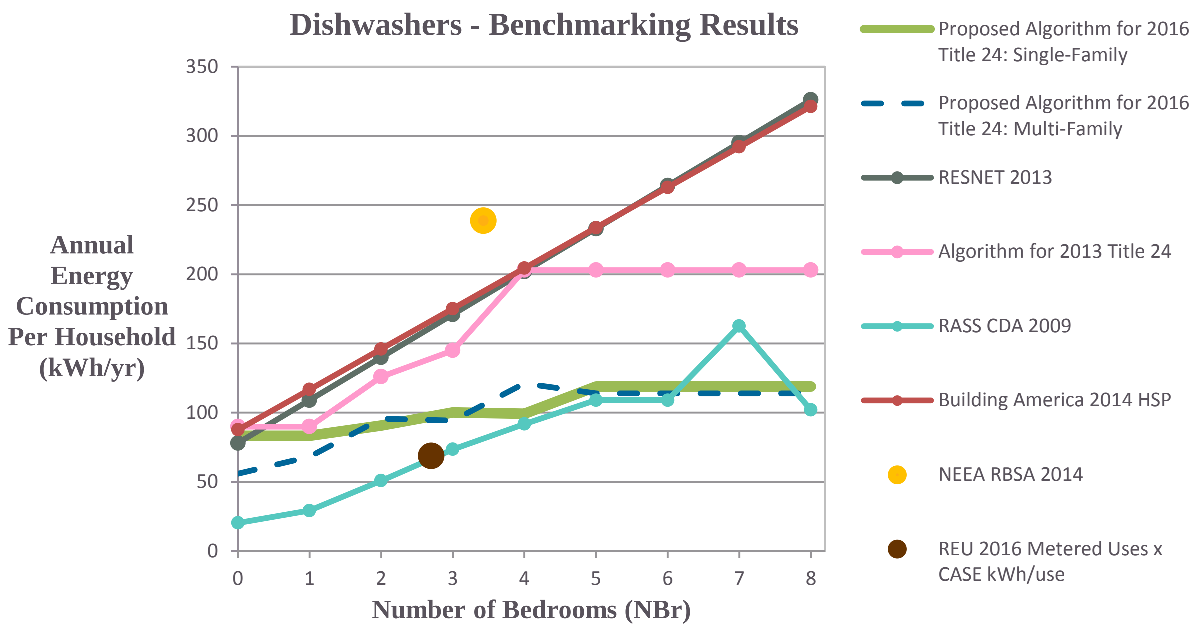

Figure 13: Comparison of recommended dishwashers AEC algorithm with various benchmarks

4.3 Clothes Washers

4.3.1 Technology Introduction

Clothes washers are defined by DOE as "machines that use a water solution of soap and/or detergent and mechanical agitation or other movement to clean clothes" (DOE 2012a). They are common appliances, present in approximately 95 percent of homes (Parker et al. 2011). The rulesets described below are meant to clothes washers installed in new single-family homes and multi-family dwelling units with clothes washers within the dwelling unit.

In multi-family buildings that do not have laundry hookups in each dwelling and have a shared laundry facility onsite, it may be appropriate to assign some fraction of the modeled laundry energy use to each unit. A 2001 study by the Multi-housing Laundry Association suggests that residents who rely on communal laundry facilities on average only wash roughly one third as many loads per week compared to residents with in-unit laundry facilities (Multi-housing Laundry Association 2001). The proposed language for the Residential ACM Reference Manual presented in Section 9.3 of this report does not include a methodology to calculate energy use from communal laundry facilities within multifamily buildings. This revision could be made at a future date.

Prior to 2015, the metric used to evaluate energy use of residential clothes washers was Modified Energy Factor (MEF), which is the quotient of the capacity of the clothes container divided by the total energy use per cycle (ft^3/kWh/cycle) where total energy used includes energy used by the machine, to heat water, and to remove remaining moisture in the load. In March 2015, the efficiency metric became the Integrated Modified Energy Factor (IMEF), which takes standby energy use into account when calculating total energy use in addition to active mode machine energy use, water heating energy use, and drying energy use. The recommended rulesets were derived using IMEF ratings, but data was adjusted so the resulting algorithms only include machine and standby energy uses. Water heating energy use is already accounted for in the water heating model, and drying energy use is accounted for in the clothes dryer algorithm, which is discussed in Section 5.4.

Residential clothes washers can be either front-loading or top-loading. Front-loading washers are generally more efficient than top-loading washers, because washing clothes in a horizontal drum requires less water. Although top-loading washers have historically been more common in the residential market, sales of front-loading washers have been increasing in recent years.

4.3.2 Existing Energy Efficiency Standards

DOE efficiency requirements for residential clothes washers have been in effect since 1988. The most recent updates had effective dates of 2007 and 2015, and another revision will take effect in 2018 (see Table 20). The most recent federal efficiency standards for clothes washers were adopted on May 31, 201 2 and established two tiers of efficiency standards, as specified in 10 CFR 430.32(g)(3). For Tier 1, clothes washers manufactured and sold after March 7, 2015 must meet the energy efficiency standards shown in for the most common product classes (DOE 2012a). The more stringent Tier 2 standards will become effective on January 1, 2018, but these standards will not impact the modeling assumptions used in this analysis, which assume compliance with the minimum efficiency standards that are in place in 2017. As discussed in Section 3.2, the default algorithms were developed assuming that some clothes washers in new homes will be newly purchased and therefore meet the 2015 standards and some washers will be old and meet the 2007 standards.

DOE's technical support documents for standards adopted in 2012 estimated that shipments of compact-size washers would be less than 1 percent of total shipments in 2017. The Statewide CASE Team therefore assumed all clothes washers would meet the federal standards for standard-size washers.

Table 20: Federal energy efficiency standards for clothes washers

Product Class	Minimum Integrated Modified Energy Factor (ft^3/kWh/cycle)		
	Effective 2007[1]	Effective 2015	Effective 2018
Top-loading, Standard (1.6 ft^3 or greater capacity)	0.84 (MEF: 1.26)	1.29	1.57
Front-loading, Standard (1.6 ft^3 or greater capacity)	0.84 (MEF: 1.26)	1.84	1.84

1. Standards that took effect in 2007 were based on Modified Energy Factor (MEF). The minimum MEF values have been translated to IMEF values for comparison purposes.

4.3.3 Key Variables Impacting Energy Use

The Statewide CASE Team accounted for the device configuration (e.g. standard or compact, top-loading or front-loading) and appliance vintage in the clothes washer AEC algorithm. Other factors that affect real-world AEC of clothes washers include other device features like suds-saving mode, steam wash mode, self-clean mode, and sensing/adaptive controls. Although the Statewide CASE Team was not able to account for these other variables with available data, future updates to the model may be able to do so through use of real-world adjustment factors or by relying on more detailed or empirical data sources.

The age of the clothes washer also impacts the energy use considerations since devices have become more efficient over time. The Statewide CASE Team determined the average age of a clothes washer to be half of the useful life of 12 years, assuming an even distribution of devices from brand new to the end of the design life (Database for Energy Efficient Resources 2016). It was assumed that all clothes washers purchased prior to the effective date of the 2015 federal efficiency standard will likely comply with the 2007 standard.

The annual energy use of clothes washers is directly related to the number of wash cycles per year. With a greater number of cycles, more time is spent in active mode, and more energy is used throughout the year.

Table 21 lists the key variables used in the clothes washers methodology, along with how the variable was used when developing the ruleset, and the data source used to obtain them.

Table 21: Key variables and their functions within the clothes washers methodology

Variable	Function	Source
Saturation	Determine whether household is assigned a clothes washer AEC	Reported by software user, confirmed through on-site inspection
Configuration	Determine code baseline performance	RASS 2009
Age	Determine percentage of washers compliant with 2015 and 2007 standards to determine weighted average AEC	RASS 2009[1]
Integrated Modified Energy Factor (IMEF)	Disaggregated to determine per-cycle active and standby energy use.	DOE efficiency standards
Per-cycle active energy use	Separated from IMEF and multiplied by cycles per year to determine washing machine energy consumption	DOE rulemaking documents
Standby power	Determine standby energy use	DOE rulemaking documents
RASS self-reported cycles per year	Establish relationship between energy use and use cycles	RASS 2009
Usage by NBr	Establish relationship between AEC and NBr	Title 24 WH ruleset

1. Method explained in Appendix A: Age of Non-Builder Supplied White Goods.

4.3.4 Methodology

4.3.4.1 Methodology Overview

To calculate the rulesets for clothes washers, the Statewide CASE Team disaggregated per-cycle active energy use and standby energy use from the IMEF metric. For each home in RASS 2009 that reported owning a clothes washer, the Statewide CASE Team calculated the active mode and standby mode machine AEC assuming first, that the washers were minimally compliant with the 2015 federal efficiency standard, and then that the washers were minimally compliant with the 2007 federal efficiency standard. Given assumptions about the percentage of washers that would be compliant with the 2007 and 2015 standards, the Statewide CASE Team calculated the weighted average AEC then performed a linear regression to capture the relationship between total active mode and standby mode AEC and the self-reported number of cycles per year from RASS. Finally, the Statewide CASE Team applied the usage assumptions from the CEC's WH ruleset, which have unique cycle per year assumptions by NBr, to arrive at an algorithm that describes AEC by NBr.

4.3.4.2 Determining Per-Cycle Active Energy Use and Standby Power

The Statewide CASE Team determined the per-cycle active energy use and standby power for minimally compliant clothes washers. To do this, active cycle machine energy use was disaggregated from the IMEF metric, which required some additional assumptions due to the interdependence of the metric components. Two washers with the same IMEF may have different machine energy use, even with the same load capacity. The Statewide CASE Team used the representative machine energy uses from the tables in Chapter 7 of the 2015 DOE Technical Support Document (TSD) on clothes washers. The values include both total machine energy use and standby energy use. DOE supplied these values as test results for units that were considered to be representative of a particular IMEF and standby power. The standby power was separated from total machine energy use using the DOE 2012 Amended Test Procedure for clothes washers (10 CFR Part 430, Subpart B, Appendix J2). The calculations for this step are provided below:

$$U_{w,yr,conf} = R_{w,yr,conf} - R_s$$

$$= R_{w,yr,conf} - \frac{\left(8760\,\frac{hrs}{yr} - 295\,\frac{hrs\ in\ active\ mode}{yr}\right)}{\left(295\,\frac{hrs\ in\ active\ mode}{yr}\right)}\left(P_{s,yr,conf}\right)$$

$U_{w,yr,conf}$ = the per-cycle active energy use without a standby component for a given configuration;

$R_{w,yr,conf}$ = the DOE reported machine energy use that includes a standby component for a given configuration;

R_s = the standby component of the DOE reported machine energy use for a given configuration corresponding assuming each machine spends 295 hours per year in active mode;

$P_{s,yr,conf}$ = the standby power for a given configuration.

Table 22 presents per-cycle active energy use and standby power for top-loading and front-loading washers that meet the 2007 and 2015 federal efficiency standards.

Table 22: Minimally compliant IMEF values and their corresponding (representative) per-cycle active use and standby power

Standard Year	Washer Configuration	Minimum IMEF Requirement (ft^3/kWh/cycle)	DOE-reported Machine Energy Use (includes standby) (kWh/cycle)	Per-Cycle Active Energy Use (no standby) (kWh/cycle)	Standby Power (W)
2015	Top-loading	1.29	0.228	0.228	0
	Front-loading	1.84	0.154	0.152	0.08
2007	Top-loading	1.26	0.279	0.279	0
	Front-loading	1.26	0.279	0.279	0

Note: Most minimally compliant washers are assumed to have 0 standby power, with newer front-loading washers being the exception. However, this is likely to change in the next rulemaking cycle.

4.3.4.3 Determining AEC as a Function of NBr

For each home in RASS 2009 that reported the presence a clothes washer, the Statewide CASE Team determined active mode and standby mode AEC values assuming the washer was minimally compliant with the 2007 standards, then the 2015 standard.

To calculate total AEC, the Statewide CASE Team multiplied the per-cycle active energy use that corresponds to the survey-reported washer configuration by self-reported cycles per year values from RASS. Annual standby energy use was calculated by multiplying the standby power by the hours per year that the device is not in use, assuming one hour per wash cycle.

The calculations are as follows:

$$AEC_{yr} = E_{w,yr,conf} + E_{s,yr,conf}$$
$$= \left(U_{w,yr,conf}\right)\left(N_{cycles}\right) + \left(H_{standby}\right)\left(P_{s,yr,conf}\right)$$

$E_{w,yr,conf}$ = active washing machine energy for a given configuration corresponding to the year of interest;
$E_{s,yr,conf}$ = standby energy for a given configuration corresponding to the year of interest;
$U_{w,yr,conf}$ = the per-cycle active energy use for a given configuration corresponding to the year of interest, as calculated in Section 4.3.4.1;
N_{cycles} = number of cycles per year;
$H_{standby}$ = number of hours per year in standby $= 8760 - \left(N_{cycles} \times \frac{1\ hr}{cycle}\right)$;
$P_{s,yr,conf}$ = standby power for a given configuration corresponding to the year of interest.

The Statewide CASE Team used RASS 2009 to predict that 28.8 percent of clothes washers installed in newly constructed homes during the 2016 code cycle will comply with the 2015 standard, and 71.2 percent will comply with the 2007 standard. The method for this prediction is discussed in Appendix A: Age of Non-Builder Supplied White Goods. Using this information, the team calculated the weighted average total AEC.

Using calculations for all homes in RASS 2009 that reported owning a clothes washer, the Statewide CASE Team performed a linear regression to capture the relationship between age-weighted AEC and the self-reported information number of cycles per year. The intercept of this regression was fixed to equal the lowest possible washer AEC. In this case, the lowest possible value is zero, which corresponds to a top-loading or front-loading washer with zero standby power, run for zero cycles per year. Equation 2 presents the results of the linear regression.

Equation 2: Clothes washer AEC as a function of the number of wash cycles per year

$$Clothes\ washer\ AEC = 0.259 \times cycles\ per\ year$$

From the relationship of AEC to cycles per year (i.e. 0.259 kWh/cycle), the Statewide CASE Team determined the relationship of AEC to number of bedrooms by relying on usage assumptions from the Title 24 WH rulesets. Table 23 presents the most recent data provided to the Statewide CASE Team on assumed cycles per year by NBr from the Title 24 WH rulesets.[29]

Table 23: Assumed clothes washer cycles per year (Title 24 WH rulesets)

NBr	Clothes Washer Cycles per Year	
	Single-Family	Multi-Family
0	326	255
1	326	271
2	327	383
3	384	377
4	389	455
5+	451	414

By multiplying the estimated energy per cycle by the above cycles per year, the Statewide CASE Team derived the recommended algorithm for predicting clothes washer AEC based on NBr.

4.3.5 Results

Figure 14 presents the recommended algorithm for estimating the AEC of a clothes washer based on NBr. Because the CEC's WH rulesets have different usage assumptions for single-family and multi-family residences, the recommended algorithms for clothes washers also depend on house type. Table 24 presents the results of the algorithm by NBr for single-family and multi-family residences.

Clothes washer AEC is only assigned if the compliance software user reports that one will be present. For multi-family dwelling units, the recommended algorithm only applies to in-unit clothes washers. Laundry equipment in common spaces is not covered by the existing algorithms or the recommended algorithms; however, this is problematic, because these

[29] In general, the Title 24 WH ruleset assumptions are current as of May 18, 2016. The assumptions of 0-Br and 1-Br single-family homes are from a slightly older iteration of the WH model (May 5, 2016). The Statewide CASE Team recommends that the algorithm for clothes washer machine energy use the most recent version of the Title WF rulesets.

devices nonetheless contribute to on-site energy consumption.[30] In future updates to the models, it will be important to account for communal laundry equipment if ZNE multi-family new construction is to be truly ZNE.

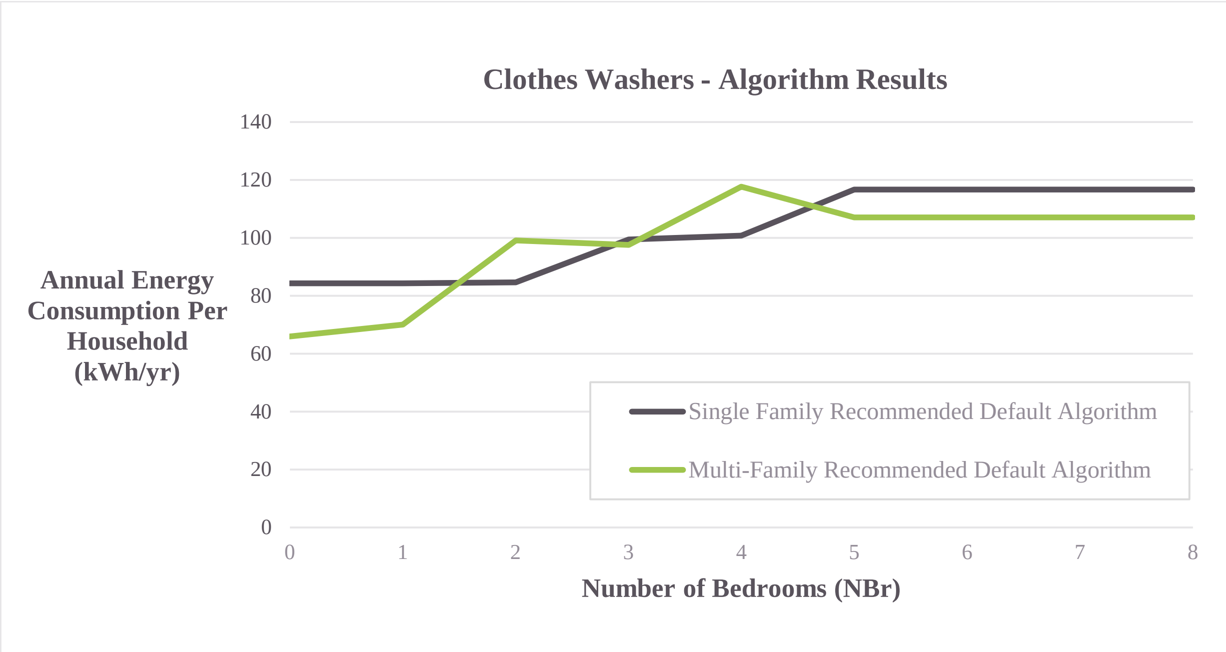

Figure 14: Estimated AEC of a clothes washer, as a function of NBr

Table 24: Average clothes washer AEC of single-family and multi-family homes by NBr

NBr	Average AEC	
	Single-Family	Multi-Family
0	84	66
1	84	70
2	85	99
3	100	98
4	101	118
5+	117	107

Figure 15 compares the recommended clothes washer algorithms to various benchmarks, described in Section 3.5.2. The recommended algorithms result in slightly higher AECs than the RESNET algorithms, the Building America House Simulation Protocols, or the NEEA RBSA. This is may be due in part to the assumed efficiency standard for clothes washers—the majority of washers were assumed to by minimally compliant with the 2007 standard. The average clothes washers in the aforementioned studies would likely be more efficient. In addition, the Statewide CASE Team also accounted for standby energy, which may not have been accounted for in other studies.

[30] Clothes washer machine energy use may be relatively low, but this issue also applies to the energy use of clothes washer water heating and clothes dryers.

The current 2013 code cycle algorithm for clothes washers was based on a regression analysis of the RASS CDA results, and therefore closely tracks the average AEC by NBr estimated in the RASS CDA for surveyed homes that had clothes washers. The average CDA estimate for one-bedroom homes is negative, as is the 2013 clothes washer algorithm given the average square footage of a studio zero-bedroom home (i.e. studio apartment).

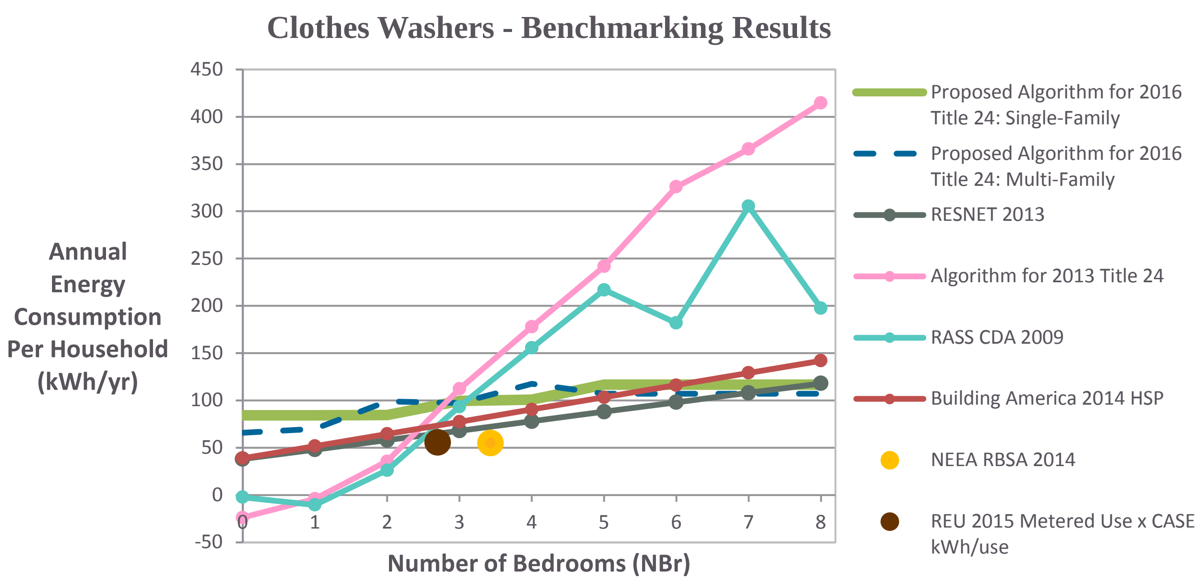

Figure 15: Comparison of recommended clothes washers AEC algorithm with various benchmarks

4.4 Clothes Dryers

4.4.1 Technology Introduction

Residential clothes dryers are machines that use a tumble-type drum with forced air circulation to dry clothes (DOE 2011c). Prior to 2015, the metric used to evaluate energy use of clothes dryers was Energy Factor (EF), which is a measure of the pounds of laundry that can be dried per kWh (lbs/kWh). EF is a function of the load weight and remaining moisture content (RMC) in the load as it enters the dryer. In June 2015, the efficiency metric became the Combined Energy Factor (CEF), which takes into account standby energy.

Clothes dryers can be either electric or gas, including propane. Both electric and gas dryers use electric motors to spin the drum, but gas dryers use heat generated from fuel combustion to heat air used for drying. The Statewide CASE Team has proposed rulesets to estimate energy use for both electric and gas dryers. Users will be asked to input the dryer fuel type and the appropriate electric or gas ruleset will be used based on the user's fuel type selection.[31]

4.4.2 Existing Energy Efficiency Standards

DOE efficiency requirements for of residential clothes dryers have been effect since 1988. The most recent updates had effective dates in 1994 and 2015 (see Table 25). The most recent federal efficiency standards for clothes dryers were adopted on August 24, 2011 and took effect in January 1, 2015, as codified in 10 CFR 430.32(h)(3)(15). Since the 2015 DOE TSD estimated that shipments of compact-size dryers would be less than 2 percent in 2017, the Statewide CASE Team assumed all clothes dryers would meet the federal standards for standard-size dryers.

As discussed in Section 3.2, the default algorithms were developed assuming that some clothes washers in new homes will be newly purchased and therefore meet the 2015 standards, and some washers will be old and meet the 1994 standards.

Table 25: Federal efficiency standards for clothes dryers in 2015 and 1994

Product Class	Minimum Combined Energy Factor (pounds/kWh)	
	Effective 2015	**Effective 1994[1]**
Vented Electric, Standard Size (4.4 ft^3 or greater capacity)	3.73	3.55 (EF: 3.01)
Vented Gas	3.30	3.14 (EF: 2.67)

1. Standards that took effect in 1994 were based on Energy Factor (MEF). The minimum EF values have been translated to CEF values for comparison purposes.

4.4.3 Key Variables Impacting Energy Use

The Statewide CASE Team accounted for the following factors in the clothes dryer AEC algorithm:

- Fuel type (gas vs. electric);
- Device age (assumed to be the same as clothes washer);
- Configuration of the associated clothes washer (top-loading vs. front-loading, used to estimate the initial moisture content of the dryer load);
- Dryer usage factor (relative to washer usage); and
- Standby mode energy use.

Other factors that affect real-world AEC of clothes dryers include other device features like dry sensing technology. Although the Statewide CASE Team was not able to account for these other variables with available data, future updates to the model may be able to do so through use of real-world adjustment factors or by relying on more detailed or empirical data sources.

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[31] The Statewide CASE Team has not found evidence that there are efficiency differences between natural gas or propane appliances, and therefore the estimated energy consumption in therms is the same, even though the corresponding volume of fuel differs. The propane-specific TDV coefficients should be applied for propane devices.

The age of the clothes dryer impacts the energy use considerations since devices have become slightly more efficient over time. The Statewide CASE Team assumed that the age of the dryer is equal to the age of the associated washer. That is, dryers manufactured in 2015 or later are assumed to be compliant with the 2015 standard and assumed to be used in conjunction with washers compliant with their 2015 standard; dryers manufactured before 2015 are only assumed to be compliant with the previous (1994) standard are assumed to be used in conjunction with washers compliant with the previous (2007) washer standard.

The energy use of clothes dryers is intrinsically dependent on the performance of the associated clothes washers. If the washer produces a load with high RMC, then the dryer must use more energy to remove the moisture. Also, the average load weight used in the dryer depends on the load coming out of the washer, which is related to the washer capacity. These factors depend on both the associated washer configuration.

The annual energy use of clothes dryers is directly related to the number of cycles in a year. With a greater number of cycles, more time is spent in active mode and more energy is used throughout the year. The dryer usage factor is the ratio of the number of dry loads per year to the number of wash loads per year. This value is historically less than one, indicating a higher usage of the washer—not all clothes are dried in the dryer.

Table 26 lists the key variables used in the clothes dryer methodology, along with how the variable was used when developing the ruleset and the data source used to obtain them.

Table 26: Key variables and their functions within the dryers methodology

Variable	Function	Source
Saturation	Determine whether household is assigned a clothes dryer AEC	Reported by user, confirmed through on-site inspection
Fuel type	Determine whether to use gas or electric algorithms	Reported by user, confirmed through on-site inspection
Associated washer configuration and fuel type	Determine the associated remaining moisture content (RMC) and average load weight	RASS 2009
Combined Energy Factor (CEF)	Used with the RMC, average load weight, and cycles per year to determine active energy use	DOE efficiency standards
Age	Determine percentage of washers compliant with 2015 and 2007 standards to determine weighted average AEC	RASS 2009[1]
RASS self-reported cycles per year	Determine active energy use and standby energy use and establish relationship between energy use and usage	RASS 2009
Standby Power	Determine standby energy use	DOE rulemaking documents
Usage	Establish relationship between AEC and NBr	Title 24 WH ruleset

1. Method explained in Appendix A: Age of Non-Builder Supplied White Goods.

4.4.4 Methodology

4.4.4.1 Methodology Overview

For each home in RASS 2009 that reported owning both a clothes washer and dryer, the Statewide CASE Team calculated the active energy use and standby energy for each fuel type assuming the dryer was minimally compliant with the 2015 federal efficiency standard, then the 1994 standards.[32] Using assumptions about the age of dryers installed in newly constructed homes and assuming new or nearly new dryers met the 2015 standards and the remaining dryers met the 1994 standards, the Statewide CASE Team determined an age-weighted average AEC. A linear regression was performed to capture the relationship between age-weighted average AEC and the self-reported number of cycles per year from RASS. Finally, the Statewide CASE Team applied usage assumptions from the Title 24 WH ruleset, which reports annual clothes washer usage by NBr, to develop algorithms that describe AEC based on NBr; it was assumed that clothes dryer usage is proportional to clothes washer usage.

[32] Less than 1 percent of homes in RASS 2009 reported owning a clothes dryer and did not indicate the clothes washer configuration. These homes were excluded from the analysis.

4.4.4.2 Determining Per-cycle Active Energy Use and Standby Power

For each home in RASS 2009, the Statewide CASE Team calculated active energy use of clothes dryers, again, assuming minimal compliance with the 2015 and 1994 federal efficiency standards. There are unique values depending on dryer fuel type (Table 25).

Energy use was disaggregated into the following components shown in Table 27.

Table 27: Dryer active and standby mode energy use by fuel type

Fuel Type	Standby Mode Energy Use	Active Mode Energy Use
Natural Gas	Standby power (kWh)	Electricity use to rotate drum (kWh) Natural gas use to heat air (therms)
Electricity		Electricity use to rotate drum (kWh) Electricity use to heat air (kWh)

Note: The standby power is the same for gas and electric dryers

To determine each active energy use, the Statewide CASE Team followed the procedure outlined in Chapter 7 of the 2011 DOE TSD for clothes dryers. The procedure calculates the active energy use from the dryer CEF by replacing test procedure values with actual values for the following variables: initial RMC, final RMC, average load weight, standby power, and cycles per year. The Statewide CASE Team assumed a final RMC of zero. For the initial RMC and average load weight, the Statewide CASE Team used the representative values for the survey-reported washer configuration (DOE 2012d).[33] The Statewide CASE Team used the standby power that is representative of the dryer CEF, as determined by the tables in Chapter 5 of the 2011 DOE TSD on clothes dryers. The number of cycles per year was calculated from the RASS survey-reported cycles per week and assuming 52 weeks of operation per year.

Table 28 summarizes the key input used in estimates of dryer active energy use. Note, these key inputs are all dependent on the clothes washer configuration and performance.

Table 28: Factors used to estimate active mode dryer energy use

Standard Year	Washer Configuration	IMEF (ft^3/kWh/cycle)	Average Load Weight (lbs)	RMC (%)
2015	Top-loading	1.29	8.35	48.8
	Front-loading	1.84	8.55	38.6
2007	Top-loading	1.26	7.75	51.9
	Front-loading	1.26	7.75	51.9

Note: The standby power is the same for gas and electric dryers.

Table 29 presents the assumed dryer standby mode power as determined by the tables in Chapter 5 of the 2011 DOE TSD on clothes dryers.

[33] The DOE Test Procedure assumes a linear relationship between RMC reduction and energy use. However, reports have indicated that the actual relationship deviates from linearity when RMC is below 30 percent (CLASP 2013). Future updates may account for this discrepancy.

Table 29: Dryer standby mode power

Standard Year	Dryer Standby Power[1] (W)
2015	0.08
1994	2.00

1. The standby power is the same for gas and electric dryers.

To separate the total calculated active energy use of natural gas dryers into electric and gas components, the Statewide CASE Team assumed 0.107 kWh/cycle electric consumption of gas dryers. This value was derived from tests results presented in Chapter 7 of the 2015 DOE TSD on clothes dryers.

At the end of this step, the Statewide CASE Team had estimates of active mode energy use per cycle and estimated standby power for both gas and electric dryers.

4.4.4.3 Determining AEC as a Function of NBr

For each home in RASS 2009 that reported the presence of a clothes dryer and a clothes washer, the Statewide CASE Team determined the active and standby mode clothes dryer AEC values assuming the dryer was minimally compliant with the 1994 standards, then the 2015 standards. For gas dryers, the electric and gas AECs were calculated separately. To calculate the electric AEC of active energy use the Statewide CASE Team multiplied per cycle AEC values calculated in the previous step by self-reported cycles per year estimates from RASS. AEC from standby energy use was determined by multiplying standby power from Table 26 by the annual hours the dryer is in standby mode, assuming the dryer is in use one hour per wash cycle.

Next the Statewide CASE Team calculated the age-weighted average AEC assuming that clothes dryers have the same age distribution as clothes washers. RASS 2009 data was used to predict that 28.8 percent of clothes dryers installed in newly constructed homes during the 2016 code cycle will comply with the 2015 standard, and 71.2 percent will comply with the 1994 standard. The method for this prediction is discussed in Appendix A: Age of Non-Builder Supplied White Goods. Using this information, the team calculated the weighted average total AEC.

For each fuel type, the Statewide CASE Team used the calculations for all homes in RASS 2009 that reported owning a clothes dryer of that fuel type, to perform a linear regression that captures the relationship between fuel-specific AEC and the number of self-reported cycles per year. The intercept of this regression was fixed to equal the lowest possible AEC. For electric dryers, this minimum was 12.67 kWh; for gas dryers, 0.7008 kWh and zero therms.[34]

[34] The minimum values occur when the cycles per year is zero. However, due to age-weighting, and since the standby powers are different for each year, the minimum power is actually the age-weighted standby value.

Equation 3, Equation 4, and Equation 5 present the results of the linear regressions. The slope of each equation represents the Statewide CASE Team's estimate of energy per clothes dryer cycle.

Equation 3: Electric clothes dryer AEC (kWh) as a function of cycles per year

$$\text{Electric clothes dryer AEC} = (2.162 \times cycles\ per\ year) + 12.674$$

Equation 4: Gas clothes dryer AEC_g (therms) as a function of cycles per year

$$\text{Gas clothes dryer } \text{AEC}_\text{g} = (0.07698 \times cycles\ per\ year) + 0$$

Equation 5: Gas clothes dryer AEC_e (kWh) as a function of cycles per year

$$\text{Gas clothes dryer } \text{AEC}_\text{e} = (0.1069 \times cycles\ per\ year) + 0.7008$$

From the relationship of AEC to cycles per year derived through the linear regression analyses, the Statewide CASE Team was able to estimate clothes dryer AEC based on NBr, by relying on usage assumptions from the Title 24 WH ruleset. The Statewide CASE Team multiplied the clothes washer cycles per year assumptions from the Title 24 WH ruleset (Table 23) by the average number of clothes dryer cycles per clothes washer cycle (0.89), as calculated from the RASS microdata.[35] The Statewide CASE Team interprets this result to mean that approximately 11 percent of washer loads are line-dried.

By multiplying the estimated energy per cycle from linear regression analyses by the calculated clothes dryer cycles per year, the Statewide CASE Team derived the recommended algorithm for predicting clothes dryer AEC based on NBr.

4.4.5 Results

Figure 16, Figure 17, and Figure 18 present the recommended algorithms for estimating the AEC of an electric or gas dryer based on NBr. Because the CEC's WH rulesets have different usage assumptions for single-family and multi-family residences, the recommended algorithms for dishwashers also depend on house type. Clothes dryer AEC is only assigned if the compliance software user reports that one will be present.

Similarly, whether the gas or electric algorithm is applied depends on the fuel type reported by the software user. If the user indicates that natural gas is not available on-site, the user has the option to indicate whether the installed clothes dryer will use electricity or propane. The Statewide CASE Team recommends that the default assumption for a home that does not have natural gas available is that the clothes dryer is electric. On the other hand, if the user indicates that natural gas is available on-site, the user has the option to indicate whether the installed clothes dryer will use electricity, natural gas, or propane. The Statewide CASE Team recommends that the default assumption for a home that has natural gas available is that the

[35] Respondents reported their weekly clothes washer and dryer uses, choosing between options that ranged from "0" to "10 or more." The Statewide CASE Team used the microdata to determine that on average, respondents reported fewer clothes dryer uses than clothes washer uses; however, the ratio did not have a clear pattern of variation with NBr. A benchmarking analysis of the RECS 2009 microdata confirmed a similar ratio (0.95 clothes dryer uses per washer use.)

clothes dryer uses natural gas. The “gas” rulesets in the following figures and tables apply to clothes dryers that combust natural gas or propane.[36]

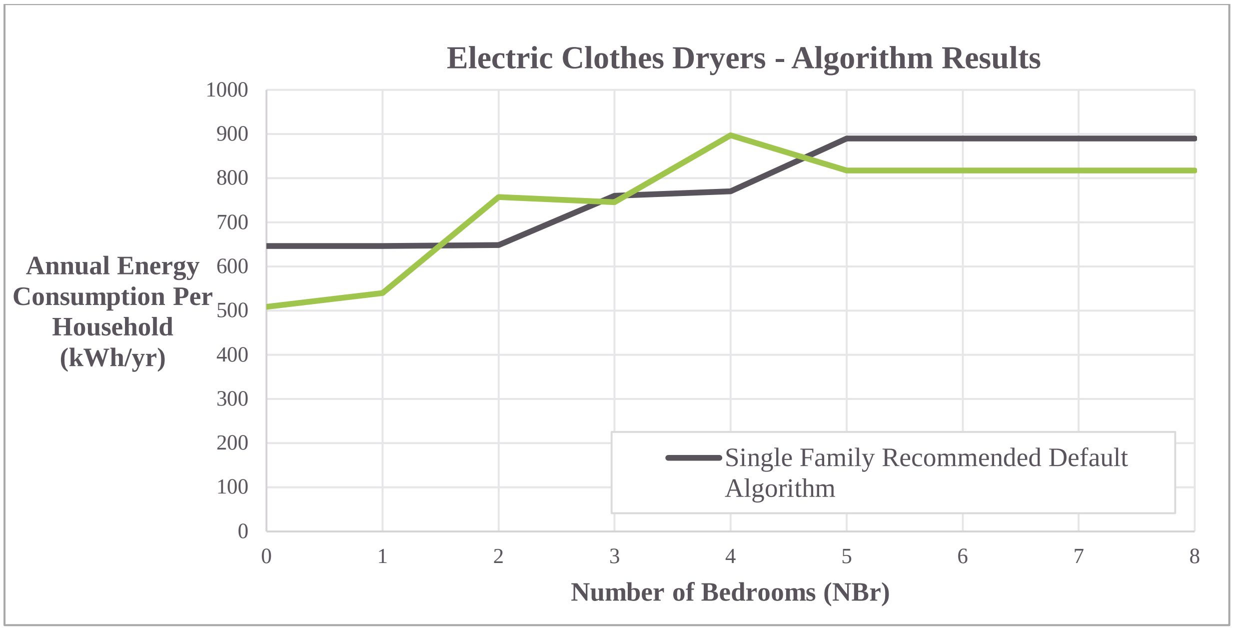

Figure 16: Estimated AEC of an electric clothes dryer as a function of NBr

[36] The Statewide CASE Team has not found evidence that there are efficiency differences between natural gas or propane appliances, and therefore the estimated energy consumption therms is the same, even though the corresponding volume of fuel differs. The propane-specific TDV coefficients should be applied for propane devices.

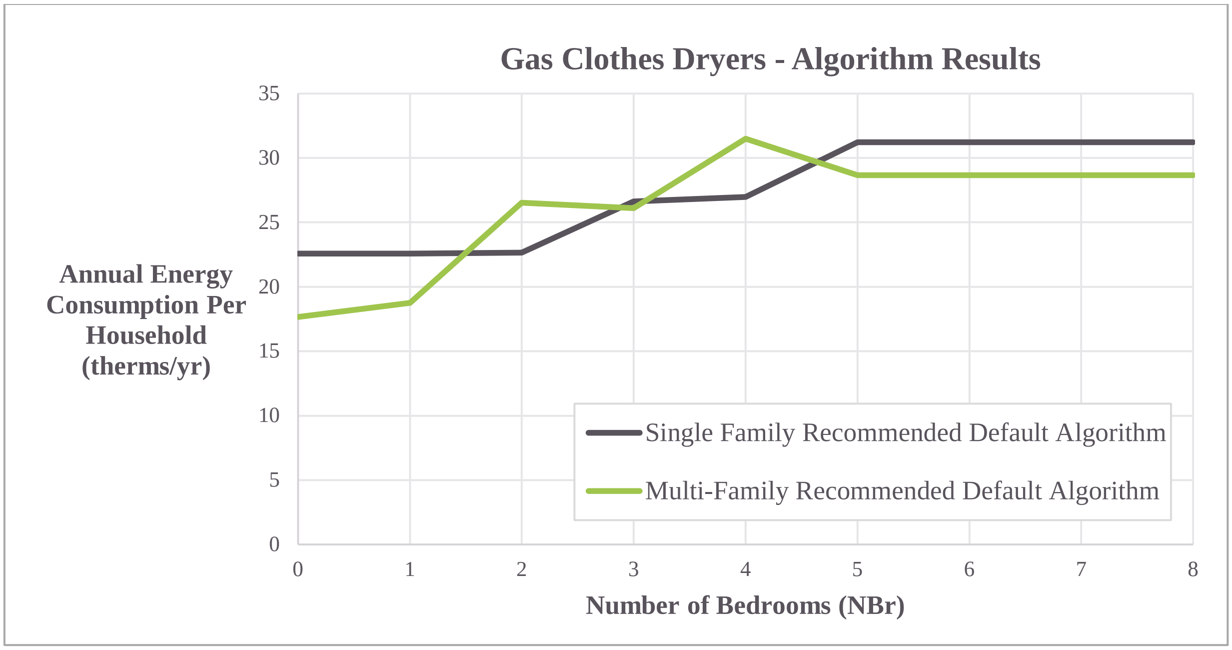

Figure 17: Estimated AEC of a gas clothes dryer as a function of NBr (therms)

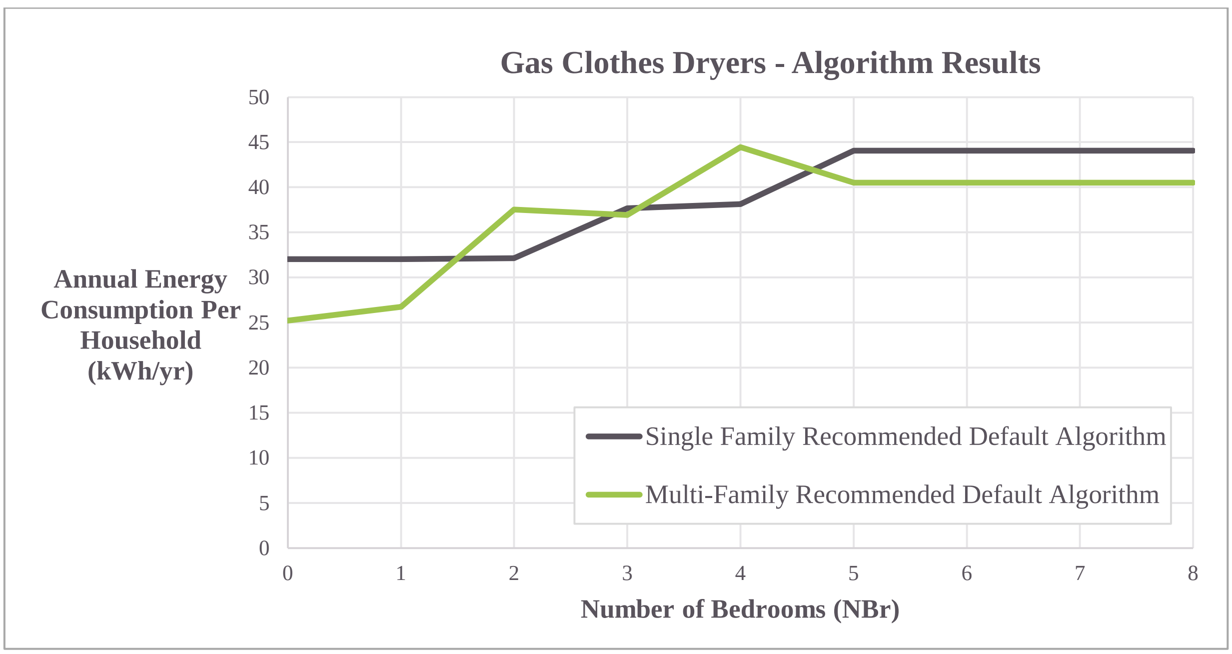

Figure 18: Estimated AEC of a gas clothes dryer as a function of NBr (kWh)

For multi-family dwelling units, the recommended algorithms only apply to in-unit clothes dryers. Laundry equipment in common spaces is not covered by the existing algorithms or the recommended algorithms. This is problematic, because these devices nonetheless contribute to on-site energy consumption. In future updates to the models, it will be important to account for communal laundry equipment if ZNE multi-family new construction is to be truly ZNE. This is particularly true for electric clothes dryers, which have the highest estimated electricity use of any single device when present.

Table 30 presents the results of the electric and gas dryer algorithms by NBr, for single-family and multi-family residences.

Table 30: Estimated AEC of electric or gas clothes dryers based on NBr, single-family or multi-family homes

NBr	Single-Family			Multi-Family		
	Electric (kWh)	Gas (therms)	Gas (kWh)	Electric (kWh)	Gas (therms)	Gas (kWh)
0	634	22	32	496	18	25
1	634	22	32	527	19	26
2	636	22	32	745	26	37
3	747	26	37	733	26	39
4	757	27	38	885	31	44
5+	877	31	44	805	28	40

Figure 19, Figure 20, and Figure 21 compare the recommended clothes dryer algorithms to various benchmarks.

The recommended electric algorithms result in lower AECs than the RESNET algorithms or the Building America House Simulation Protocols. The average magnitude of the recommended electric AEC algorithm is comparable to the NEEA RBSA, the existing 2013 Title 24 rulesets, and the RASS CDA that informed those rulesets. The RASS CDA and the existing rulesets estimate less electric AEC than the recommended rulesets for smaller (zero-bedroom to two-bedroom) dwelling units. The recommended gas (therms) algorithms result in lower AECs than the RESNET algorithms or the Building America House Simulation Protocols, but are similar in magnitude and slope to the RASS 2009 CDA. For larger dwelling units (4 or more bedrooms), the recommended gas (therms) algorithms estimate less AEC than the 2013 rulesets. Of the data sources considered for comparison, only RESNET has an estimate of the electric AEC of gas clothes dryers, which is higher than the estimated AEC of the recommended algorithm.

The overall lower AEC values are likely due to the washer-side assumptions in determining clothes dryer AEC. For example, the FSEC report assumes an RMC of 66 percent (compared to 40 to 50 percent in this report) and a washer MEF of 0.817 (compared to 1.26-1.84 in this report). In addition, number of cycles per NBr also affected AEC estimates (FSEC uses RECS 2009 values).

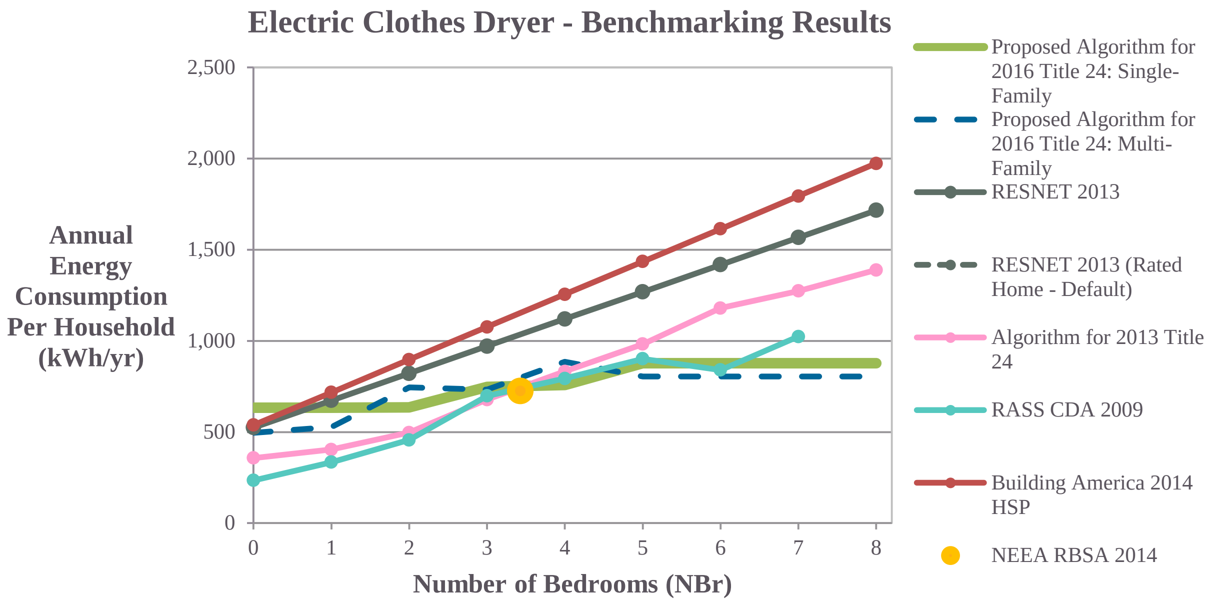

Figure 19: Comparison of recommended electric clothes dryer AEC algorithm with various benchmarks

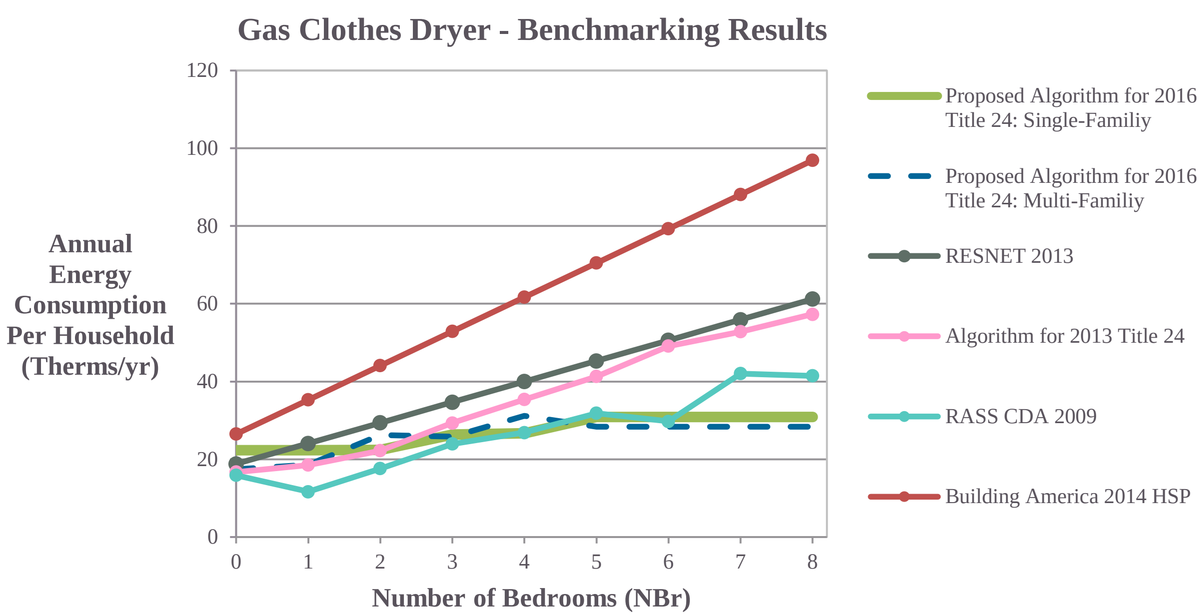

Figure 20: Comparison of recommended gas clothes dryer AEC (therms) algorithm with various benchmarks

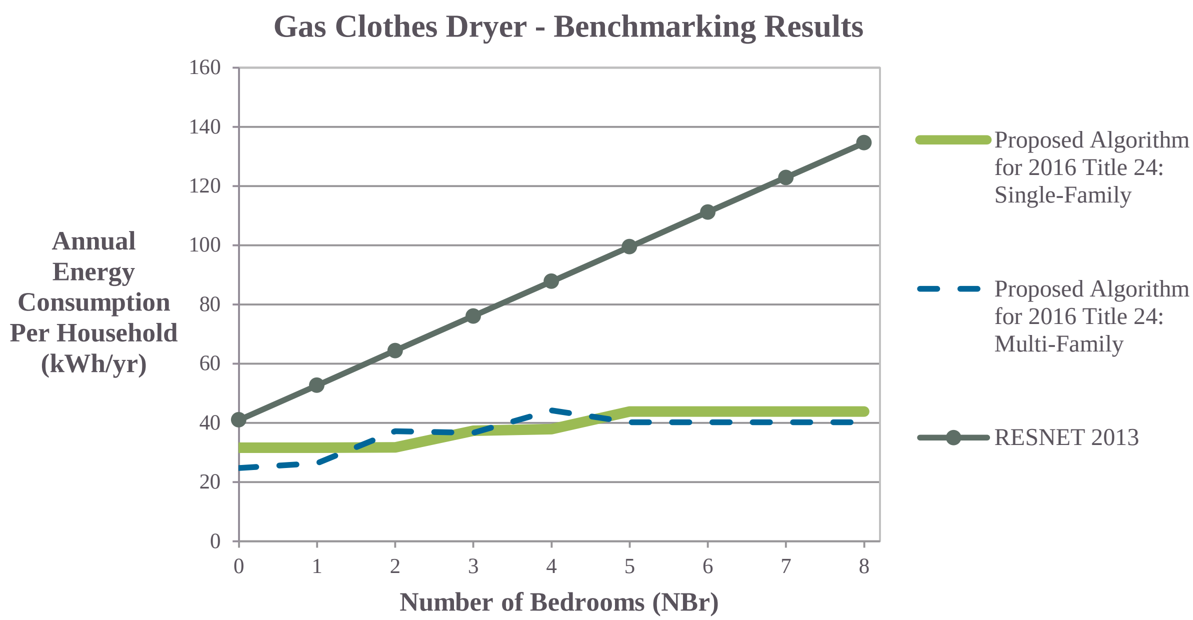

Figure 21: Comparison of recommended gas clothes dryer AEC (kWh) algorithm with various benchmarks

4.5 Ovens and Cooktops

4.5.1 Technology Introduction

DOE defines conventional ovens as "household cooking appliances consisting of one or more compartments intended for the cooking or heating of food by means of either a gas flame or electric resistance heating" (10 CFR 430.2). Conventional cooktops are defined as "household cooking appliances consisting of a horizontal surface containing one or more surface units which utilize a gas flame, electric resistance heating, or electric inductive heating" (10 CFR 430.2). Products that combine an oven and cooktop into a single appliance are commonly referred to as "ranges".

Ovens and cooktops can thus be either electric or gas, including propane. Electric ovens and cooktops convert electricity into heat by joule heating (resistance) or induction, while their gas counterparts use heat generated from fuel combustion. The Statewide CASE Team has proposed rulesets to estimate energy use for both electric and gas ovens and cooktops. Users will be asked to input the appliance fuel type and the appropriate electric or gas ruleset will be used based on the user's fuel type selection.[31]

4.5.2 Existing Energy Efficiency Standards

There are currently no state or federal energy efficiency standards for cooking appliances that regulate active mode energy use. However, since 1990, the DOE has prohibited gas cooking products with an electrical supply cord from being equipped with a constant burning pilot light through prescriptive energy efficiency requirements (DOE 2014b). This requirement was extended to all gas cooking products in 2012, as shown in Table 31.

In June 2015, DOE issued a Notice of Proposed Rulemaking (NOPR) to establish energy efficiency standards for conventional ovens, which will likely take effect in 2018 (80 FR 33030). The proposal also indicates DOE's intention to conduct a separate rulemaking in the future to address energy efficiency standards for conventional cooktops.

Table 31: Federal energy efficiency requirements for cooking products

Prescriptive Requirement	Effective Date
Gas cooking products with an electrical supply cord shall not be equipped with a constant burning pilot light.	January 1, 1990
Gas cooking products without an electrical supply cord shall not be equipped with a constant burning pilot light.	April 9, 2012

4.5.3 Key Variables Impacting Energy Use

The Statewide CASE Team accounted for the following device characteristics in the oven and cooktops AEC algorithm:

- Fuel type (gas vs. electric);
- Presence of a pilot light;
- Self-clean capability; and
- Standby mode.

Other factors that affect real-world AEC of cooking products include the heating technology, cavity size, insulation, and extraneous functional capabilities. Specifically, induction-heating technology has since increased in popularity and will likely be of a significant consideration in future updates. Although the Statewide CASE Team was not able to account for these variables with available data, future updates to the model may be able to do so through use of real-world adjustment factors or by relying on more detailed or empirical data sources. In particular, the Statewide CASE Team's benchmarking efforts suggest that future modeling updates may need to account for increasing energy per use in homes with more bedrooms.

The annual energy consumption of ovens and cooktops is directly related to the number of cooking cycles in a year. With a greater number of cycles, more time is spent in active mode, and more energy is used throughout the year. The key variables used in the Statewide CASE Team's analysis of ovens and ranges are listed in Table 32, along with how the variable was used when developing the ruleset and the data source used to obtain them.

Table 32: Key variables and their function within the ovens and cooktops methodology

Variable	Function	Source
Saturation	Determine whether household is assigned oven and/or cooktop AEC	Reported by builder, confirmed through on-site inspection
Fuel type	Determine whether to use gas or electric algorithms	Reported by builder, confirmed through on-site inspection
Average unit energy consumption of electric ranges in California	Disaggregated into average annual energy consumption of components for gas and electric ranges	RASS 2009

Variable	Function	Source
Average annual oven and cooktop uses	Divides the annual energy consumption of oven and cooktop to determine per-cycle active-mode energy use for each product and fuel type	RASS 2009
Cycles per year	Multiplied by the per-cycle active-mode energy use to determine active-mode energy use	RASS 2009
Fraction of gas and electric ovens that are self-cleaning	To average active-mode energy consumption of self-cleaning and standard ovens	DOE rulemaking documents
Standby mode annual energy consumption	Added to home active-mode energy use to determine home annual energy consumption	DOE rulemaking documents

4.5.4 Methodology

4.5.4.1 Methodology Overview

For each home in RASS 2009 that reported using a cooking product of a specified fuel type, the Statewide CASE Team calculated that AEC of that product by multiplying the survey-reported number of cycles per year by a calculated per-cycle active mode energy use, and then adding an estimated standby mode annual energy consumption. For each survey-reported fuel source, the Statewide CASE Team performed a linear regression to capture the relationship between AEC and NBr.

4.5.4.2 Determining Per-Cycle Active Mode Energy Use

To calculate per-cycle active mode energy use, the Statewide CASE Team divided annual active mode energy use estimates for gas and electric ovens and cooktops by the average number of cycles per year for all homes in RASS 2009 that reported using the cooking product.

The Statewide CASE Team estimated the annual active mode energy use for each fuel type using the DOE TSD from the 2009 and 2015 rulemaking cycles for cooking products. Appendix 6A of the 2009 TSD disaggregates an estimated unit energy consumption of self-cleaning and standard ranges into the energy consumption of each component, including ignition, pilot light, and self-cleaning energy. Likewise, Appendix 7A of the 2015 TSD follows the same procedure, but with updated input values (e.g. cooking efficiencies, standby power, market share), and built-in and slide-in ovens only–cooktops will be addressed in a future rulemaking. The Statewide CASE Team thus used the 2009 TSD method, with updated values from the 2015 TSD wherever applicable.

In the 2009 and 2015 rulemakings on cooking products, DOE estimated the unit energy consumption of a range to be an average of CA RASS and FSEC value (DOE 2015c). The Statewide CASE Team chose to use only the RASS 2009 value of 268 kWh/yr.

The Statewide CASE Team determined the annual active mode energy use for each cooking product in 2017 and disregarded the energy consumption of the pilot light (to correspond with the 2012 standard) as well as the standby mode annual energy use, which will be included in a later calculation.

In order to aggregate the active mode energy uses of standard and self-cleaning ovens, the Statewide CASE Team calculated a weighted average by using the relative share of projected shipments in 2017 as reported by the 2015 TSD. The relative share of shipments is shown in Table 33.

For each fuel type, the Statewide CASE Team divided the active mode energy uses for ovens and cooktops by the average number of cycles per year to calculate the final per-cycle active mode energy use.[37] The results of the disaggregation process are shown in Table 34.

Table 33: Relative market share of standard and self-cleaning oven shipments in 2017, as projected by DOE 2015 TSD

	Electric Ovens				Gas Ovens			
	Standard		Self-Cleaning		Standard		Self-Cleaning	
	FSR (%)	BSO (%)	FSR (%)	BSO (%)	FSR (%)	BSO (%)	FSR (%)	BSO (%)
Percent of Total Shipments	20.5	1.1	54.1	17.4	34.5	5.9	45.2	2.5
Relative Market Share	23.2		76.8		45.9		54.1	

Note: FSR = Free-Standing Range; BSO = Built-In/Slide-In Oven

Source: (DOE 2015c)

Table 34: Results of range (oven and cooktop) energy use disaggregation and calculation of per-cycle active-mode energy-use

Component	Units per year	Electric (%)			Gas (%)		
		Oven		Cooktop	Oven		Cooktop
		Standard	Self-Cleaning		Standard	Self-Cleaning	
Cooking Energy	kWh	118	130	102	-	-	-
	Therms	-	-	-	8.77	6.77	5.74
Cooking Efficiency		10.8	9.8	74.0	4.4	5.7	39.9
Self-clean Energy	kWh	-	32.8	-	-	0.7	-
	Therms	-	-	-	-	1.70	-
Standby	kWh	19.2	19.2	-	-	19.2	-
Ignition	kWh	-	-	-	43.5	43.5	-
Active-Mode Energy Use	kWh	152		102	43.9		-
	Therms	-		-	8.61		5.74
Cycles per year		103		239	103		239
Per-cycle Active-Mode Energy Use	kWh	1.49		0.424	0.428		-
	Therms	-		-	0.0839		0.0240

[37] The average number of cycles per year in RASS 2009 was calculated to be 239 for cooktops and 103 for ovens. The fuel type is not distinguished in this average. The cycles per year was determined by multiplying the reported number of uses per week in RASS 2009 by 52 weeks per year.

4.5.4.3 Determining AEC as a function of NBr

For each home in RASS, the Statewide CASE Team determined the AEC of every survey-reported oven and cooktop. This AEC was calculated as the sum of active mode AEC and standby mode AEC. For each home in RASS, the Statewide CASE Team calculated active mode AEC as the product of the per-cycle active mode energy use (Section 4.5.4.2) and the number of annual oven or cooktop uses reported by that household. The Statewide CASE Team then added standby mode AEC of every survey-reported device, as determined in Table 34 thus calculating total AEC.

Finally, for each fuel type and cooking product, the Statewide CASE Team performed a linear regression to capture the relationship between the calculated AEC and the survey-reported NBr. The Statewide CASE Team recommends capping the resulting equation at seven bedrooms for the reasons discussed in Section 3.4.4.

4.5.5 Results

Figure 22, Figure 23, and Figure 24 present the recommended algorithms for estimating the AEC of an electric or gas oven and cooktop based on NBr. The points in the graphs represent the average oven and cooktop AEC calculated for RASS homes with a given NBr (that have both devices).[38]

Although the figures present the combined AEC of an oven and cooktop that use the same fuel type, the recommended algorithms can accommodate any combination of fuel types, as well as only one of the devices being present. Oven and cooktop AEC is only assigned if the compliance software user reports they will be present.

Whether the gas or electric algorithms are applied depends on the fuel type(s) reported by the software user. If the user indicates that natural gas is not available on-site, the user has the option to indicate whether the installed oven/cooktop will use electricity or propane. The Statewide CASE Team recommends that the default assumption for a home that does not have natural gas available is that the oven and cooktop are both electric. On the other hand, if the user indicates that natural gas is available on-site, the user has the option to indicate whether the installed oven/cooktop will use electricity, natural gas, or propane. (Because there are separate oven and cooktop algorithms, users can specify combinations of fuel types, such as an electric oven and gas cooktop.) The Statewide CASE Team recommends that the default assumption for a home that has natural gas available is that the oven and cooktop both use natural gas. The "gas" rulesets in the following figures and tables apply to ovens and cooktops that combust natural gas or propane.[31]

[38] Technically, the points do not correspond to homes that have both an oven and a cooktop, because the Statewide CASE Team conducted its analysis separately for the two devices; however, this is a useful interpretation. (The points are actually the sum of two sets of average AEC by NBr values: the average AEC by NBr for RASS home with a cooktop and the average AEC by NBr for RASS homes with an oven.)

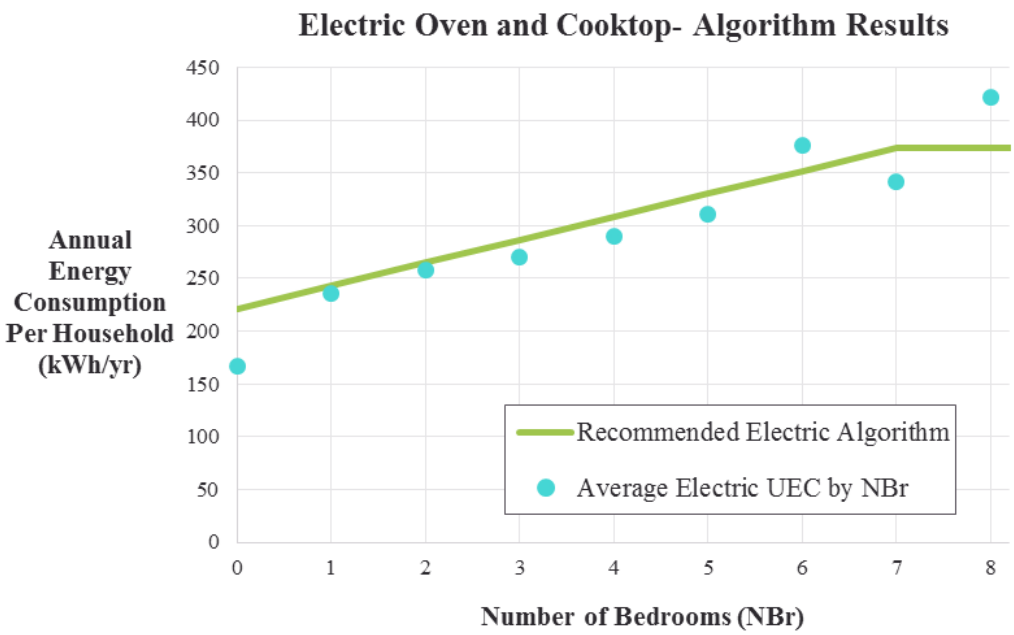

Figure 22: Estimated AEC of an electric oven and cooktop as a function of NBr

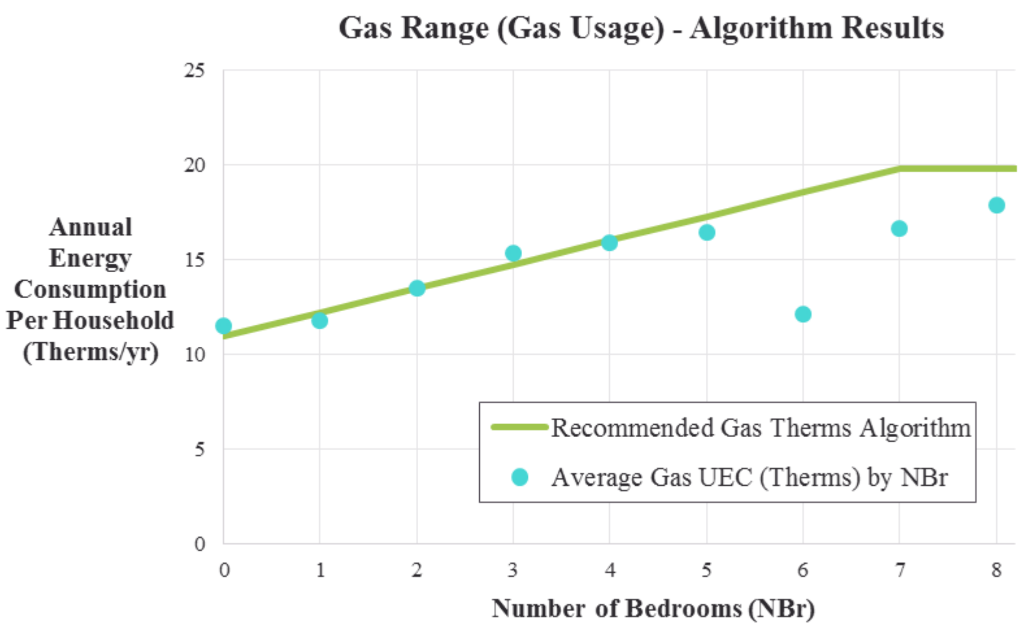

Figure 23: Estimated AEC of a gas oven and cooktop as a function of NBr (therms)

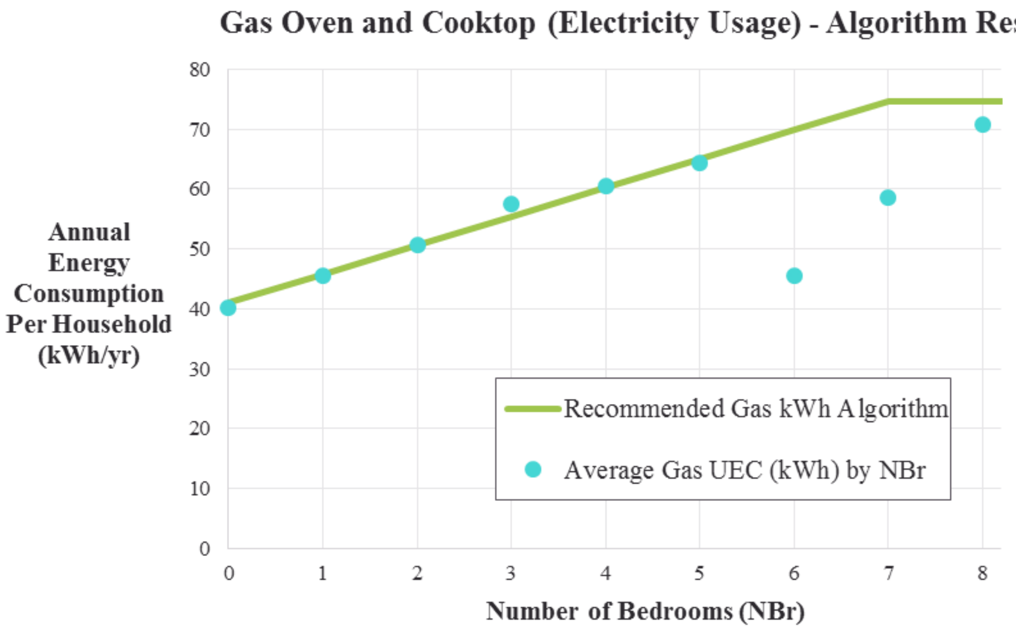

Figure 24: Estimated AEC of a gas oven and cooktop as a function of NBr (kWh)

Table 35 presents the results of the ovens and cooktops algorithms by NBr, for gas and electric devices. The sum of oven and cooktop AEC (range AEC) is also shown.

Table 35: Estimated AEC of gas and electric ovens, cooktops, and ranges by NBr

NBr	Electric			Gas				
	Oven (kWh)	Cooktop (kWh)	Range (kWh)	Oven		Cooktop	Range	
				(kWh)	(therms)	(therms)	(kWh)	(therms)
0	138	84	221	41	6.0	5.0	41	11.0
1	154	89	243	46	6.9	5.3	46	12.2
2	170	95	265	51	7.9	5.6	51	13.5
3	186	101	287	55	8.8	5.9	55	14.7
4	202	106	308	60	9.8	6.2	60	16.0
5	218	112	330	65	10.7	6.5	65	17.3
6	234	118	352	70	11.7	6.9	70	18.5
7+	250	124	373	75	12.6	7.2	75	19.8

Note: Range AECs are determined by adding the oven and cooktop AECs. For gas ranges, the cooktop uses no electricity.

Figure 25 compares the sum of the oven and cooktop (range) algorithms to various benchmarks, described in Section 3.5.2 for electric AEC and gas (therms) AEC. Gas (kWh) AEC is not shown because none of the data sources that the Statewide CASE Team compared to had estimates.

The recommended electric cooking algorithm estimates lower AEC than RESNET or the Building America House Simulation Protocols. The recommended rulesets estimate roughly the same amount of AEC of average-sized homes as was measured in the 2014 NEEA RBSA and as was estimated by the RASS CDA and the current 2013 rulesets. Although their average magnitudes are similar, the 2013 code cycle algorithm and the underlying RASS 2009 CDA have a steeper slope than the recommended rulesets. This may be because there is a trend that cooking energy per cycle tends to increase with NBr, but the Statewide CASE Team's methodology assumes constant energy per cycle.[39] A recent submetering study by Redwood Energy of low-income, California families living in multi-family housing also shows a steeper relationship than our proposed algorithm, as well as substantially more cooking AEC within this subset of the population.[40] Additional field data would help for future updates to address the question of how cooking energy and use varies with NBr (or just how overall cooking energy varies with NBr). Although RESNET is similar in slope to the Statewide CASE Team's analysis, RESNET was also based on an analysis of how self-reported cooking uses vary with NBr. The California Utility Allowance Calculator tool (CUAC) estimates substantially more electric cooking energy than the proposed algorithms.[41] This tool is used to estimate AEC for affordable housing construction projects, so the differences between CUAC and the other models may indicate that: CUAC overestimates electric cooking AEC; low-income families use much more cooking energy than the statewide average; or both.

[39] In other words, the steeper slope of the RASS CDA may reflect that homes with more bedrooms (and thus more occupants, on average) tend to not only cook more often, but also use more cooking energy per meal.

[40] In 2015 Redwood Energy monitored the average cooking energy use in 85 newly built subsidized apartments with one, two, three and four bedrooms. Consistent with the findings from the 2001 EIA RECS, this metered study found that lower income and higher density households cook significantly more often than the average population.

[41] For more information on CUAC, see http://www.gosolarcalifornia.ca.gov/affordable/cuac/index.php

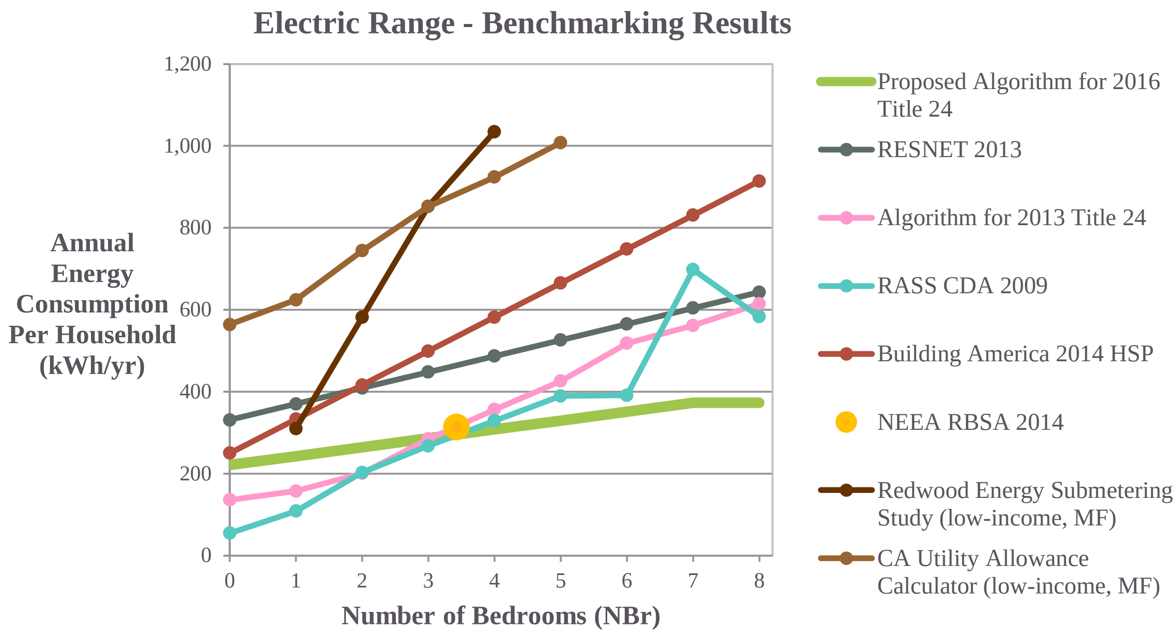

Figure 25: Comparison of electric oven and cooktop AEC model against various reference points

The recommended gas cooking algorithm estimates significantly lower natural gas AEC than most of the other benchmarks. This is primarily due to the 2012 federal design standard prohibiting the use of a pilot light for gas cooking products. According to the 2009 DOE TSD for cooking products, a pilot light uses 60 to 70 percent of the total cooking AEC. The various benchmarks presented in Figure 25 determined cooking AEC using studies (e.g. Quantum Consulting, KEMA, LBNL) that date back to before the federal design standard was adopted. The one data source that estimates less gas AEC the proposed rulesets is the CUAC tool, which is surprising, because CUAC estimates more electric AEC than the proposed algorithms.

The recommended gas cooking algorithm estimates slightly higher electric AEC of gas ovens and cooktops, mainly due to the inclusion of standby energy.

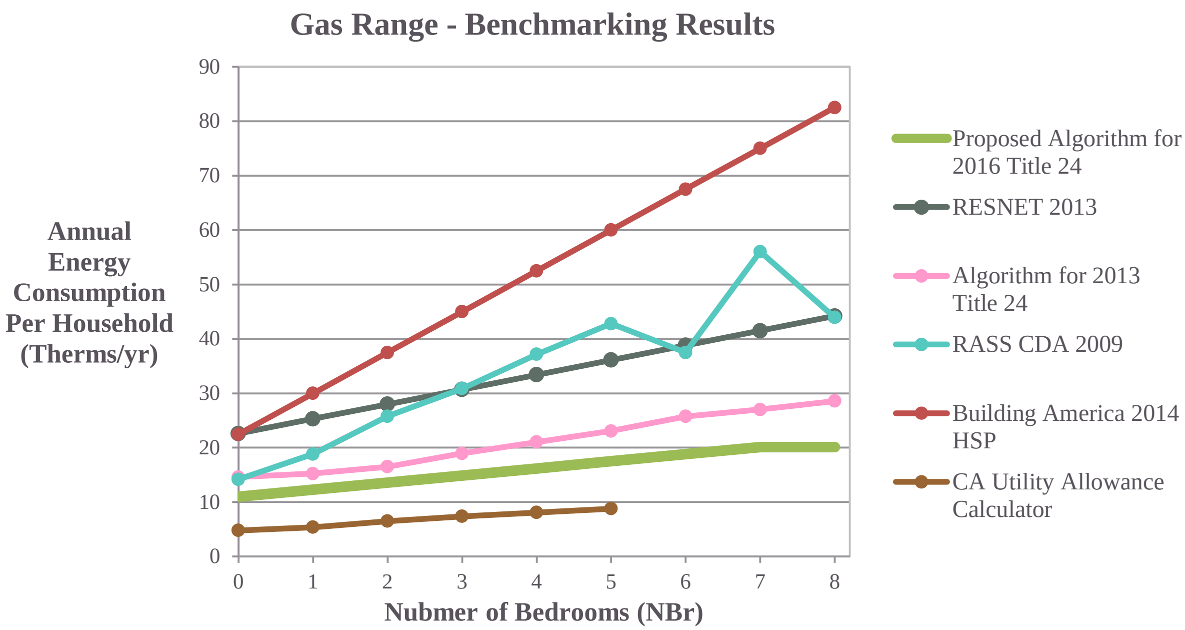

Figure 26: Comparison of gas range AEC model against various reference points (therms)

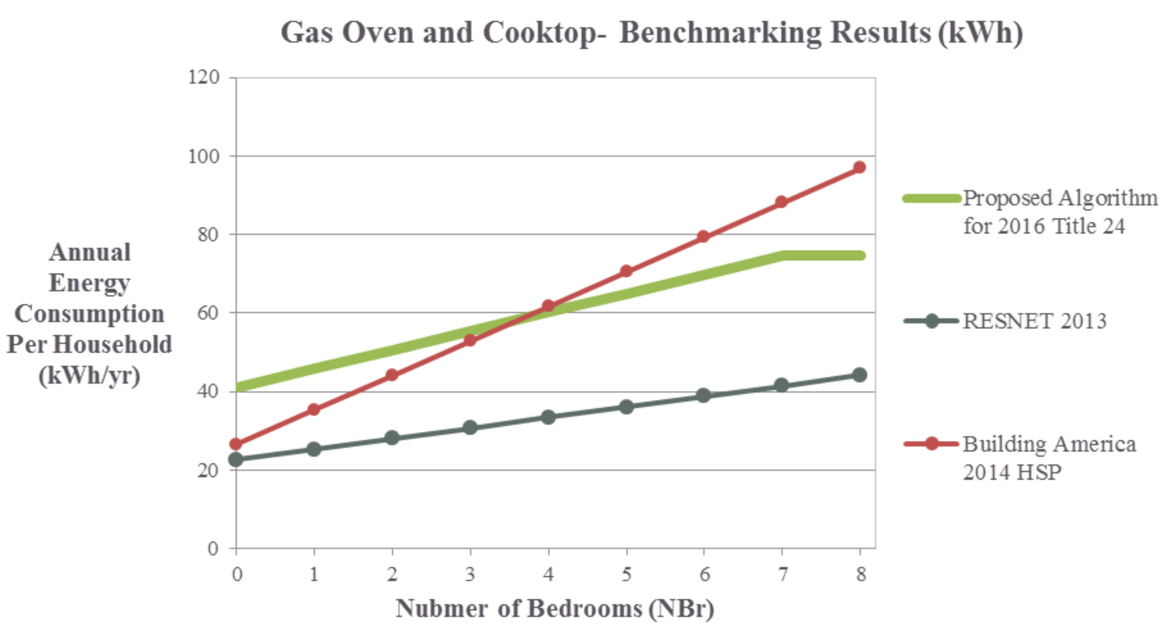

Figure 27: Comparison of gas oven and cooktop model against various reference points (kWh)

4.6 Televisions

4.6.1 Technology Introduction

Televisions are among the highest energy consuming residential appliances outside of white goods, accounting for approximately 50 TWh/year in homes nationwide (Urban et al. 2014). Over the past decade, the type and size of televisions has changed dramatically due to newer technologies entering the market. Cathode-ray tube (CRT) television technology has given way to more advanced technologies such as plasma and light-emitting diode (LED) televisions, which provide higher quality displays at drastically reduced power. The 2013 CE Usage Survey estimated that a majority of televisions today are either liquid crystal display (LCD) or plasma (63 percent and 7 percent, respectively), while CRT televisions accounted for 27 percent of the existing stock of televisions (Urban et al. 2014). Mandatory appliance efficiency regulations in California under Title 20 and voluntary standards such as ENERGY STAR (now featuring a "most efficient" product category) have had a significant impact in limiting the power draw of televisions. The standards reduce energy consumption by prescribing maximum power draw requirements for on and standby-passive mode as a function of screen area as well as an automatic power management capability.

The energy savings resulting from the shift away from CRT televisions are countered by increases in average screen size over time and in the rising market share of ultra-high definition (UHD) televisions (NRDC 2015b). UHD televisions use approximate 30 percent more energy than standard-definitions of the same size (NRDC 2015b).

4.6.2 Existing Energy Efficiency Standards

California's mandatory Title 20 standards for televisions became effective on January 1, 2006. The CEC has amended the standards twice, effective in 2011 and 2013, with changes that regulated the maximum on mode power usage for the first time and lowered the allowed standby-passive mode power, as detailed in Table 36.

Table 36: Title 20 appliance efficiency regulations for televisions

Effective Date	Screen Area (square inches)	Max Standby-passive Mode Power (W)	Max On Mode Power (W)	Minimum Power Factor for ($P \geq 100W$)
January 1, 2006	All	3	No standard	No standard
January 1, 2011	A < 1,400	1	$P \leq 0.20*A + 31$	0.9
January 1, 2013	A < 1,400	1	$P \leq 0.12*A + 25$	0.9

Additionally, the Title 20 standards for televisions require that televisions enter a standby-passive mode or standby-active mode after a maximum of 15 minutes without video or audio input on or when turned off by remote or by an integrated button. This requirement reduces the AEC of televisions by reducing the amount of time televisions spend in active mode.

Televisions are currently covered in the voluntary ENERGY STAR program. The Statewide CASE Team expects that televisions in use in 2017 will, on average, meet ENERGY STAR version 6.0 specifications, as explained in Section 4.6.4.3. The ENERGY STAR version 6.0

specification for televisions provides a maximum power draw allowance for active mode as a function of screen area and requires that qualified products consume no more than one watt in standby mode.

4.6.3 Key Variables Impacting Energy Use

Per-household television AEC is highly dependent on the number of televisions per household as well as the screen area, resolution, display type (e.g. LCD vs. CRT), screen size, and hours of use. The Statewide CASE Team accounted for the following factors and relationships in the televisions AEC algorithm:

- Average age;
- How television saturation scales with NBr;
- How typical screen area varies with television primacy;
- How average power mode varies with screen size; and
- How average hours of use vary between the primary, secondary, tertiary, etc. television.

The Statewide CASE Team estimated average power draw as a function of screen size as opposed to projecting the market share of different television display types and the typical power draw of each display type. This methodology streamlined the modeling approach and significantly reduced the number of inputs required to update the televisions model.

Other factors that affect real-world television AEC that the Statewide CASE Team did not explicitly model include energy savings from automatic brightness control (ABC) and the greater power draw of UHD televisions and smart televisions (NRDC 2015b). Additionally, the Statewide CASE Team applied a fixed weighted average age assumption to all televisions, and thus did not account for the fact that less-watched televisions tend to be older than the average and the more primary televisions tend to be newer.[42]

Table 37 lists the key variables in the television methodology, along with how the variable was used when developing the ruleset, and the data source used to obtain them.

[42] As a result of this simplification, AEC estimates for less-primary televisions (e.g. fourth-most watched television in a household) will likely underestimate AEC, because these televisions are more likely to be old, CRT models. On the other hand, AEC estimates for the most-watched televisions will likely underestimate AEC, because these televisions are more likely to use highly efficient display technologies. (Even with the increasing penetration of UHD television, the net market trend has been for newer televisions to draw less power per square inch.)

Table 37: Key variables and their function within the television methodology

Variable	Function	Source
Average Age	Determine typical screen size of televisions in 2017; determine ENERGY STAR specification that most televisions will meet in 2017	CLASS 2012
Average Screen Size	Determine average screen area of 1^{st}-6^{th} televisions	CLASS 2012 (televisions manufactured 2010-2012)
Relative Screen Area of 1^{st}-6^{th} Televisions		Urban et al. 2014
Screen Size vs. Screen Area		ENERGY STAR QPL
Power Draw vs. Screen Area	Determine power draw of 1^{st}-6^{th} televisions	ENERGY STAR version 6.0 specification
Duty cycle by primacy	Determine AEC of 1^{st}-6^{th} televisions	Nielson 2012 in-home metering
Saturation	Determine per-household television AEC	RASS 2009

4.6.4 Methodology

4.6.4.1 Methodology Overview

For each home in RASS 2009, the Statewide CASE Team calculated the AEC of each survey-reported television.

The Statewide CASE Team determined duty cycle (i.e. hours of use and hours in standby mode) and screen area by television primacy (i.e. the first through sixth most-watched televisions in a household) from a 2012, California-specific metering study conducted by Nielson (Nielson 2012). The Statewide CASE Team determined the average screen size for televisions using the CLASS 2012 building audit for the newest televisions (DNV GL 2012), and then scaled up or down according to primacy to reflect that people watch their largest televisions the most. The screen size scaling factors were determined using data from the 2013 CE Usage Survey (Urban et al. 2014). The Statewide CASE Team converted diagonal screen size (in inches) to screen area (in square inches), using a regression equation derived from ENERGY STAR QPL data on television screen size and area.

From the estimated screen area, the Statewide CASE Team calculated the active mode power draw, using the relationship between screen area and maximum allowable active mode power draw from the ENERGY STAR version 6.0 specification. Next, the Statewide CASE Team multiplied the assumed hours in active and standby mode by the power draw by mode to calculate AEC of the first through sixth-most watched televisions.

The Statewide CASE Team then summed the estimated AEC of all survey-reported televisions for each household in RASS to calculate the per-household AEC of all televisions in each RASS home. For example, if a home reported having three televisions, the Statewide CASE Team summed the estimated AEC of a primary, secondary, and tertiary television.

Finally, the team performed a linear regression to capture the relationship between NBr and the per-household AEC values calculated for each home in RASS.

4.6.4.2 Determining Screen Area by Device Primacy

Because television size is increasing over time (NRDC 2015b), the Statewide CASE Team had to determine the average manufacture date of televisions in new homes built during the 2016 Title 24 code cycle to determine the average screen size of televisions in those homes. According to the CLASS 2012 building audits, the average age of televisions in existing buildings is five years (DNV GL 2012). Lacking specific data on the age of televisions in newly built homes, it was assumed that the average television in a home built in 2017 would be five years old and thus manufactured in 2012.

The Statewide CASE Team determined the average size of televisions of this vintage by analyzing data from the CLASS 2012 building audits. According to CLASS, the average diagonal screen size of the most recently manufactured televisions (those manufactured from 2010-2012) in the surveyed homes was 44 inches (DNV GL 2012).

To account for the fact that the most-watched televisions tend to be larger, the team used data from the 2013 CE Usage Survey to scale the average television size with television primacy. According to the survey, the average television screen size in American households in 2013 was 34 inches. The Statewide CASE Team divided the average screen size of the first through sixth most-watched televisions, as determined by the CE Usage Survey, by the average television screen size derived from the survey to calculate screen size scaling factors by primacy. The Statewide CASE Team then multiplied the estimated average screen size (44 inches) by these ratios to calculate average screen size by primacy. Table 38 presents the scaling factors by television primacy.

Table 38: Calculation of average television screen size by primacy

Television Primacy	Average Screen Size – CE Usage Survey 2013 (inches)	Ratio Relative to Average – CE Usage Survey 2013	Calculated Screen Size for Television in New California Homes (inches)
TV 1	41	1.21	53
TV 2	32	0.94	41
TV 3	29	0.85	37
TV 4	29	0.85	37
TV 5	28	0.82	36
TV 6+	28	0.82	36
All TVs	34	1.00	44

Next, the Statewide CASE Team converted the calculated screen sizes to screen area using data from the ENERGY STAR QPL for televisions (ENERGY STAR 2015d). Figure 28 presents a quadratic regression analysis of the relationship between screen size and area based on the models on the QPL.

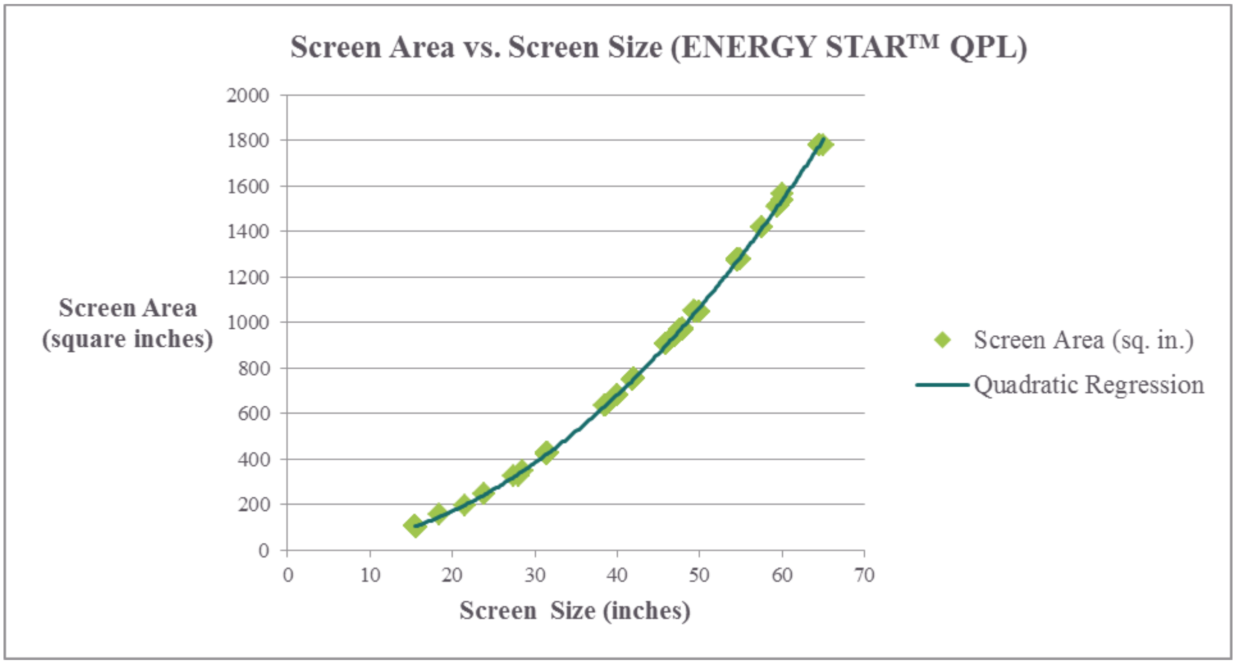

Figure 28: Relationship between television screen size and screen area ((ENERGY STAR 2015d)

The Statewide CASE Team used the resulting regression equation (Equation 6) to calculate screen area from estimated screen size (Table 39).

Equation 6: Television screen area as a function of screen size

$$ScreenArea = 0.4241 * (ScreenSize)^2 + 0.2203 * (ScreenSize) - 3.9376$$

Table 39: Estimated television screen area by primacy

Television Primacy	Average Screen Size (inches)	Equivalent Screen Area (square inches)
TV1	53	1,198
TV2	41	729
TV3	37	599
TV4	37	599
TV5	36	558
TV6+	36	558
All TVs	44	823

4.6.4.3 Determining Power Draw as a Function of Screen Area

The Statewide CASE Team used the ENERGY STAR version 6.0 specification for televisions to convert the estimated screen area by primacy to estimated power draw by mode.

As explained in Section 4.6.4.1, the Statewide CASE Team assumed that the average television in 2017 homes will be manufactured in 2012. According to ENERGY STAR's 2012 Unit Shipment Data Summary, the ENERGY STAR version 6.0 specification for televisions had a 74 percent market penetration rate in 2012 (ENERGY STAR 2012c). The Statewide CASE

Team therefore assumed the requirements of the version 6.0 specification to be representative of the efficiency of the televisions that will be in homes in 2017.

The ENERGY STAR version 6.0 specification prescribes a maximum standby mode power draw of one watt, as do the 2011 and 2013 Title 20 standards for televisions. The Statewide CASE Team therefore assumed that televisions will draw one watt in standby mode. Future updates to the model may need to re-evaluate this assumption, as the Title 20 standards do not cover televisions with a screen size greater than 1,400 square inches, and televisions in this size category are both increasingly common and have rising standby energy use (NRDC 2015b).

The ENERGY STAR version 6.0 specification defines a maximum active mode power draw (in watts) requirement, calculated as a function of screen area (in square inches), as shown in Equation 7 (ENERGY STAR 2012d).

Equation 7: Maximum allowable active mode power draw for televisions meeting the ENERGY STAR version 6.0 specification

$$On.Mode.Power_{max} = 100 \times \tanh(0.00085 \times (Screen.Area - 140) + 0.052) + 14.1$$

The Statewide CASE Team applied this equation to the screen area estimates in Table 39 to estimate active mode power draw for the first through sixth most-watched televisions. Table 40 presents the resulting power draw assumptions by primacy.

Table 40: Estimated power draw by mode by television primacy

Television Primacy	Active Mode Power (W)	Standby Power (W)
TV1	169	1
TV2	113	1
TV3	97	1
TV4	97	1
TV5	92	1
TV6+	92	1
All TVs	124	1

4.6.4.4 Determining Duty Cycle by Device Primacy

The Statewide CASE Team used data from a 2012 Nielson study commissioned by PG&E that measured the amount of time that televisions were in active mode to determine television duty cycles by primacy (Nielson 2012). This California-specific study quantified household television usage for the first through sixth most-watched televisions, based on metering data from over 2,500 households, as shown in Table 41 (Nielson 2012).

Table 41: Daily active mode usage estimates for primary, secondary, and tertiary televisions

Television Primacy	Daily Time in Active Mode (hours)
TV1	7.7

TV2	4.0
TV3	2.9
TV4	2.4
TV5	2.0
TV6+	2.0
All TVs	5.0

Source: (Nielson 2012)

The Statewide CASE Team assumed that televisions spent the remainder of the daily hours in standby-passive mode, since Title 20 standards prescribe that televisions enter this mode after 15 minutes with no audio or video input signal.

4.6.4.5 Determining AEC by Primacy

To calculate the AEC of the first through sixth most-watched televisions in a household, the Statewide CASE Team multiplied the estimated power draw in each mode by the estimated time in each mode. Table 42 presents the resulting AEC estimates by primacy.

Table 42: Estimated AEC per television by primacy

Television Primacy	Annual Energy Consumption per Television (kWh/yr)
TV1	254
TV2	101
TV3	67
TV4	57
TV5	47
TV6+	37
All TVs	137

4.6.4.6 Determining Per-Household AEC as a Function of NBr

The Statewide CASE Team then summed the estimated AEC of all survey-reported televisions for each household in RASS to calculate their per-household AEC of all televisions. For example, if a home reported having three televisions, the Statewide CASE Team summed the estimated AEC of a primary, secondary, and tertiary television. Table 43 presents the resulting per-household AEC estimates for RASS households as a function of the survey-reported number of televisions.

Table 43: Estimated per-household AEC of televisions as a function of survey-reported number of televisions

Number of Televisions	% of CA Households (RASS 2009)	Estimated Per-Household Annual Energy Consumption (kWh)
0	5%	0
1	24%	254
2	31%	355
3	25%	422
4	9%	479
5	2%	526
6	3%	563
7	1%	700
8	0%	837
9	0%	974
10	0%	1,111
11	0%	1,248
12	0%	1,385
Total:	**100%**	**8,854**

The Statewide CASE Team then performed a linear regression to capture the relationship between NBr and the per-household AEC values calculated for each home in RASS. Per-household AEC of televisions was estimated to increase with NBr because the average number of televisions per household increases with NBr, as shown in Table 44.

Table 44: Average number of televisions per household reported in RASS by NBr

NBr	Average Total Televisions per Household (RASS)
0	1.0
1	1.5
2	2.1
3	2.5
4	2.8
5	3.0
7	3.3
8	3.1

4.6.5 Results

Figure 29 presents the recommended algorithm for estimating the per-househould AEC of televisions based on NBr. The points in the graph represent the average, per-household AEC calculated for RASS homes with a given NBr.

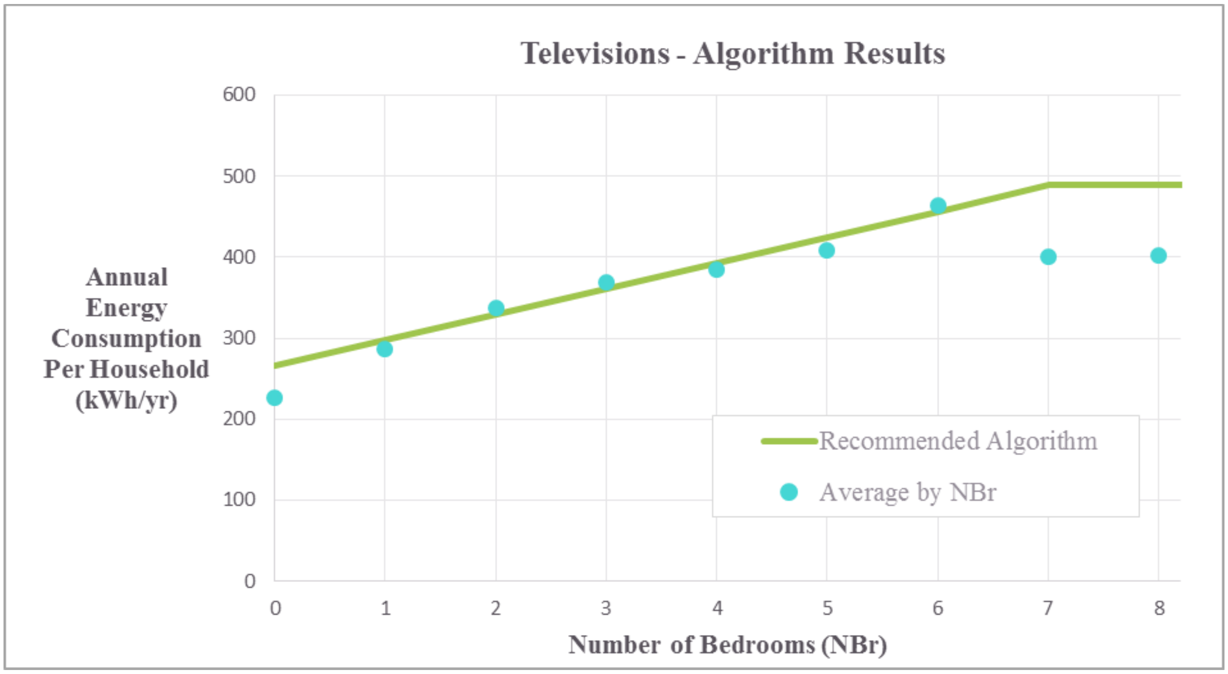

Figure 29: Per-household AEC of televisions as a function of NBr

Table 45: Per-household AEC of televisions, estimated based on NBr

NBr	Annual Television Energy Consumption (kWh/yr)
0	265
1	297
2	329
3	360
4	392
5	424
6	456
7+	488

Figure 30 compares the refrigerators and freezers algorithms to various benchmarks, as described in Section 3.5.2. The recommended algorithm comes very close to the per-household AEC that the Statewide CASE Team calculated by applying the per-device AEC estimates from the most recent data sources to the RASS saturation data (Urban et al. 2014; NEEA 2014). Although these benchmarks are represented as points, if the Statewide CASE Team had analyzed the RASS saturation data as a function of NBr, the resulting lines would have a similar slope to the recommended rulesets, as all sources scale based on the RASS data.

RESNET, Building America, and the RASS CDA all estimate substantially more per-household television AEC. The most likely reason for this difference is that the recommended algorithms assume more efficient display technology. In contrast, these benchmarks reflect an era when inefficient CRT televisions were much more popular. It is less plausible that the proposed algorithms are lower because the Statewide CASE Team's methodology assumes fewer televisions, smaller screens, or fewer hours of active mode usage.

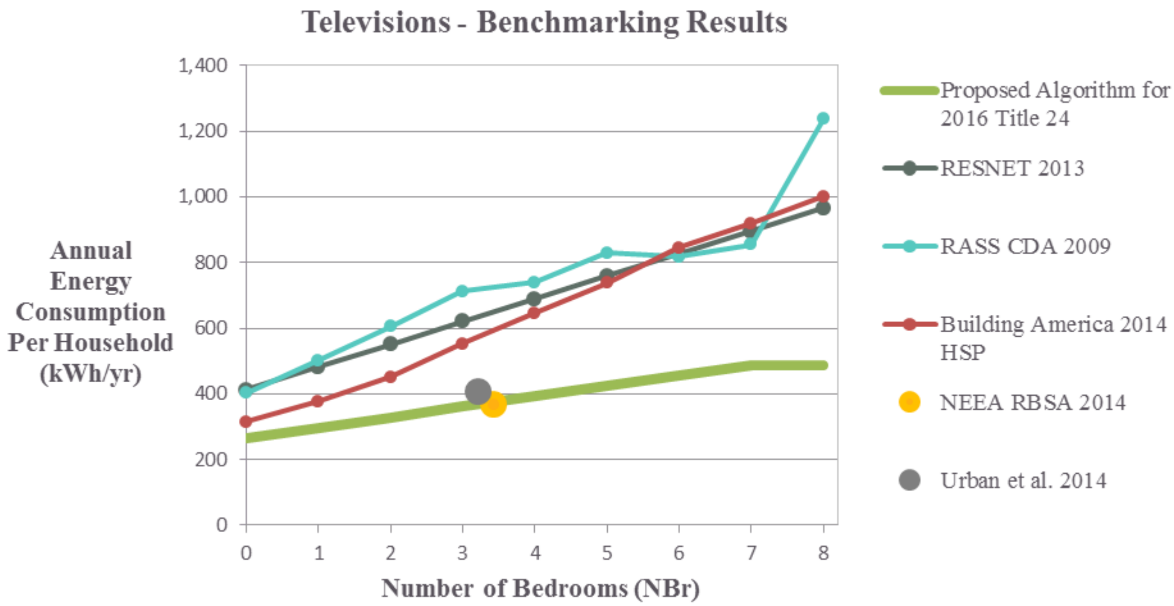

Figure 30: Comparison of televisions AEC algorithm against various benchmarks

4.7 Set-top boxes

4.7.1 Technology Introduction

DOE defines the set-top box as "a device combining hardware components with software programming designed for the primary purpose of receiving television and related services from terrestrial, cable, satellite, broadband, or local networks" (DOE 2015b). Cable and satellite television service providers provide set-top boxes to their customers who purchase television services, typically through long-term contracts. These devices require their own power source connection to standard electrical outlets. In 2013, the Consumer Electronics Association (CEA) commissioned a study to quantify the electricity consumption of consumer electronics in U.S. households in 2013 (Urban et al. 2014). This study estimates a current stock of 294 million set-top boxes (including most set-top box device types available in the market, such as cable and satellite boxes) and an AEC of approximately 30.8 TWh/year in homes nationwide. This estimate includes another category of set-top boxes known as internet protocol (IP) devices provide television services through a local IP network (whether hard-wired or through Wi-Fi). Example products include Apple TV and Roku. Urban et al. 2014 estimated a low existing stock of IP set-top box devices in 2013, at 1.7 million total or approximately 0.71 percent of the total stock. Data released in the report describing the industry Voluntary Agreement indicated a similar market share for thin client devices, which operate through local IP networks, at 0.90 percent (D&R International 2014). The Statewide CASE Team did not include these products in the set-top boxes analysis; given the rapid increase in the popularity of these devices, future updates to the set-top box model will need to account for the AEC of IP set-top boxes.

4.7.2 Existing Energy Efficiency Standards

There currently are no mandatory energy efficiency standards for set-top boxes applicable in California. However, set-top boxes are covered products in the voluntary ENERGY STAR program. The Statewide CASE Team expects that set-top boxes in use in 2017 will, on average, meet ENERGY STAR version 3.0 specifications, as explained in Section 4.7.4.5. The ENERGY STAR version 3.0 specification for set-top boxes provides maximum AEC values for different classes of set-top box, with functional adder to provide allowances for certain features and capabilities (ENERGY STAR 2012b).

4.7.3 Key Variables Impacting Energy Use

The Statewide CASE Team accounted for the following factors in the set-top boxes AEC algorithm:

- How the saturation of different types of set-top boxes scales with NBr;
- Average duty cycle of different types of set-top boxes; and
- Average power by mode of different types of set-top boxes.

Although there are many types of set-top boxes, the Statewide CASE Team distinguished between cable boxes, satellite boxes, and Digital-to-Analog (DTA) converter set-top boxes.[43] In addition, the Statewide CASE Team accounted for the substantial differences between set-top boxes with and without Digital Video Recording (DVR) capability. Set-top boxes with DVR capability draw approximately 47 percent more power on average than devices without DVR capability (ENERGY START 2012b). This is due to additional media processing components within the set-top box such as hard drives to provide DVR functionality for the set-top box. Furthermore, the set-top boxes with DVR units spend less time in sleep mode due to their ability to record television programming for future viewing during times when the user is not actively using the television.

The Statewide CASE Team did not account for the full set of variation in hardware, functionalities, usage, and network topology that can affect set-top boxes AEC. In particular, the Statewide CASE Team did not account for growing market share of IP and thin client set-top boxes—product classes that were not accounted for in the RASS 2009 data. The Statewide CASE Team also did not attempt the estimated hours of television usage for each home in RASS to the set-top box model. Although television usage does affect set-top AEC, the impact is minor because set-top boxes have such high sleep mode power draw compared to their active mode power draw (ENERGY STAR 2012b).

[43] The Digital Television Transition and Public Safety Act of 2005 marked the end of analog television broadcasting nationwide, and since then, DTA converters have been necessary for analog televisions to receive and display digital transmissions. DTA (also known as over-the-air DTA) converters are tuners for televisions that receive digital television transmission and convert the digital signal into an analog signal for display on analog televisions. Since all new televisions have digital tuners installed, the number of DTA devices is expected to decline over time as the stock of televisions turns over and analog televisions are retired (D&R International 2014).

Table 46 lists the key variables in the set-top box methodology, along with how the variable was used when developing the ruleset, and the data source used to obtain them.

Table 46: Key variables within the set-top box modeling methodology

Variable	Function	Source
Saturation by type	Estimate power draw and duty cycle for each survey-reported device	RASS 2009
Power draw by type	Determine AEC per device for each type of set-top box recorded in RASS	ENERGY STAR version 3.0 QPL
Duty cycle by type		DOE rulemaking documents

4.7.4 Methodology

4.7.4.1 Methodology Overview

For each home in RASS 2009, the Statewide CASE Team calculated the AEC of the survey-reported set-top boxes. The Statewide CASE Team calculated separate AEC estimates for each type of set-top box reported in RASS. These AEC estimates for each type of set-top box were calculated by multiplying estimated power draw in each operational mode by an assumed annual duty cycle. The Statewide CASE Team used the ENERGY STAR version 3.0 QPL for set-top boxes to define a representative power draw by mode for set-top boxes in new homes built during the 2016 Title 24 code cycle and relied on DOE rulemaking documents for duty cycle assumptions. Finally, the Statewide CASE Team performed a linear regression to capture the relationship between NBr and the AEC values calculated for each home in RASS.

4.7.4.2 Determining Set-top Box Presence and Type

Respondents to RASS specified the number of and type of set-top boxes they own, choosing between three categories:

- Converter box or standard TV (digital to analog);
- Cable or satellite box without DVR; or
- Cable or satellite box with DVR.

The RASS data indicates 1.4 set-top boxes per household, on average. Table 47 presents further detail on the relative popularity of the three types of set-top boxes recorded in RASS.

Table 47: Share of set-top boxes by type in California households

Set-Top Box Type	Share of Set-Top Boxes Reported in RASS (%)
DTA	22
Cable or Satellite Box without DVR	43
Cable or Satellite Box with DVR	35
Total:	100

Source: RASS 2009

Furthermore, the RASS data shows that homes with more bedrooms tend to have more set-top boxes, at least through seven bedrooms. Table 48 quantifies this trend by presenting the average number of set-top boxes in California homes of increasing NBr based on RASS.

Table 48: Average number of set-top boxes in California homes of varying NBr (RASS 2009)

NBr	Average Number of Set-Top Boxes per Household
0	0.56
1	0.84
2	1.21
3	1.54
4	1.76
5	1.92
6	2.08
7	2.07
8	1.86

Source: RASS 2009

Although RASS does not distinguish between cable boxes and satellite boxes—only set-top boxes with and without DVR—the Statewide CASE Team was able to estimate this added layer of specificity using data from the 2009 Residential Energy Consumption Survey (EIA 2009). Table 49 presents the relative share of cable boxes and satellite boxes among set-top boxes with and without DVR.

Table 49: Relative share of cable and satellite boxes among set-top boxes with and without DVR

Set-Top Box Type	% Cable	% Satellite
Cable or satellite without DVR	72%	28%
Cable or satellite with DVR	60%	40%

Source: (EIA 2009)

Combining the data in Table 49 with the RASS data, the Statewide CASE Team estimated the number of set-top boxes of five types:

- Converter box or standard TV (digital to analog);

- Cable box without DVR;
- Satellite box without DVR;
- Cable box with DVR; or
- Satellite box with DVR.

4.7.4.3 Determining Set-top Box Power Draw by Type

The Statewide CASE Team used the ENERGY STAR version 3.0 QPL for set-top boxes to define a representative power draw by mode for set-top boxes in new homes built during the 2016 Title 24 code cycle.

Although there are no existing energy efficiency standards for set-top boxes, the DOE published a Notice of Proposed Rulemaking for a set-top box test procedure on January 23, 2013. Later that year, on December 31, DOE withdrew the Notice of Proposed Rulemaking "in light of a consensus agreement entered by a broadly representative group that DOE believes has the potential to achieve significant energy savings" (D&R International 2014). The agreement DOE referenced is the Voluntary Agreement for Ongoing Improvement to the Energy Efficiency of Set-Top Boxes—a voluntary agreement signed by 11 cable, satellite, and telecommunications service providers whose distribution of set-top boxes accounts for over 91 percent of the 2013 set-top box market (D&R International 2014). The goal of the Voluntary Agreement is to increase the efficiency of set-top boxes without hampering the rapid innovation and evolution of the market (D&R International 2014). The Voluntary Agreement specifies a Tier 1 requirement that 90 percent of set-top boxes procured by service providers after December 31, 2013 must meet the ENERGY STAR specification version 3.0.

The Statewide CASE Team was unable to define a precise estimate of the average age of set-top boxes in new homes built during the 2016 Title 24 code cycle due to a lack of data availability. Given the voluntary agreement, ENERGY STAR version 3.0 appears to be a reasonable estimate of the industry standard efficiency for modern set-top boxes. Estimating the average age of set-top boxes is difficult because devices may be leased from multichannel television providers or directly purchased of residents choose to buy a standalone set-top box, such as the increasingly popular over-the-top set-top boxes (e.g. Apple TV) (Urban et al. 2014). In either case, set-top boxes in new homes are not guaranteed to be new, but the Statewide CASE Team assumes that devices are not likely to be more than four years old, on average, especially in light of how quickly older models are becoming obsolete (D&R International 2014). Therefore, given the 2013 effective date of the Tier 1 requirement of the voluntary standard, the Statewide CASE Team considered the ENERGY STAR version 3.0 specification to be representative of the efficiency of the set-top boxes that will be in homes built in 2017.[44]

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[44] The voluntary agreement also defines a more stringent Tier 2 requirement which will become effective in January 2017, and therefore would only affect new set-top boxes in homes built during the 2016 Title 24 code cycle. According to the agreement, the Tier 2 requirements will be "similar but not identical to ENERGY STAR version 4.1" specifications. Based on data from service providers included in the same report, approximately 47 perfect of the set-top boxes procured in 2013 meet the v4.1

The Statewide CASE Team determined power draw by mode values for each of the five types of set-top boxes considered by using the average power draw of products on the ENERGY STAR version 3.0 QPL.[45] The Statewide CASE Team analyzed the set of operational modes defined in both the ENERGY STAR specification and DOE data: on mode, sleep mode, and multi-stream mode.[46] Table 50 summarizes the Statewide CASE Team's power draw by mode assumptions for set-top boxes.

Table 50: ENERGY STAR version 3.0 power draw values for set-top boxes

Device Type	On mode (W)	Multi-stream mode (W)	Sleep mode power (W)
Cable without DVR	11.25	N/A	9.48
Cable with DVR	20.78	20.78	16.21
Satellite without DVR	9.18	N/A	8.23
Satellite with DVR	17.69	17.69	16.95
DTA	5.15	N/A	4.96

4.7.4.4 Determining Set-Top Box Duty Cycles by Type

The Statewide CASE Team then used data from the 2013 DOE rulemaking to determine the duty cycle of five types of set-to boxes under consideration.

DOE's duty cycle assumptions were derived from 2011 metering data that binned daily set-top box usage into on the three modes described above: on, multi-stream, and sleep. The Statewide CASE Team assumed duty cycles from the DOE analysis shown in Table 51 below (DOE 2013b). The DOE data does not contain information on DTA usage, so the Statewide CASE Team estimated the DTA duty cycle as equivalent to that of cable boxes without DVR, because DTA converters provide similar functionalities to basic cable set-top boxes.

Table 51: Daily duty cycle (hours/day by mode) for different types of set top boxes

Operational Mode	Cable without DVR [47]	Cable with DVR	Satellite without DVR	Satellite with DVR
On	12.4	12.9	12.7	11.5
Multi-stream	0	1.8	0	3.8
Sleep	11.6	9.3	11.3	8.7

Source: (DOE 2013b)

performance levels. Ultimately, whether the v4.1 or v3.0 specification will be more representative of set-top boxes in new homes built during the 2016 Title 24 code cycle depends on the average age of set-top boxes in new homes.

[45] The ENERGY STAR version 3.0 QPL did not contain power draw data for multi-stream mode; however DOE rulemaking data supports the Statewide CASE Team's assumption that multi-stream power draw for set-top boxes is approximately equivalent to on-mode power draw (DOE 2015b).

[46] Mult-stream mode is an operational mode applicable to set-top boxes with DVR capability in which the device "may provide independent video content to one or more clients, TVs, or DVR" (DOE 2015b).

[47] DTA duty cycle assumed to be equivalent to that of cable without DVR.

4.7.4.5 Determining Set-Top Box AEC by Type

For each home in RASS, the Statewide CASE Team calculated the AEC of every survey-reported set-top box by multiplying its estimated power by mode by its estimated duty cycle.[48] Table 52 presents the resulting AECs for the five types of set-top boxes considered.

Table 52: Estimated AEC of each type of set-top box analyzed

Device Type	AEC (kWh/yr)
Cable without DVR	91
Cable with DVR	167
Satellite without DVR	76
Satellite with DVR	153
DTA	44

4.7.4.6 Determining Per-Household AEC as a Function of NBr

For each home in RASS, the Statewide CASE Team summed the AEC of all survey-reported set-top boxes to calculate the per-household AEC of all set-top boxes combined. The Statewide CASE Team then performed a linear regression to capture the relationship between NBr and the AEC values calculated for each home in RASS.

4.7.5 Results

Figure 31 presents the recommended algorithm for estimating the per-househould AEC of set-top boxes based on NBr. The points in the graph represent the average, per-household AEC calculated for RASS homes with a given NBr.

[48] The daily duty cycles presented above were converted to annual hours in each mode by multiplying by 365.

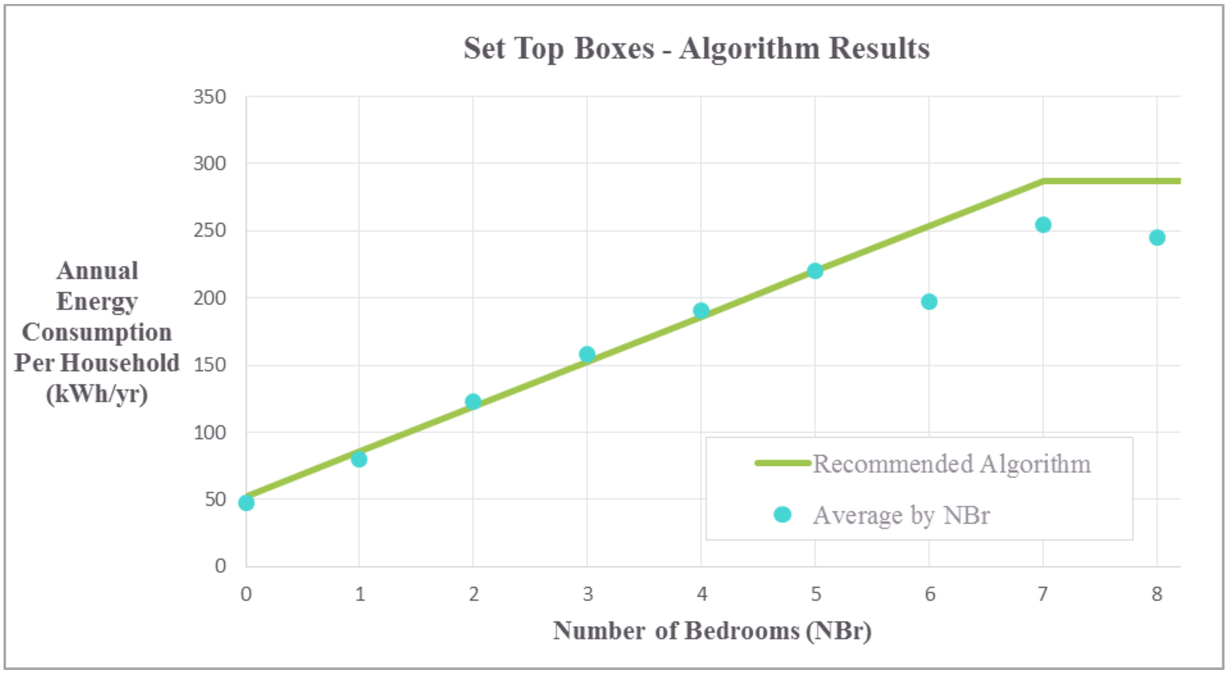

Figure 31: Per-Household Set-Top Box AEC as a Function of NBr

Table 53 presents the results of the set-top boxes algorithm by NBr.

Table 53: Per-Household AEC of Set-Top Boxes, Estimated Based on NBr

NBr	Annual Set-top Box Energy Consumption (kWh)
0	76
1	135
2	195
3	254
4	314
5	373
6	432
7+	492

Figure 32 compares the set-top boxes algorithm to various benchmarks, described in Section 4.7.4.5. The recommended algorithm is close to the metered value from the 2014 NEEA RBSA. It is somewhat higher than the AEC estimated by the 2014 SCE meta-analysis used to inform the residual MELs estimate (SCE 2014). The Building America Home Simulation Protocols and a 2013 meta-analysis of nationwide consumer electronics AEC (Urban et al. 2014) estimate substantially less AEC. Given these benchmarking results and the fact that the set-top box marketplace is increasingly complex and innovative, it would be helpful to collect data on the types of set-top boxes installed in modern, California homes and their typical energy use.

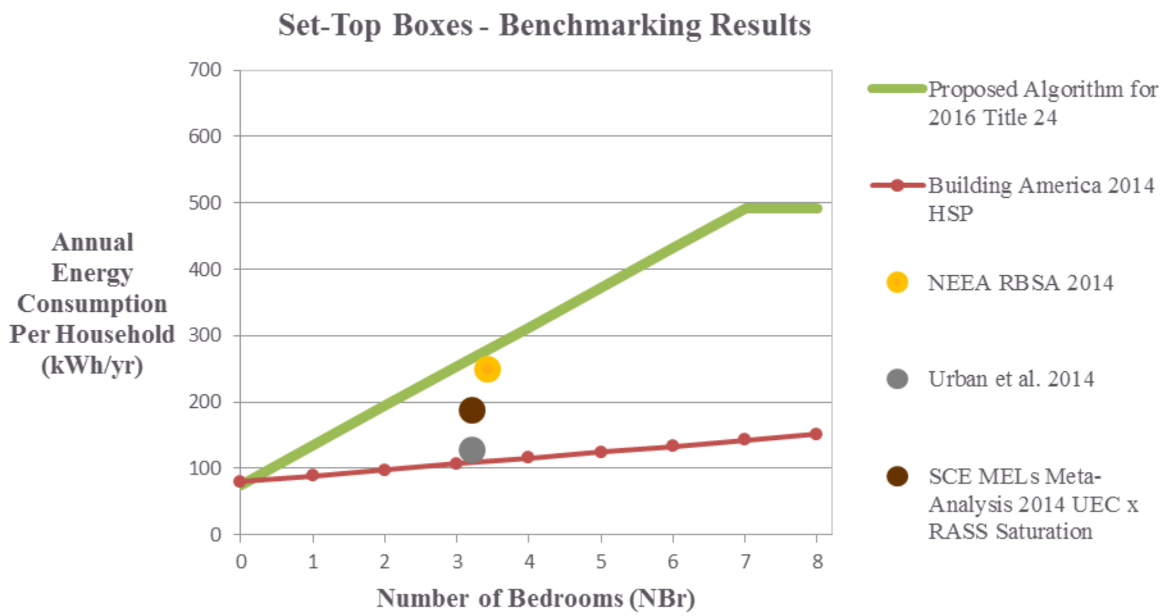

Figure 32: Comparison of set-top boxes AEC algorithm against various benchmarks

4.8 Computers and Monitors

4.8.1 Technology Introduction

In their research based on the 2013 CE Usage Survey, Urban et al. 2014 estimate that there is an installed base of 88 million computers (desktops and notebooks) that have been used nationwide "within the past month." Desktops include desktops with detached monitors and desktops with integrated monitors, also called all-in-ones. Notebooks (also called laptops or netbooks) are portable computers that are smaller and have attached monitors. The Statewide CASE Team also incorporated computer monitors into the AEC calculation methodology presented in this section. Urban et al. 2014 estimate the nationwide stock of monitors was 97 million in 2013.

The Statewide CASE Team's AEC estimate for computers and monitors does not include smaller mobile devices such as tablets with touch screen devices without keyboards and smaller storage capacity and fewer computer processing components. Devices such as external hard drives, keyboards, mouse devices, and printers, which are not part of a desktop or notebook, are excluded from the analysis. The AEC of these devices is included in the Statewide CASE Team's estimate of residual MELs AEC.

4.8.2 Existing Energy Efficiency Standards

At the time of writing there are no mandatory energy efficiency standards for computers or monitors applicable in California, however, CEC does have an open rulemaking and has proposed Title 20 standards for computers and monitors that are expected to be adopted in 2016, with an effective date as early as 2017.

In January 2014 and November 2014, the California IOUs submitted a supplemental technical report and CASE Report addendum for computers to the CEC's Title 20 docket to recommend standards for desktops and notebooks (CA IOUs 2014a; CLASP 2014), respectively. These Title 20 rulemaking documents provide data and assumptions regarding power draw values and duty cycles, all of which informed the analysis presented in this report.

Computers are currently covered products in the voluntary ENERGY STAR program. The Statewide CASE Team expects that computers in use in 2017 will, on average, meet ENERGY STAR version 6.0 specifications, as explained in Section 4.8.4.3. The ENERGY STAR version 6.0 specification for computers provides base energy allowances for each of several specification-derived categories of computers (ENERGY STAR 2014), plus functional adders, the applicability of which is also determined by a computer's specifications, resulting in a maximum Total Energy Consumption (TEC)[49].

Stand-alone monitors are also covered products in the voluntary ENERGY STAR program. The ENERGY STAR specification for monitors provides maximum active and standby mode power draw levels as a function of screen area and screen resolution. The Statewide CASE Team expects that monitors in use in 2017 will, on average, meet ENERGY STAR version 6.0 specifications, as explained in Section 4.8.4.5.

4.8.3 Key Variables Impacting Energy Use

A number of variables influence AEC of computers. The presence and type of hardware components such as processors, hard drives, and graphics cards can impact the energy consumption of both desktops and notebooks. Desktops use significantly more energy than notebooks, so estimating the number of desktops and notebooks per household is an important consideration for estimating total household AEC of computers. The duty cycle (average time spent in each operational mode) of computers is also an important factor, because there are substantial differences in power draw between the different modes. For example, spending more time in active mode as opposed to idle mode will increase overall energy consumption. The duty cycle of computers is a function of the type of computing tasks that users perform (e.g. running graphics-intensive simulations or using simple text-editing software), how often they use their devices, and which power management features are enabled. In addition, since desktops and notebooks have become significantly more energy efficient over the past decade, the estimated age of these products is an important factor in estimating computer AEC.

The factors that affect monitor AEC are similar to the key variables impacting television AEC. Monitor AEC is primarily a function of the number of monitors per household and the display type (e.g. LCD vs. CRT), screen size, and duty cycle of those monitors. Monitor duty cycle is turn affected by frequency of use, which automatic power management features are enabled, and whether or not the user turns off the device when not in use.

[49] TEC is a term primarily used to describe AEC for desktops and laptops and is used here to remain consistent with ENERGY STAR terminology.

The Statewide CASE Team accounted for the following factors in the computers and monitors AEC algorithm:

- How desktop and notebook saturation scales with home size;
- Trends over time in desktop and notebook saturation;
- Energy use per desktop and per notebook, applying a real-world adjustment factor to reflect field data on actual duty cycle and energy-usage patterns, as compared with the ENERGY STAR test procedure;
- Average number of monitors per desktop and notebook;
- Duty cycle of monitors; and
- Power draw by mode of monitors.

The Statewide CASE Team took the simplified approach of estimating a single set of average, per-device AEC values for desktops, notebooks, and monitors, respectively. These AEC values were assumed the constant, regardless of NBr;[50] only the number of devices per household was assumed to vary with NBr.

Similarly, the Statewide CASE Team did not model differences in AEC between primary and non-primary computers. That is, if a household reported owning two notebooks that are regularly used, one device was not assumed to use more energy than the other because it is primary notebook. In part, this was due to a lack of data, but more fundamentally because it is unclear if the concept of primacy applies to computers and monitors in the same way that it applies to devices like refrigerators.[51]

One additional aspect of computer use that was considered but not quantified was the prevalence of gaming computers, which use significantly more energy than the average desktop (Mills et al. 2014). Drawing on in-depth metering of five gaming computers of varying efficiency levels, the study estimates that the typical gaming computer consumes 1,400 kWh/yr (Mills et al. 2014). However, the authors also report that saturation of gaming computers is 2.5 percent. Given this very low saturation, the Statewide CASE Team did not add this approximately 35 kWh/yr per household of gaming computer AEC to the computers and monitors model[52]. This choice is exemplary of the larger question of whether the models should estimate typical AEC or the weighted average of all possibilities. Future updates should

[50] Further field studies would be needed to determine whether there is a relationship between NBr and computer and monitor AEC. It is not clear whether homes with more bedrooms would theoretically tend to have lower or higher energy use per device. On the one hand, homes with more bedrooms tend to have slightly more computers per person (according to the RASS microdata), which may result in less usage per device. On the other hand, more bedrooms are associated with more household income, which may correlate with higher performing computers and larger monitors. Additionally, households with more income may be more likely to have newer devices, which tend to be more energy efficient.

[51] For example, a household with two adults and two notebooks may not have a primary computer. Computer use seems to be most often an individual activity, as compared with television use, for example. This usage pattern may be changing with the growing popularity of streaming services such as Netflix.

[52] $1{,}400 \frac{kWh}{device} \times 0.025 \frac{devices}{household} = 35 \frac{kWh}{household}$

reexamine the treatment of gaming computers and precise intention of modeling "average" home energy use.

Table 54 and Table 55 list key variables used to develop the methodology for estimating annual computer and monitor use along with their function and data source used to obtain them.

Table 54: Key variables and their function within the computers energy consumption methodology

Variable	Function	Source
2008 saturation	Determine product category and applicable power draw characteristics	RASS 2009
Saturation adjustment factors	Account for trends over time in average number of desktops and notebooks per household	Urban et al. 2014; RECS 2009; IDC 2013, 2014, 2105
Average age	Determine most applicable ENERGY STAR specification for stock of desktops and notebooks in new homes	CEC Staff Report on Computers, Computer Monitors, and Electronic Displays
Market share meeting ENERGY STAR specification over time		CLASP 2014 comment letter on Title 20 rulemaking
TEC values	Estimate AEC of desktops and notebooks	ENERGY STAR QPL version 6.0
Real-world adjustment factors	Adjust TEC values from ENERGY STAR to reflect field data on actual usage patterns	CA Title 20 rulemaking documents

Table 55: Key variables and their function within the monitors energy consumption methodology

Variable	Function	Source
Average age	Determine most applicable ENERGY STAR specification for stock of desktops and notebooks in new homes	CEC Staff Report on Computers, Computer Monitors, and Electronic Displays
Market share meeting ENERGY STAR specification over time		ENERGY STAR 2013 Unit Shipment Data
Monitors per desktop and per notebook	Determine number of monitors per RASS household	Urban et al. 2014
Power draw values for monitors	Determine AEC per monitor	ENERGY STAR QPL version 6.0
Duty cycle (usage) for monitors		Urban et al. 2014

4.8.4 Methodology

4.8.4.1 Methodology Overview

For each home in RASS 2009, the Statewide CASE Team estimated the number of regularly used computers in a comparable home built during the 2016 Title 24 code cycle by multiplying the survey-reported number of regularly used computers by a saturation adjustment factor designed to account for the increase in desktop and notebook saturation since the 2009 RASS.

Next, the Statewide CASE Team estimated the typical AEC of a desktop and of a notebook in 2017. The Statewide CASE Team derived these from the average AEC of desktops and notebooks on the ENERGY STAR version 6.0 QPL. The use of the version 6.0 specification to represent the 2017 stock of computers was based on three factors: 1) the average age of desktops and notebooks, 2) market research and analysis conducted by CLASP 2013, 3) and accounting for market trends over time (see Section 4.8.4.3). Since AEC values on the ENERGY STAR QPL are calculated using an duty cycle assumption that is a blend of both residential and commercial duty cycles, the Statewide CASE Team used a real-world adjustment factor (previously developed as part of the Title 20 rulemaking process) to generate more realistic AEC estimates for desktops and notebooks.

For each home in RASS 2009, the Statewide CASE Team then calculated the per-household AEC of all computers by multiplying the saturation-adjusted number of desktops and notebooks by the estimated AEC per desktop and per notebook (with real-world adjustment factors).

The Statewide CASE Team next used the number of desktops and notebooks per home to estimate the number of monitors for each home in RASS 2009 by multiplying the saturation-adjusted number of desktops and notebooks by the average number of monitors per desktop and per notebook, as reported in the CE Usage Survey 2013.

As with computers, the Statewide CASE Team multiplied the number of monitors by an estimated “2017 AEC” per monitor to calculate the per-household AEC of all monitors. The Statewide CASE Team derived the 2017 AEC estimate by combining survey data on typical monitor duty cycles with power draw by mode values from the ENERGY STAR v.6.0 QPL. As with computers, the Statewide CASE Team determined that in 2017 the average monitor will meet today’s ENERGY STAR version 6.0 requirements. This assumption was based the average age of monitors and the penetration of the ENERGY STAR products over time (CLASP 2014).

Finally, the Statewide CASE Team summed the estimated per-household AEC of desktops, notebooks, and monitors for each home in RASS and performed a linear regression to capture the relationship between per-household AEC and NBr.

4.8.4.2 Estimating Desktop and Notebook Saturation

For each home in RASS 2009, the Statewide CASE Team estimated the number of regularly used computers in a comparable home built during the 2016 Title 24 code cycle by multiplying the survey-reported number of regularly used computers by a saturation adjustment factor (to account for increasing number of computers per household since the RASS survey).

Respondents to the RASS survey reported the number of desktops and notebooks regularly used in their homes. Based on the RASS data, the average number of regularly used computers in California households in 2008 was 0.84 desktops and 0.75 laptops. Table 56 presents further detail on the distribution of desktop and notebook saturation underlying these population averages.

Table 56: Distribution of desktop and notebook ownership in California households in 2008

Number of Devices	Desktops (%)	Notebooks (%)
0	33	46
1	53	37
2	11	13
3 or more	3	4
Total:	**100%**	**100%**

Source: (KEMA 2010b)

Furthermore, the RASS data shows that homes with more bedrooms tend to have more desktops and notebooks, at least through seven bedrooms. Table 57 quantifies this trend by presenting the average number of desktops and notebooks in California homes of increasing NBr.

Table 57: Average number of desktops and notebooks in California homes of varying NBr

NBr	Average Number of Regularly Used Devices Per Household	
	Desktops	Notebooks
0	0.38	0.46
1	0.46	0.48
2	0.66	0.52
3	0.92	0.69
4	1.11	0.89
5	1.32	1.15
6	1.44	1.23
7	1.85	1.37
8	1.43	1.00

Source: (KEMA 2010b)

The Statewide CASE Team calculated saturation adjustment factors for desktops and notebooks to account for changes in saturation between the RASS survey and the 2016 Title 24 code cycle. These saturation adjustment factors were derived in two parts: 1) an adjustment from RASS to 2013, and 2) an adjustment from 2013 to the 2016 Title 24 code cycle. The use of a two-part conversion was motivated by available data, as was the choice of 2013 as the bridge year.

To convert from RASS to 2013, the Statewide CASE Team relied on saturation data from the 2013 CE Usage Survey. Because the CE Usage Survey was a national survey, the Statewide CASE Team had to multiply by the ratio of California computer ownership to national computer ownership (1.09:1) to correct for the underestimate in computer saturation that would otherwise occur from using national data. To convert from 2013 to 2017, the Statewide CASE Team used historical shipment data and forecasted shipment from the market research firm International Data Corporation (IDC), which was also used in the Title 20 CASE Reports and addendums (IDC 2016). Table 58 presents the net effect of the two-part saturation adjustment described above: an increase of 17 percent for desktops per household and an increase of 66 percent for notebooks per household.

Table 58: Result of saturation-adjustment factor for desktops and notebooks

Number of Devices	Desktops	Notebooks
RASS 2009	0.84	0.75
2016 Title 24 code cycle	0.98	1.24

See Appendix E: Desktop and Notebook Saturation-Adjustment Factors for a more detailed derivation of the desktop and notebook saturation-adjustment factors.

4.8.4.3 Estimating Desktop and Notebook AEC

The Statewide CASE Team assumed the design life of desktops to be five years and the design life of notebooks to be four years based on a 2015 CEC Staff Report on computers, computer monitors, and electronic displays (CEC 2015b) The Statewide CASE Team calculated the average age of desktops and notebooks as half the design life, assuming an even distribution of devices from brand new to the end of the design life. Given an average age of 2.5 years for desktops and 2 years for notebooks, the Statewide CASE Team assumed that desktops and notebooks in new homes built in 2017 would be manufactured in 2014 and 2015.

Data and analysis that the Collaborative Labeling and Appliance Standards Program (CLASP) submitted for the Title 20 computers rulemaking indicates that roughly half of the computers available on the market in China in 2013 met the ENERGY STAR version 6.0 specification levels (CLASP 2014). Given the global nature of computer markets, it is reasonable to assume that this saturation of efficient products is somewhat similar in the United States. Even if the U.S. market were to lag behind the Chinese market, the estimated average manufacture year of desktop and notebooks in 2017 homes is 2014 and 2015, respectively, which affords more time for efficiency improvements. Therefore, the Statewide CASE Team used the ENERGY STAR version 6.0 QPL to calculate the model-weighted TEC base allowances (and functional adder average) for desktops and notebooks, as presented in Table 59.[53] The Statewide CASE Team considered two distinct classes of desktops with different average AECs: integrated desktops (i.e. desktops that include a built-in monitor, also known as "all-in-one" desktops) and conventional desktops (with separate monitors).

[53] The values in Table 59 are derived using a model-weighted average of all categories of desktops and notebooks in the QPL. TEC values include energy consumed by added accessories beyond the basic configuration. For example, most computers that qualify for ENERGY STAR version 6.0 use significantly more energy than the base allowance because they contain additional hardware, such as additional storage, memory, discrete graphics cards, etc.

Table 59: ENERGY STAR version 6.0 QPL TEC values for desktops and notebooks (annual energy consumption)

Computer Type	TEC (kWh/year)
Integrated desktop	181
Desktop	155
Notebook	45

Since ENERGY STAR TEC values are calculated using a duty cycle assumption that is a blend of both residential and commercial duty cycles, and the test procedure underestimates energy use, the Statewide CASE Team used a real-world adjustment factor to more accurately reflect both the duty cycle and energy use typical of residential applications (CA IOUs 2014a). The IOUs noted during the Title 20 regulatory proceedings on computers that the ENERGY STAR version 6.0 test procedure does not accurately represent real-world usage for desktops and notebooks—in part because the ENERGY STAR TEC metric utilizes idle mode power as a proxy for active mode power (CA IOUs 2014a). Though recent technology trends have increased the capability of desktops and notebooks to effectively scale down active mode power draw during periods of inactivity, assuming idle mode power as a proxy for active mode power will likely result in an inaccurate underestimate of real-world TEC.

Real-world adjustment factors were derived using data from laboratory testing that characterized the power draw of real-world active and idle modes, combined with a residential-only duty cycle based on several duty cycle studies with large sample sizes (e.g. 37,000 users in Microsoft 2008). The difference between the adjusted usage and the ENERGY STAR reported TEC was used to develop real-world adjustment factors; these factors were then used to calculate more accurate TEC estimates for both product classes, resulting in the adjustments to the TEC values presented in Table 60.

Table 60: ENERGY STAR version 6.0 TEC values and real-world adjustment factor adjustments for desktops and notebooks

Computer Type	Original TEC (kWh/year)	Adjusted TEC (kWh/year)	Real-world adjustment factor
Integrated desktops	181	187	+3.3%
Desktops	155	151	-2.3%
Notebooks	45	39	-13.3%

The resulting real-world adjustment factors in Table 60 had mixed results on the TEC values from the ENERGY STAR version 6.0 QPL cited in Table 60. Even though the higher energy usage of active mode is properly accounted for, the duty cycle was adjusted to exclude commercial duty cycle assumptions, ultimately decreasing the total time spent in active and idle modes. Within these adjustment factors, the power draw values from ENERGY STAR were also modified to account for operating background software and peripheral devices that are more representative of real-world computer usage. To estimate AEC per desktop or notebook, the Statewide CASE Team relied on the adjusted TEC values in Table 60, because these TEC values better represent real-world residential desktop and notebook usage.

The Statewide CASE Team used the ratio of integrated desktops to conventional desktops reported by the 2013 CE Usage Survey conducted to calculate the weighted average AEC per desktop of all desktops. According to the survey, 30 percent of desktops were integrated desktops and 70 percent were conventional in 2013 (Urban et al. 2014). The resulting weighted average AEC value for desktops is 162 kWh/yr.

In comparison with other estimates, several additional sources were considered in the analysis, with two in particular—the 2016 CEC Staff Report and Greenblatt 2014 study—providing reasonable boundaries for final results on the low and high end (see Table 61 for comparison). The CEC Staff Report AEC estimates are based on the ENERGY STAR QPL but without the real world adjustment factor, which explains why they are lower than the Statewide CASE Team's results. The Greenblatt 2014 study was a metered study, and while it was California-specific, it had a limited sample size. When considering this other studies, it should also be noted that there have noticeable trends of computer efficiency improvements over time. For example, CLASP estimates that the difference between the ENERGY STAR version 5.0 finalized in 2008 and version 6.0 specification finalized in 2013 is 30 percent, a 6 percent improvement per year.

Table 61: Two additional sources of TEC values

Source	Methodology	Sample Size	AEC Per Device (kWh/yr)	
			Desktop	Notebook
CEC Staff Report 2016	ENERGY STAR QPL (lab metered & ENERGY STAR duty cycle, both residential & commercial)	Unknown	143	33
Greenblatt 2014	Metered	39	198	59

4.8.4.4 Estimating Monitor Saturation

RASS 2009 did not include a question about the number of monitors per household. As such, the Statewide CASE Team had to estimate the number of monitors for each home in RASS by multiplying the saturation-adjusted number of desktops or notebooks by the average number of monitors per desktop or notebook. The Statewide CASE Team arrived at the assumption of 0.9 monitors per desktop and 0.2 monitors per notebook based on data from the 2013 CE Usage Survey (Urban et al. 2014).

4.8.4.5 Estimating Monitor AEC

The Statewide CASE Team determined the average age of monitors to be 2.5 years, calculated as half the design life that is reported for monitors in the 2015 CEC Staff Report on computers, computer monitors, and electronic displays (CEC 2015b). Given this estimate, the Statewide CASE Team assumed that monitors in new homes built in 2017 would, on average, be manufactured in 2014.

The Statewide CASE Team used recent data indicating the level of ENERGY STAR product penetration in the market to estimate the AEC of monitors sold in 2014. This ENERGY STAR data indicated that 55 percent of displays in use in 2013 met the ENERGY STAR version 6.0 specification for displays (ENERGY STAR 2012c). Additionally, a 2013 report from LBNL identifying opportunities for improving energy efficiency of personal computers showed that in 2013, the majority of the display market (77 percent) met ENERGY STAR version 6.0 (Park et al. 2013). As a result, the Statewide CASE Team believed it was conservative to assume that in

2017 monitors will meets the version 6.0 specification, thus used the ENERGY STAR version 6.0 QPL to derive power draw values for the different operational modes.

Similarly to televisions, monitor energy use is highly dependent on monitor size. Data from the 2013 CE Usage Survey indicates that the current stock of monitors is between 15 and 34 inches (Urban et al. 2014). The Statewide CASE Team therefore determined average power draw values for active, sleep, and off mode for the range of monitor sizes between 15 and 34 inches on the ENERGY STAR version 6.0 QPL.[54] Table 62 presents the power draw values that informed the Statewide CASE Team's estimate of monitor AEC.

Table 62: ENERGY STAR version 6.0 QPL power draw values for displays between 15 and 34 inches

Operation mode	Power draw (W)
Active	19.5
Sleep	0.31
Off	0.21

To calculate AEC per monitor from these power draw values, the Statewide CASE Team used data from Urban et al. 2014 on the duty cycle of computer monitors, shown in Table 63 below.

Table 63: Duty cycle values for monitors

Operation mode	Usage (hours per year)
Active	1,533
Sleep	4,533
Off	2,774

Source: (Urban et al. 2014)

The Statewide CASE Team calculated the AEC of monitors as follows:

$$AECperMonitor = (P_{Active} \times t_{Active}) + (P_{Sleep} \times t_{Sleep}) + (P_{Off} \times t_{Off})$$

P represents power draw for a given mode and *t* represents annual hours in that mode. The resulting AEC for monitors is 32 kWh/yr.

4.8.4.6 Determining Per-Household AEC as a Function of NBr

The Statewide CASE Team calculated the AEC of all desktops, notebooks, and monitors for each home in RASS by multiplying the estimated number of devices by the estimated AEC per device. The Statewide CASE Team performed a linear regression to capture the relationship between this calculated per-household AEC of all computers and monitors combined and the survey-reported NBr.

[54] The average screen size of the nearly 1,200 monitors on the ENERGY STAR v6.0 QPL is 23 inches.

4.8.5 Results

Figure 33 presents the recommended algorithm for estimating the per-househould AEC of computers and monitors based on NBr. The points in the graph represent the average, per-household AEC calculated for RASS homes with a given NBr.

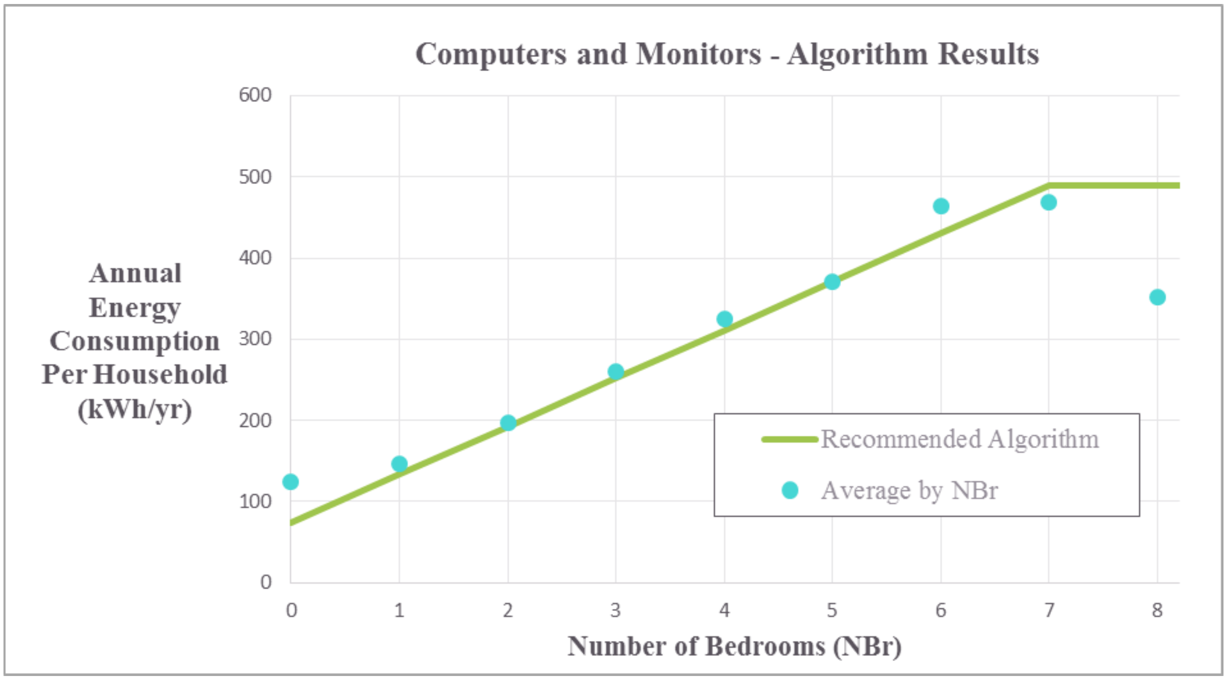

Figure 33: Per-household computer and monitor AEC as a function of NBr

Table 64 presents the results of the algorithm by NBr.

Table 64: Per-household computer and monitor AEC, estimated based on NBr

NBr	Annual Computers and Monitors Energy Consumption (kWh)
0	79
1	134
2	190
3	245
4	301
5	356
6	411
7+	467

Figure 34 compares the computers and monitors algorithm to various benchmarks, described in Section 3.5.2. The recommended algorithm is in line with the Building America House Simulation Protocols, both in terms of magnitude and slope. The magnitude of the recommended algorithms is also in line with what the Statewide CASE Team calculated by multiplying the average RASS saturations by the AEC per device from the Energy Consumption of Consumer Electronics in U.S. Homes in 2013 Meta-Analysis (Urban et al. 2014). NEEA’s 2014 RBSA yielded a somewhat higher average AEC estimate. The 2009

RASS CDA appears to represent a far less efficient vintage of computers; the underlying saturation assumptions are the same, so the much greater AEC estimates are due to AEC per device.

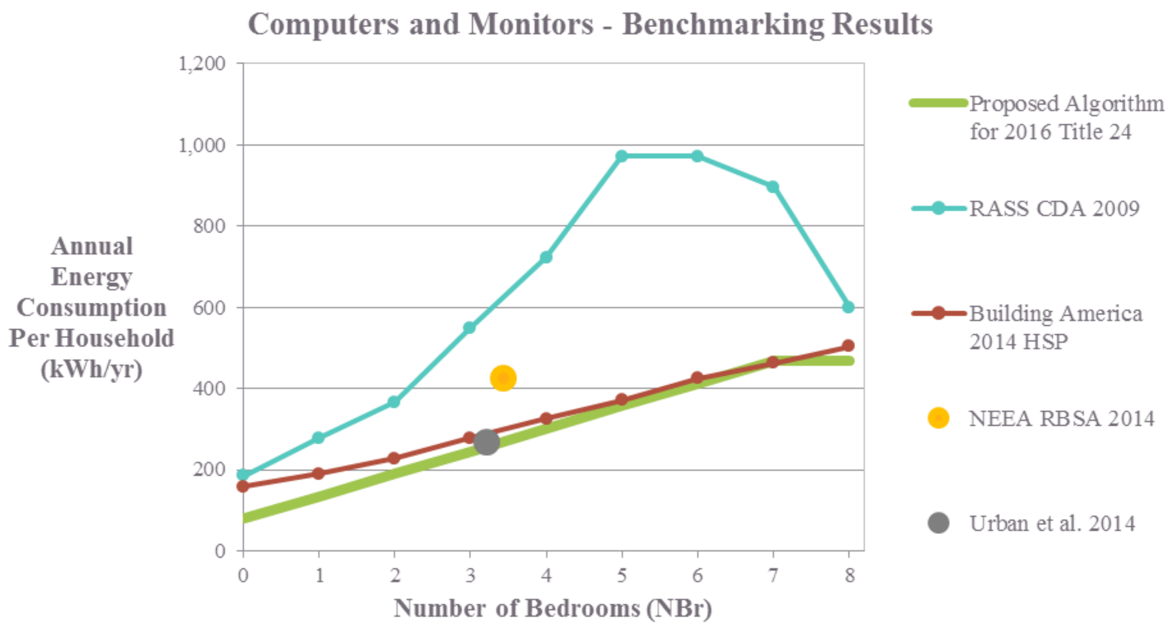

Figure 34: Comparison of computers and monitors AEC algorithm against various benchmarks

4.9 Residual Miscellaneous Electric Loads (Other)

4.9.1 Technology Introduction

Residual MELs are all of the remaining MEL end-uses for which unique energy use models had not been developed and proposed in this CASE Report. This product class contains a large variety of products, such as microwaves, DVD players, tablets, smartphones, plug-in furniture, electric toilets, and many other end uses.

The extreme diversity of products presents a challenge for building a targeted model for estimating the AEC of these other MELs. For example, some end uses may be increasing in efficiency as technologies evolve, while others may be adding new features and growing in power demand. Furthermore, new end uses may enter the market while others become less common. Moreover, since energy use studies vary in scope and specificity, the type of end-uses considered in the "other" or "miscellaneous" sections of their accompanying reports (if presented) are often not well-defined. The lack of a uniform definition for this product class creates a challenge for comparing study results and for deriving meaningful trends.

4.9.2 Existing Energy Efficiency Standards

Energy efficiency standards exist for some products considered to be residual MELs, but no standards exist for the aggregate sum of end uses. The following federal efficiency standards account for one or more of the products considered in this section:

- **Battery chargers** are federally covered products that currently do not have efficiency standards. However, DOE is currently undergoing a rulemaking process aimed to establish standards for these products. A Supplementary Notice of Proposed Rulemaking (SNOPR) for battery chargers was issued on September 1, 2015.
- **External power supplies** have had energy conservation standards since 2007. The minimum efficiency of an external power supply depends on whether it operates directly, or indirectly, and whether it is Class A, as codified by 42 U.S.C. §6291, or not. Only indirect, non-Class A type external power supplies currently have no standards.
- **Microwaves** manufactured on or after June 17, 2016 cannot have an average standby power of more than 1 watt, while built-in and over-the-range convection microwave ovens manufactured on or after June 17, 2016 cannot have an average standby power of more than 2.2 watts.
- **Dehumidifiers** manufactured on or after October 1, 2007 must meet a minimum energy factor (liters/kWh) depend on the product capacity (pints/day)
- **Miscellaneous refrigeration** products currently do not have federal efficiency products. However, DOE is currently undergoing a rulemaking process aimed to establish standards for these products. A Supplemental Notice of Proposed Determination (SNOPD) for miscellaneous refrigeration products was issued on April 4, 2016.

In addition to these federal efficiency standards, the following products are covered by California Title 20 standards:

- DVD/Blu-Ray Players;
- Compact audio (including radios); and
- Wine coolers (miscellaneous refrigeration products).

4.9.3 Key Variables Impacting Energy Use

The factors that impact the energy use of residual MELs are broad and diverse, and so the Statewide CASE Team was unable to consider the characteristics of each individual product classified as a residual MEL. Instead, the Statewide CASE Team considered the following factors that affect the accuracy of the residual MELs AEC algorithm:

- Completeness of the list of significant residual MELs;
- Annual growth rate of residual MELs; and
- Scaling with home size.

Although the Statewide CASE Team was not able to account for more device-specific variables with available data, future updates to the model may be able to do so. See Section

8.1.2 for a discussion of how data from a California-specific RBSA and submetering study could be used to better characterize the AEC of residual MELs.

4.9.4 Methodology

4.9.4.1 Methodology Overview

The Statewide CASE Team first compiled a comprehensive list of electric loads that were not considered in any of the previous sections (and are not otherwise accounted for in the compliance software). By cross-referencing five data sources—each of which had synthesizes a list of MELs and their respective AEC—the Statewide CASE Team estimated the total, nationwide energy consumption of these products in the reference year (2013).

The Statewide CASE Team then projected this value to 2017, using the average annual growth determined in CEC Energy Demand Forecast for the "miscellaneous" residential energy use (CEC 2014).

In order to estimate residual MELs AEC based on NBr, the Statewide CASE Team assumed that the AEC scaling of residual MELs is commensurate with that of the major consumer electronics (televisions, set-top boxes, computers, and monitors). The Statewide CASE Team calculated the average ratio of residual MELs AEC to major consumer electronics AEC, using the previously derived estimate of nationwide residual MELs AEC in 2017 and the algorithms for the major consumer electronics (see Sections 4.6, 4.7, and 4.8). Finally, the Statewide CASE Team multiplied this ratio by the combined AEC of major consumer electronics as a function of NBr in order to predict residual MELs AEC as a function of NBr.

4.9.4.2 Estimating National Energy Consumption of Residual MELs

The Statewide CASE Team first compiled a comprehensive list of end-uses that contribute to the home AEC of residual MELs. The following studies were considered:

- **Southern California Edison (SCE) 2014 meta-analysis on residential MELs and consumer electronics:** this study, led by the California utility Southern California Edison (SCE), synthesized the extant estimates of the AEC per device and per-household AEC of the miscellaneous product categories with the highest per-household AEC. The study provides the estimated national energy consumption of over 50 different end uses (SCE 2014).
- **DOE 2012 TSD for Battery Chargers and External Power Supplies:** DOE created a 30-year forecast of the estimated unit energy consumptions and national shipments of battery chargers and/or external power supplies for 52 different end uses (DOE 2012f).
- **Building America 2014 House Simulation Protocols (HSP):** As discussed in Section : the HSP estimates the average home AEC by considering whether a variety of end uses is present in the home. Embedded in the calculations are the per-household energy consumptions for almost a hundred different end uses (Wilson et al. 2014).
- **EIA Annual Energy Outlook 2015 Disaggregated Data:** The Annual Energy Outlook determines and projects the national energy consumption of several product categories. The Statewide CASE Team obtained further disaggregated data from the EIA, showing

the 2014 national energy consumption of the 30 different end uses considered in the report (EIA 2015).

- **NRDC 2015 Idle Loads Report:** The report identifies the idle power consumption of 10 audited homes and found there to be an average of 65 devices per home. The report considers over a hundred different end-uses, but does not provide AEC estimates (NRDC 2015a).

Although the strength of these data sources is their exhaustiveness (e.g. electric knives and guitar effects pedals are included), a key limitation is that the AEC estimates are not California-specific. As a result, their AEC estimates do not account for differences between California and the nation as a whole in consumer preferences and behavior or product efficiency that may affect residual MELs AEC. Given the high uncertainty surrounding residual MELs AEC, Statewide CASE Team was unable to develop a reliable adjustment factor to account for these variables, and thus based residual MELs AEC on the national estimates derived from the aforementioned studies.[55] Ideally, the next update to the residual MELs model could rely on data from a California-specific RBSA and submetering study (see 8.1.2).

To avoid double counting the AEC of the constituent MELs product categories, the Statewide CASE Team cross-referenced the above data sources and only included the AEC of a product category one time. The Statewide CASE Team built up a list of unique MELs product categories from the above data sources, as follows:

- **Southern California Edison (SCE) 2014 meta-analysis on residential MELs and consumer electronics:** 46 of the reported end uses are within the scope of this report, totaling 128.3 TWh/yr in national energy consumption.
- **DOE 2012 TSD for Battery Chargers and External Power Supplies:** 52 additional end uses, totaling 7.3 TWh/yr in national energy consumption.
- **Building America 2014 House Simulation Protocols (HSP):** 16 additional end uses, totaling 12.2 TWh/yr in national energy consumption.
- **EIA Annual Energy Outlook 2015 Disaggregated Data:** no additional end-uses (not already estimated by the above data sources).
- **NRDC 2015 Idle Loads Report:** 7 of the reported end uses had not yet been considered (pencil sharpeners, paper shredders, bidets, plug-in furniture, wine openers, thermometers, and exercise equipment); however, the Statewide CASE Team opted to exclude these end uses due a lack of data on their saturation and AEC per device, and because their AEC would likely be small.

From these sources, the compiled list of residual MELs accounts for 114 different end uses, totaling 147.8 TWh/y in national energy consumption. The full list is reported in Appendix C:

[55] Moreover, it is unclear as to whether a regional adjustment factor would yield a net increase or decrease in residual MELs AEC, given the diversity of MELs and the countervailing factors at play (e.g. increased saturation of certain consumer electronics but greater efficiency due to incentive programs and standards).

List of Residual MELs of this report. The Statewide CASE Team assumed 147.8 TWh/y to be representative of total residual MEL energy use in 2013—the year that most closely corresponds to the bulk of the data used to inform the SCE meta-analysis, which was the Statewide CASE Team's most prominent data source.

Given the recent growth of residual MELs AEC, the Statewide CASE Team considered it necessary to account for estimated the increase in AEC from 2013 to 2017, in order to more accurate estimate energy use during the 2016 Title 24 code cycle. The Statewide CASE Team used an annual growth rate of 4.3 percent, derived from the 2014 through 2024 CEC Energy Demand Forecast for the "miscellaneous" residential energy use (CEC 2014). Applying this growth rate to the 2013 national AEC estimate, the Statewide CASE Team calculated 2017 national AEC of residual MELs to be 167.7 TWh/yr.[56]

4.9.4.3 Determining Per-Household AEC as a Function of NBr

The Statewide CASE team was unable to determine an empirical method for scaling the AEC of residual MELs with home size.[57] However, the reasons for why the AECs of the three major consumer electronics—televisions, set-top boxes, computers and monitors—scale with home size, as discussed in Section 3.4, are reasonably similar to that of the residual MELs. The Statewide CASE Team thus assumed that the AEC scaling equations of these three products are commensurate of that of residual MELS. The AEC vs. NBr equation for residual MELS can thus be expressed as follows.

$$AEC_{RMEL} = (AEC_{TV} + AEC_{PCM} + AEC_{STB})(RMR)$$

AEC_X = the annual energy consumption of *X*, where *RMEL* = residual MELs, *TV* = televisions, *PCM* = computers and Monitors, and *STB* = set-top boxes;

RMR = the residual MELs ratio, which is the ratio of the projected national AEC of residual MELs in 2017 to the combined 2017 national AECs of televisions, computer and monitors, and set-top boxes.

To determine the above ratio (RMR), the Statewide CASE Team first used the algorithms presented in Sections 4.6, 4.7, and 4.8 to calculate average per-household AECs of televisions, set-top boxes, and computers and monitors for all homes in RECS 2009.[58] Next, the Statewide CASE Team calculated the total national energy consumption for each device by multiplying

[56] The 4.3% growth rate is compounded annually, for three years.

[57] There are no existing studies that have empirically evaluated how residual MEL energy use scales with building size, nor are there adequate data sources available to derive the relationship with reasonable accuracy. For example, the RESNET 2013 equations assume a constant energy per square foot based on the average residual MELs AEC and average floor area (RESNET 2013). The 2014 Building America House Simulation Protocols also take a theoretical approach, generally assuming that half of residual MELs AEC is fixed for all home sizes, a quarter scales based on kWh/bedroom, and a quarter scales based on kWh/square foot (Wilson et al. 2014). The RASS 2009 Conditional Demand Analysis uses a statistically-adjusted engineering approach to estimate miscellaneous electricity use for homes of varying NBr (based on whole-home metered data and survey responses), but the analysts were not able to separate residual MELs from lighting (KEMA 2010b)

[58] RECS 2009 was used instead of RASS 2009 in order to ensure that both the residual MELs and consumer electronics AEC estimates were national for the sake of calculating their relative proportions.

average per-household AEC by the 116 million occupied homes in the U.S. (U.S. Census 2015). The results of these calculations are presented in Table 65 and depicted in Figure 35.

Table 65: 2017 projected average household and national AEC of major consumer electronics

Appliance	Average household AEC (kWh)	National AEC (TWh)
Television	538	62.4
Set-top box	213	24.7
Computer	151	17.5

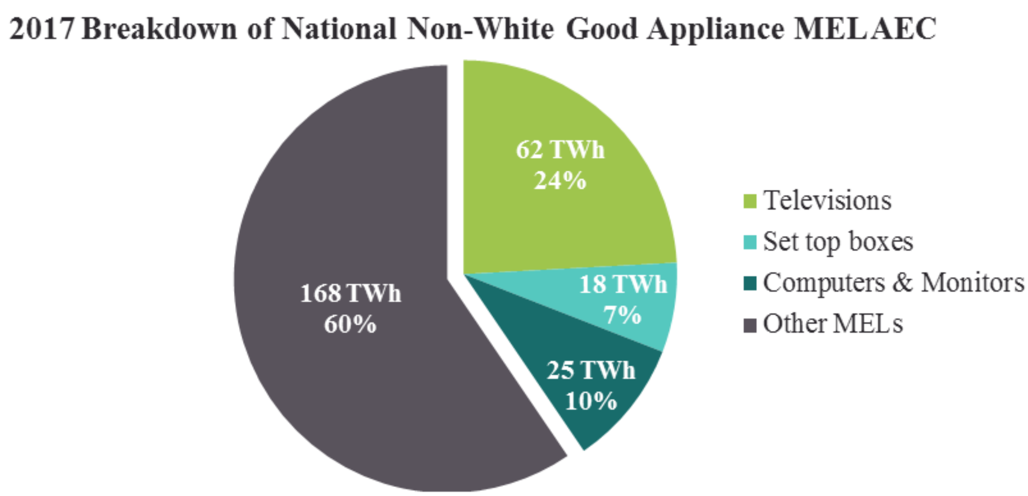

Figure 35: Breakdown of national AEC of all non-white good appliance MELs in 2017

From these values, the Statewide CASE Team determined the RMR to equal 1.6. The Statewide CASE Team therefore assumes that other MELs will on average consume roughly 160 percent of the energy use cumulatively consumed by televisions, set-top boxes, and computers and monitors, for all home sizes. Figure 36 illustrates the derivation of the Statewide CASE Team's residual MELs AEC estimate as a function of NBr, showing the application of the RMR (1.6) to the Statewide CASE Team's algorithms for the major consumer electronics modeled in Sections 4.6, 4.7, and 4.8.

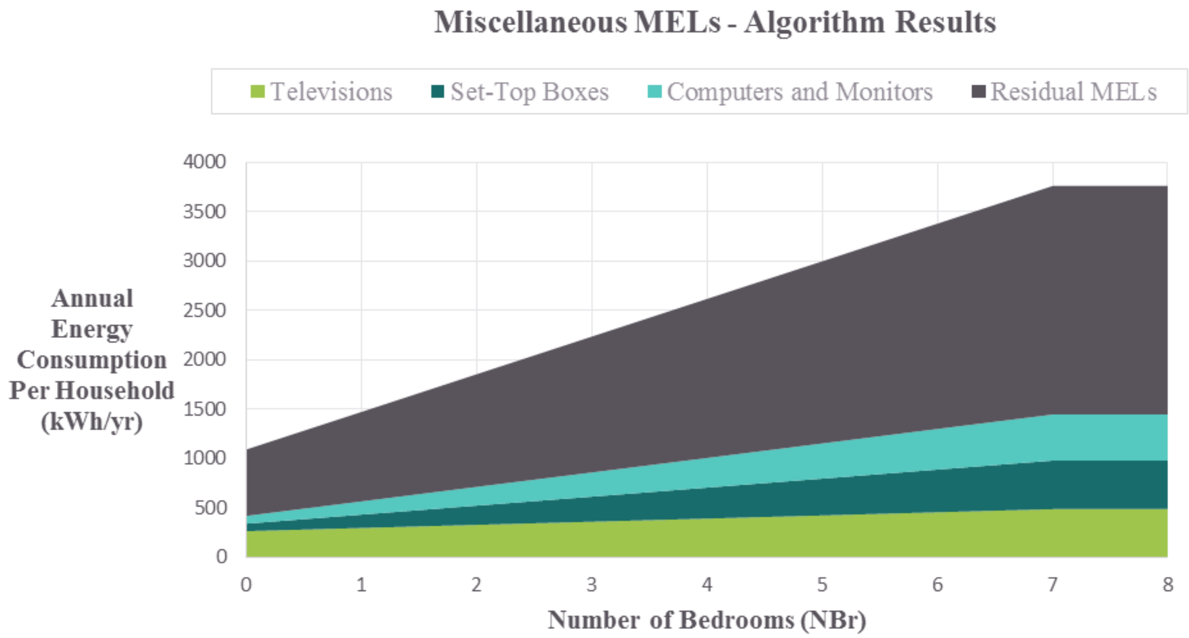

Figure 36: Residual MELs AEC as a function of NBr, calculated relative to the combined AEC estimate of major consumer electronics using a fixed ratio (1.6)

4.9.5 Results

Figure 37 and Table 66 present the recommended algorithm for estimating the per-househould AEC of residual MELs based on NBr.

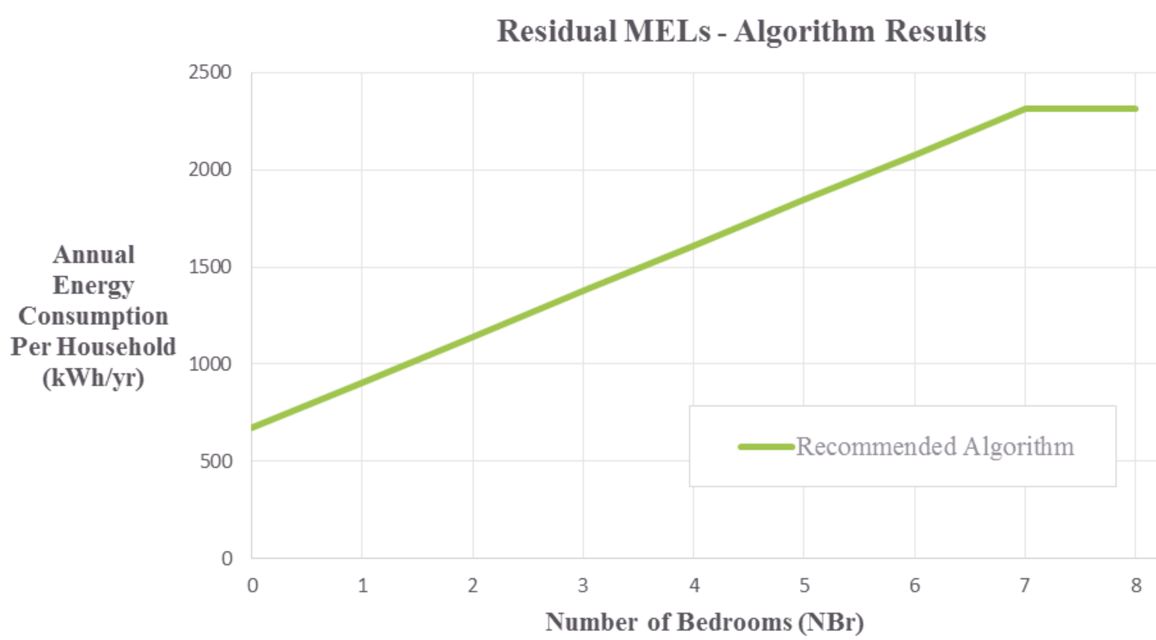

Figure 37: Per-household residual MELs AEC as a function of NBr

Table 66: Residual MELs AEC as a function of NBr

NBr	Annual Residual MELs Energy Consumption (kWh)
0	672
1	907
2	1141
3	1376
4	1610
5	1845
6	2079
7+	2314

Figure 38 compares the combined AEC of residual MELs, televisions, set-top boxes, computers, and monitors (non-white good plug load AEC) as estimated by the recommended algorithms, against various benchmarks, described in Section 3.5.2. These product categories were considered in aggregate because otherwise the comparison is not meaningful, due to differences in which end uses are included in the miscellaneous category. Overall, the slope of the recommended algorithms is similar to the referenced benchmarks described in Section 3.5.2. The recommended algorithms estimate more non-white good plug load AEC than the current (2013) algorithms, which were strongly informed by the 2009 RASS CDA. This is likely due to the growth in residual MELs AEC from 2008 to 2017. The RASS CDA results are shown as a dashed line to represent that the RASS analysts were unable to statistically disaggregate residual MELs from interior lighting.[59]

The Statewide CASE Team has also included comparisons to two data sources that represent energy use in low-income, multi-family, California homes. The California Utility Allowance Calculator tool (CUAC) has a similar estimate for non-white good plug load AEC as the 2013 Title 24 algorithms for small homes, but increases more slowly with home size. Recent submetering data pertaining to low-income, California families suggests that CUAC may overestimate non-white good plug load AEC for this demographic: a 2016 study conducted by Redwood Energy (not yet published) shows a general pattern of less non-white goods plug loads AEC than is estimated by the CUAC tool.[60] Furthermore, the Redwood Energy submetering shows substantially less AEC for non-white good plug loads than is estimated in the proposed rulesets. This supports the Statewide CASE Team's recommendation that future updates to the model account for the differences between single-family and multi-family homes, and potentially develop separate rulesets for affordable housing (see Section 8.1.1).

[59] The Statewide CASE Team assumed that 60% of the RASS "miscellaneous" AEC was due to lighting and 40% was residual MELs, based on the engineering estimates reported by the RASS analysts to disaggregate the CDA estimate for this category (KEMA 2010b). The RASS 2009 CDA values in Figure 38 also include the AEC of microwaves and office equipment, which are part of the scope of residual MELs in this report.

[60] This study involved one year of circuit-level metering of 161 newly constructed CTCAC-funded apartments for low-income (30-60% Area Median Income) residents in Woodland, King City and Oxnard.

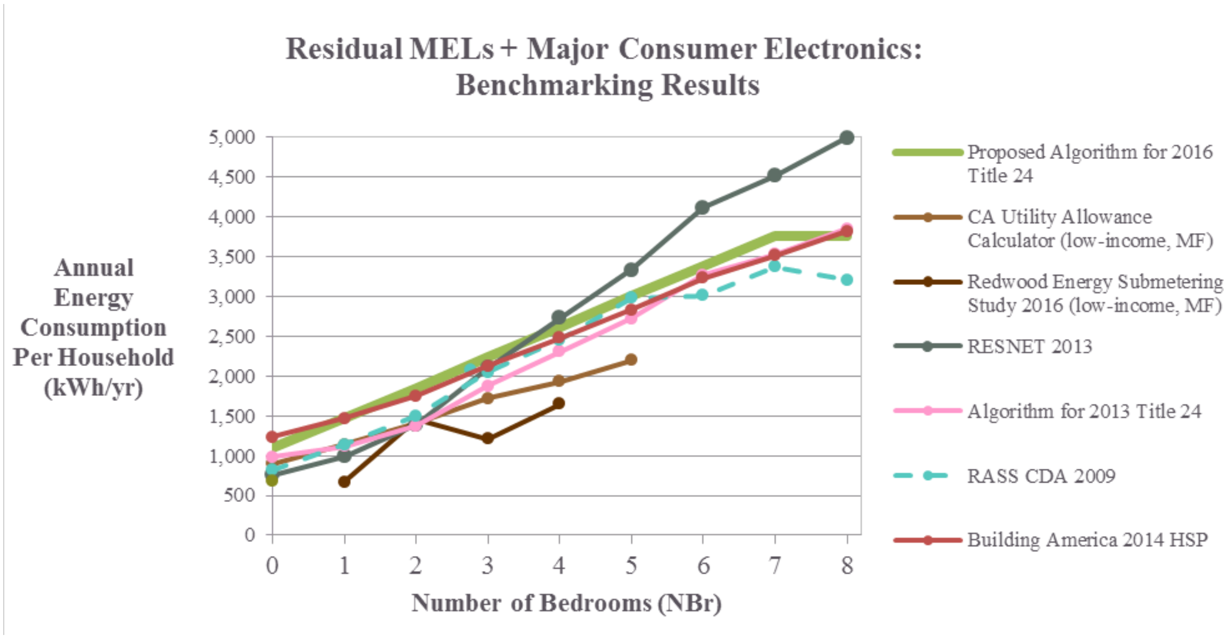

Figure 38: Comparison of the combined AEC of residual MELs, televisions, set-top boxes, computers, monitors against various benchmarks

4.10 Interior, Exterior, and Garage Lighting

4.10.1 Technology Introduction

Lighting constitutes a significant fraction of residential electricity use. The EIA estimates total lighting electricity consumption to be about 186 billion kWh, or 14 percent of all residential electricity consumption (EIA 2015).

For this product category, the Statewide CASE Team modeled lighting energy use by interior, exterior, and garage-based light sources, including both hard-wired and portable fixtures. In 2012, the majority of lamps in California homes have been incandescent, with the remainder being almost entirely fluorescent (both compact fluorescent lamps (CFLs) and linear fluorescent lamps), and only approximately 1 percent being LED.[61] Figure 39 presents the average breakdown of light source technology type for lamps in California homes, as determined by the 2012 California Lighting and Appliance Saturation Survey (DNV GL 2012).

[61] The Statewide CASE Team used the definitions found in 10 C.F.R. 430.2 for the meaning of “lamps”, the common name for which is “bulbs”.

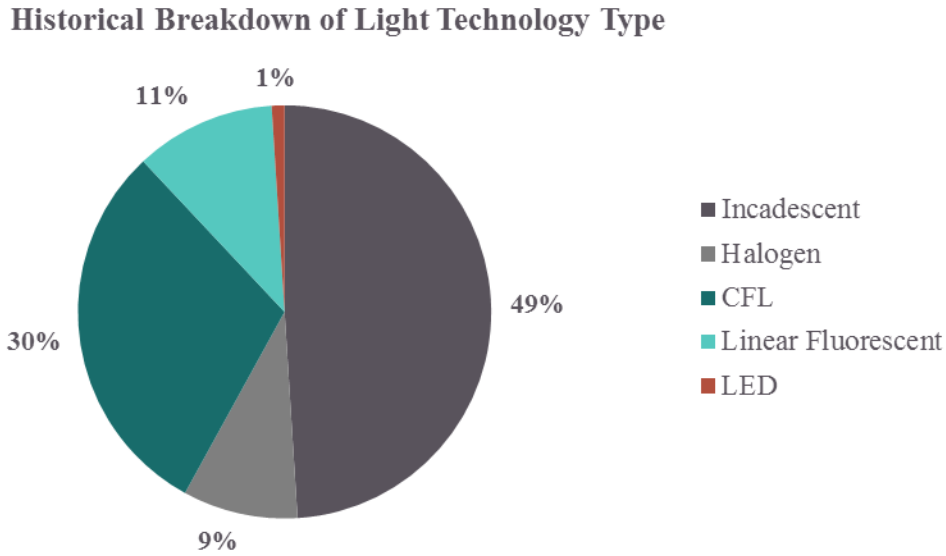

Figure 39: 2012 breakdown of light source technology type for lamps in California homes

Source: (DNV GL 2012)

However, recent advances in efficient lighting technologies, especially LEDs, are beginning to significantly impact lighting energy use throughout the country. LEDs can provide equivalent lighting utility as traditional incandescent light sources at a small fraction of the energy cost. The Statewide CASE Team has attempted to account for these rapidly changing market conditions in forecasting lighting energy use in new homes in 2017.

4.10.2 Existing Energy Efficiency Standards

Residential lighting spans several regulated products and space types. Individual technologies commonly used in residential lighting applications, such as incandescent light bulbs are covered by federal appliance efficiency standards. The most relevant federal standards that impact residential lighting are standards for general service incandescent and fluorescent lighting.

Layering on top of federal standards, interior, exterior, and garage hard-wired lighting are regulated Title 24. In 2015, the CEC adopted amendments to Title 24 to increase the stringency of these regulations, effective January 2017. These amendments will require the use of all high efficacy lighting in newly constructed homes. Essentially all hard-wired lighting will need to be high quality LED lighting (meeting the requirements of Joint Appendix 8) or so-called "legacy" high efficacy sources: GU24 sockets containing CFLs, linear fluorescents, HID, and induction lighting (CA IOUs 2014b). These requirements, which will be effective in 2017, represent a significant change to the residential lighting standards.[62]

[62] http://cltc.ucdavis.edu/publication/2016-title-24-code-changes-residential

Portable lighting is regulating by Title 20. Since 2012, Title 20 requires that most portable luminaires to be packaged with LED or CFL lamps. When considering newly constructed homes, this means that new portable lighting will consist of only LED and CFL technology. The CEC has also adopted a minimum efficacy requirement of 45 lumens/watt for all general service lamps (GSLs), and stronger requirements for LED lamps. However, these standards will not take effect until 2018 and will not be considered in this model, but they should be considered in a future update.

In addition, DOE is currently undergoing a rulemaking process for GSL, which is likely to require all GSL lamps to have a minimum efficacy of 45 lumen/watt, with more stringent standards for certain product classes. These standards will not take effect until 2020, thus should be considered in the next update to this model.

Table 67 presents an overview of the most relevant federal and state standards that are likely to affect residential lighting in new homes built in 2017.

Table 67: Federal and state standards affecting residential lighting

Scope of Coverage	**Requirements**	**Jurisdiction**
Hard-wired lighting in new homes	≥ 45 lm/W, high quality	Title 24
General service incandescent lamps sold in the state	Efficacy requirements ranging from ≥ 7.8 lm/W to ≥ 26 lm/W, depending on light output	EISA
General service fluorescent lamps sold in the state	Efficacy requirements ranging from ≥ 77 lm/W to ≥ 97 lm/W, depending on product class	DOE

4.10.3 Key Variables Impacting Energy Use

The lighting market is currently undergoing massive changes as new, high-efficiency technologies, such as LED, are becoming more cost-effective in many applications. While the previous generation of lighting products, such as incandescent and fluorescent lamps, had standardized into relatively well understood wattage bins (e.g. 75 W and 100 W incandescent lamps) for characterizing lighting needs, as new technologies develop, lighting service is becoming increasingly defined in the industry by lumen output. This allows for a more standardized method for characterizing the utility of light fixtures in a space, which is broadly applicable to all light source types. This also allows for improvements in luminous efficacy to be accounted for when modeling energy use. The Statewide CASE Team therefore relied on lumen output, rather than fixture type or fixture wattage, as the primary measure of the lighting needs in each space type in a home.

The total energy consumption of residential lighting is a function of the total number of light fixtures present, the light output of those fixtures, their average efficacy, and their average hours of use. Fixture efficiency is in turn dependent on the relative abundance of light source technology types (e.g. halogen, CFL, and LED) and the average efficacy of each light source technology type. Light source efficacy is driven by both natural market trends towards newer, more efficient technologies, as well as mandatory codes and standards that regulate efficacy, such as the Energy Independence and Security Act of 2007 and Title 24 Standards.

The Statewide CASE Team accounted for the following factors in the interior, exterior, and garage lighting AEC algorithms:

- Number of each lamp and fixture type by room type and CFA bin (e.g. 1,000-1,599 square feet of total home floor area);
- Percentage of lighting needs that can be met by portable vs. hardwired fixtures;
- Average efficacy of a lamp, based on the relative portion of the lamp technology;
- Hours of use by room type.[63]

Other factors that affect real-world AEC of lighting include the presence of lighting controls and sensors, and the variation of the hours of use for each room type as a function of home size.

Lacking a reliable adjustment method, the recommended rulesets do not explicitly model the impact of lighting controls or sensors, although their effect is reflected in the average hours of use assumptions. To the extent that there were occupancy-based or other types of controls that impact hours of use, installed in the California homes surveyed by KEMA in the 2010 lighting metering study, then the hours of use assumptions built into our proposed model will account for a typical saturation of controls in existing homes in California in 2010, However, given the increased natural market adoption of controls technology, the impact of dimmers on lighting energy use, as well as increased mandatory controls requirements that have been adopted since the lighting hours of use data was collected, actual lighting energy use in new homes built in 2017 may be even lower than predicted by our model. This introduces a conservative bias to the lighting models. It is therefore important that the next update to the model account for lighting controls. This could be accomplished by using more recent average hours of use data, or if necessary by developing controls adjustment factors. To our knowledge, recent and definitive studies to assess saturation of controls and expected savings by control type do not exist for the residential sector.

The recommended algorithms also do not model variation in hours of use as a function of total floor area. Instead, the average hours of use are assumed to be constant within each room type. Given that larger homes tend to have lower occupant densities (as shown by the RASS microdata), it is plausible that the average hours of use by room type may decrease with home size. In the recommended algorithms, this is accounted for by capping the linear equation at the midpoint of the largest CFA bin (4,150 square feet per dwelling unit). Future updates to the model may be able to incorporate California-specific metering or light logging data to more empirically capture this phenomenon.

As described above, several variables factor into estimating household lighting energy use. These variables are listed in Table 68, along with their function and the data source used to obtain them.

[63] The Statewide CASE Team considers the following room types: bedroom, bathroom, dining room, living room, hallway, kitchen, laundry/utility room or closet, and “office or other”.

Table 68: Key variables and their functions within the lighting methodology

Variable	Function	Source
Count and type of light fixtures by room and CFA	Estimating count and type of fixtures by room as a function of home size	CLASS 2012
Light output by light source type	Determining total light output by room as a function of home size	LED Lamp Title 20 CASE Report; DOE fluorescent ballasts rulemaking documents
Relative abundance of light source technology types by fixture type and area	Determining total lighting power draw by room as a function of light output	Title 24 Residential Lighting CASE Report; DOE 2013 LED Efficacy Trend Analysis; DOE 2010 U.S. LMC DOE Standard for General Service Fluorescent Lamps; ENERGY STAR QPL for CFLs; EISA 2007
Light source efficacy by light source technology type		
Annual hours of use by room type	Calculating total annual energy use by room as a function of lighting power draw	2016 Title 24 Residential Lighting CASE Report

4.10.4 Methodology

4.10.4.1 Methodology Overview

The foundational data source for the Statewide CASE Team's lighting methodology is the CLASS 2012 lighting inventory, which details the average number and type of lights in each room type of the home, for homes of varying conditioned floor area (CFA) bins.[64] For each CFA bin reported in CLASS 2012, the Statewide CASE Team applied various lighting assumptions to the building audit data to determine an average luminous flux for each room type. The Statewide CASE Team then divided the luminous flux of each room type by a combined luminous efficacy to calculate the power draw by room type. Next, the Statewide CASE Team multiplied these power draw values by the estimated lighting hours of use to calculate the AEC of each room type in every CFA bin. The process flow diagrams for determining location and room AECs are shown in Figure 40 and Figure 41, respectively.

[64] For example, all homes with CFA between 1,000 and 1,599 square feet are grouped in a CFA bin.

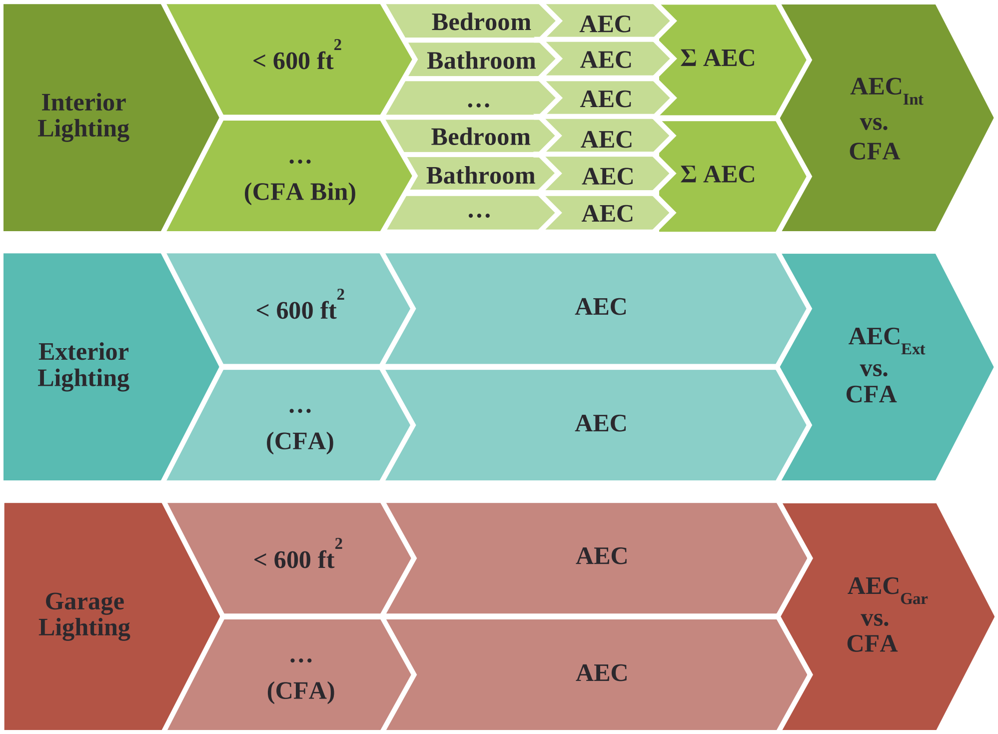

Figure 40: Process flow diagram for determining AEC vs. CFA for interior, exterior, and garage lighting

Note: Each location consists of several CFA bins, each consisting of several rooms. The AEC for each room is calculated and summed to determine the AEC for the associated bin. AEC vs. CFA is determined by linear regression using the 'Σ AEC' values. The flow diagram for calculating the AEC of each room is shown in Figure 41.

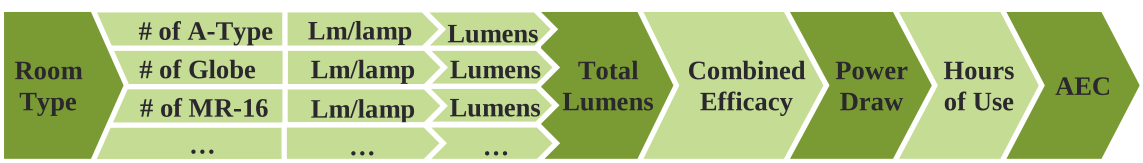

Figure 41: Process flow diagram for calculating AEC each room type

Note: In this figure, "Total Lumens" is calculated by summing the "Lumens" calculated for each lamp type. This value is the average luminous flux, which is termed as an 'average' since the number of each lamp type in the room is an average count.

4.10.4.2 Determining Average Luminous Flux for Each Room Type

The Statewide CASE Team used the data available in CLASS 2012 to identify the average number of lamps by type for each room type within a CFA bin (e.g. the average number of CFL spiral lamps in a kitchen of a home that has a CFA between 600 and 999 square feet). In order to estimate the average luminous flux for an entire room, the Statewide CASE Team assigned each lamp type a representative luminous flux per lamp that can be multiplied by the number of lamps of that type to calculate the luminous flux coming from that lamp type. The values assigned to each lamp type, and their respective sources, are shown in Table 69. The Statewide CASE Team used fairly broad lamp type categories given the limitations of the

CLASS data (as derived from the CLASS WebTool). Future updates to the model may be able to more accurately estimate representative luminous flux values for each lamp type by relying on more granular data.

Table 69: Representative luminous flux per lamp for each lamp type in CLASS 2012

Lamp Type	Includes	Luminous Flux (lumens)	Source
A-type	A-lamps, spiral, U-bend, etc.	1003	LED Lamp Title 20 CASE Report
Globe and decorative	Globe, G-Type, decorative, etc.	479	
Small Diameter Directional Lamps	MR-16, low voltage lamps (directional lamps with diameter 2.25” or less)	649	
Large Diameter Directional Lamps	Reflector/flood lamps (directional lamps with diameter greater than 2.25”	1060	
Fluorescent tubes	Linear tube, circuline, etc.	1627	DOE Fluorescent Lamp Ballasts Rulemaking
Misc.	Misc.	1003	N/A[1]

1. Assumed to be equivalent to A-type

The Statewide CASE Team calculated and summed the luminous flux coming from all lamp types in the room to determine the average luminous flux for each room type, the results of which are shown in Figure 42.

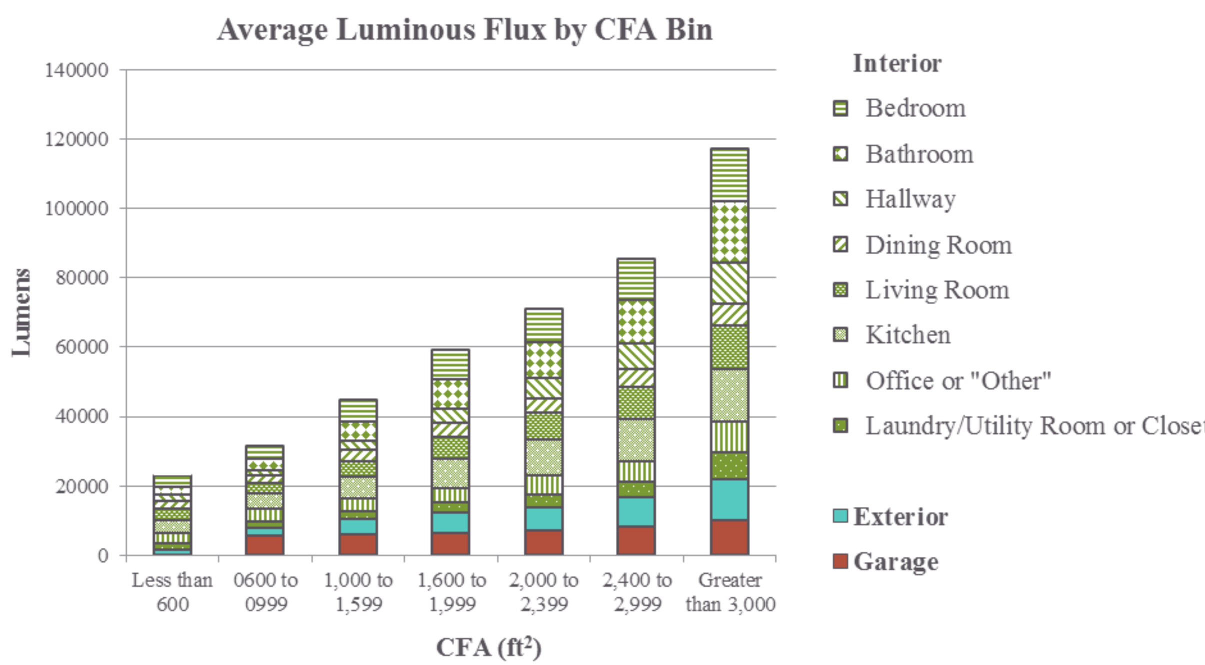

Figure 42: Luminous flux for homes at each CFA bin, from CLASS study, by room type

Source: (DNV GL 2012)

4.10.4.3 Determining Power Draw for Each Room Type

To convert the calculated average luminous flux of a room to power draw, the Statewide CASE Team used several combined luminous efficacy values, which were calculated for the portable and hard-wired lighting of each location (e.g. interior, exterior, or garage). These values were determined by averaging the assumed efficacy of each lamp technology, weighted by their relative portions.

To first determine the representative luminous efficacy of each lamp technology (e.g. LED, CFL, halogen), the Statewide CASE Team analyzed a variety of sources. Rather than assume all residential lighting sources will be minimally comply with 2017 regulations, the Statewide CASE Team based these efficacy assumptions on estimated market average values in cases where a regulation does not apply or the market efficiency trend is quickly outpacing projected regulations. These assumptions and their associated sources are summarized in Table 70.

Table 70: Efficacy assumptions by light source technology type

Light Source Technology Type	Efficacy Assumption (lm/W)	Justification	Source
LED	80	Average of the modeled efficacy of LED omnidirectional lamps for two data sets (average of 70 lm/W and 90 lm/W)	DOE 2013 LED Efficacy Trend Analysis
CFL	68	Typical efficacy for CFLs in the 600-900 lumen range	ENERGY STAR QPL for CFLs
GSFL	92	DOE minimum efficacy requirement for 4-Foot Medium Bi-pin (T8)	DOE Standard for General Service Fluorescent Lamps
Halogen	17	Minimum EISA 2007 efficacy requirement for most common lumen output (750-1050 lumens)	EISA 2007
Metal halide	49	Efficacy assumption for residential metal halide	DOE 2010 LMC

Although CLASS 2012 contains data on the relative portion of different light source technology types, the lighting market is evolving far too quickly for this information to be applied to new homes built in 2017. Instead, the Statewide CASE Team estimated the relative portion of different light source technology types using various sources, depending on location (e.g. interior, exterior, garage) and whether the light source is portable or hard-wired.

For all hardwired lighting, the Statewide CASE Team based the relative lamp portions on:

- Title 24 requirements for hard-wired residential lighting;
- The LED lamp quality Title 20 CASE Report market share projection for LED lamp abundance, assuming moderate adoption; and
- CLASS 2012 and DOE 2010 Lighting Market Characterization data on the prevalence of linear fluorescent fixtures by room type.

Specifically, the Statewide CASE Team assumed that the lighting that was found to be linear fluorescent in CLASS 2012 and the DOE 2010 Lighting Market Characterization will continue to be linear fluorescent, but the majority of the other hard-wired lighting will be LED, not CFL. According to the Title 24 Statewide CASE Team focused on residential lighting, the most likely compliance pathway for screw-based lighting will be LED, and builders have historically favored screw-based sockets over GU24.

For portable lighting, where the efficacy varies depending on the fraction of new and old lamps (i.e. the proportion of portable lighting fixtures in new homes that are brought in by occupants from previous homes vs. the proportion that are purchased new), the Statewide CASE Team used the 2016 DOE Technical Support Document for the Notice of Proposed Rulemaking for general service lamps to forecast the stock and shipment shares of each lamp type. The 2017 stock shares were used as a proxy for the relative portion of old lamps because it is representative of the probability that an old lighting fixture will be using that lamp type. For new portable lighting, the Statewide CASE Team used the 2017 shipment shares of only LED and CFL lamps. Since Title 20 Standards require newly-purchased portable luminaires to be packaged with an LED or CFL lamp, the Statewide CASE Team used the disregarded 2017 shipments of halogen and incandescent lamps. For this model, the Statewide CASE Team assumed that 50 percent of lamps in portable luminaires in newly constructed homes will be newly-purchased (the other 50% will be brought in by occupants from previous dwellings). A step-by-step explanation of the 2017 forecast is presented in Appendix D: Forecast of Lamp Shipment and Stock Shares in 2017.

The determined relative portions, and the resulting combined luminous efficacy values, are summarized in Table 71.

Table 71: Calculation of combined luminous efficacies; determined relative portion of light source technology types by location and portable/hard-wired

<table>
<tr><th colspan="3">Type</th><th>Light Source Technology</th><th>Relative Portion (%)</th><th>Luminous Efficacy (lm/w)</th><th>Combined Luminous Efficacy (lm/w)</th></tr>
<tr><td rowspan="9">Interior</td><td colspan="2" rowspan="3">Hard-wired</td><td>LED</td><td>85</td><td>80</td><td rowspan="3">80</td></tr>
<tr><td>CFL</td><td>8</td><td>68</td></tr>
<tr><td>GSFL</td><td>7</td><td>92</td></tr>
<tr><td rowspan="6">Portable</td><td rowspan="3">New</td><td>LED</td><td>70</td><td>80</td><td rowspan="6">43</td></tr>
<tr><td>CFL</td><td>30</td><td>68</td></tr>
<tr><td>Halogen</td><td>0</td><td>17</td></tr>
<tr><td rowspan="3">Old</td><td>LED</td><td>17</td><td>80</td></tr>
<tr><td>CFL</td><td>38</td><td>68</td></tr>
<tr><td>Halogen</td><td>46</td><td>17</td></tr>
<tr><td rowspan="9">Exterior</td><td colspan="2" rowspan="3">Hard-wired</td><td>LED</td><td>85</td><td>80</td><td rowspan="3">76</td></tr>
<tr><td>CFL</td><td>5</td><td>68</td></tr>
<tr><td>Metal halide</td><td>10</td><td>49</td></tr>
<tr><td rowspan="6">Portable</td><td rowspan="3">New</td><td>LED</td><td>70</td><td>80</td><td rowspan="6">43</td></tr>
<tr><td>CFL</td><td>30</td><td>68</td></tr>
<tr><td>Halogen</td><td>0</td><td>17</td></tr>
<tr><td rowspan="3">Old</td><td>LED</td><td>17</td><td>80</td></tr>
<tr><td>CFL</td><td>38</td><td>68</td></tr>
<tr><td>Halogen</td><td>46</td><td>17</td></tr>
<tr><td rowspan="9">Garage</td><td colspan="2" rowspan="3">Hard-wired</td><td>LED</td><td>43</td><td>80</td><td rowspan="3">85</td></tr>
<tr><td>CFL</td><td>8</td><td>68</td></tr>
<tr><td>GSFL</td><td>50</td><td>92</td></tr>
<tr><td rowspan="6">Portable</td><td rowspan="3">New</td><td>LED</td><td>70</td><td>80</td><td rowspan="6">43</td></tr>
<tr><td>CFL</td><td>30</td><td>68</td></tr>
<tr><td>Halogen</td><td>0</td><td>17</td></tr>
<tr><td rowspan="3">Old</td><td>LED</td><td>17</td><td>80</td></tr>
<tr><td>CFL</td><td>38</td><td>68</td></tr>
<tr><td>Halogen</td><td>46</td><td>17</td></tr>
</table>

Note: A determination of the relative portions is discussed in Appendix C: List of Residual MELs. Percentages may not add to 100 percent due to rounding.

CLASS 2012 reports the fraction of lamps that are installed in portable luminaires, for each room type, including the home exterior and garage, presented in Table 72. The Statewide

CASE Team used these values to determine the fraction of the average luminous flux that is supplied by lamps having an efficacy equal to the portable combined luminous efficacy of that location. The remaining fraction is assumed to be supplied by lamps having an efficacy equal to the hard-wired combined luminous efficacy of that location. By dividing each fraction of the average luminous flux by the relevant combined luminous efficacy, the Statewide CASE team calculated the power draw of portable and hard-wired lamps for each room (for each CFA bin). The total power draw of the room is the sum of these two calculated values.

Table 72: Percent of light sources that are portable in a typical home by location

	Portable Light Sources per CFA bin (%)						
Location	**< 600 ft^2**	**600 - 999 ft^2**	**1,000 - 1,599 ft^2**	**1,600 - 1,999 ft^2**	**2,000 - 2,399 ft^2**	**2,400 - 2,999 ft^2**	**> 3,000 ft^2**
Interior							
Bedroom	30.6	35.1	35.9	34.2	38.9	30.6	33.5
Bathroom	0.6	0.9	0.4	0.2	0.4	0.2	0.3
Hallway	3.1	1.5	1.4	1.7	2.3	2.2	1.8
Dining Room	0	5.7	5.5	3.6	8.8	3.0	3.0
Living Room	42.9	51.6	42.0	31.8	35.0	29.1	23.1
Kitchen	1.4	0.5	0.8	0.5	0.4	0.1	0.8
Laundry/Utility Room or Closet	10.9	4.4	3.8	0.7	1.1	0.8	0.3
Office or "Other"	0	25.5	23.9	18.7	26.2	20.0	13.8
Exterior	0	0.5	0.4	1.5	0.3	0.2	0.2
Garage	N/A	0.1	1.1	0.7	0.9	0.3	0.9

4.10.4.4 Determining Per-Household AEC as a Function of CFA

The Statewide CASE Team determined the AEC of each room type for each CFA bin by multiplying the power draw by estimated hours of use for that room. To remain consistent with the Title 24 Residential Lighting CASE Report, the Statewide CASE Team referenced the KEMA 2010a Final Evaluation Report of the 2006-2008 Upstream Lighting Program implemented by PG&E, SCE and SDG&E for hours of use data (KEMA 2010a).

The Statewide CASE Team also considered as alternative sources of information the DOE 2010 Lighting Market Characterization and the hours of use assumptions currently listed in the HERS technical manual, which are derived from the HMG 1999 Lighting Efficiency Technology Report. The daily hours of use reported by each of these sources are compared in Figure 43. Ultimately, the Statewide CASE Team chose to use the KEMA 2010 hours of use because the data is more recent than the existing HERS assumptions and based on California homes, not the national average (unlike the DOE 2010 LMC).

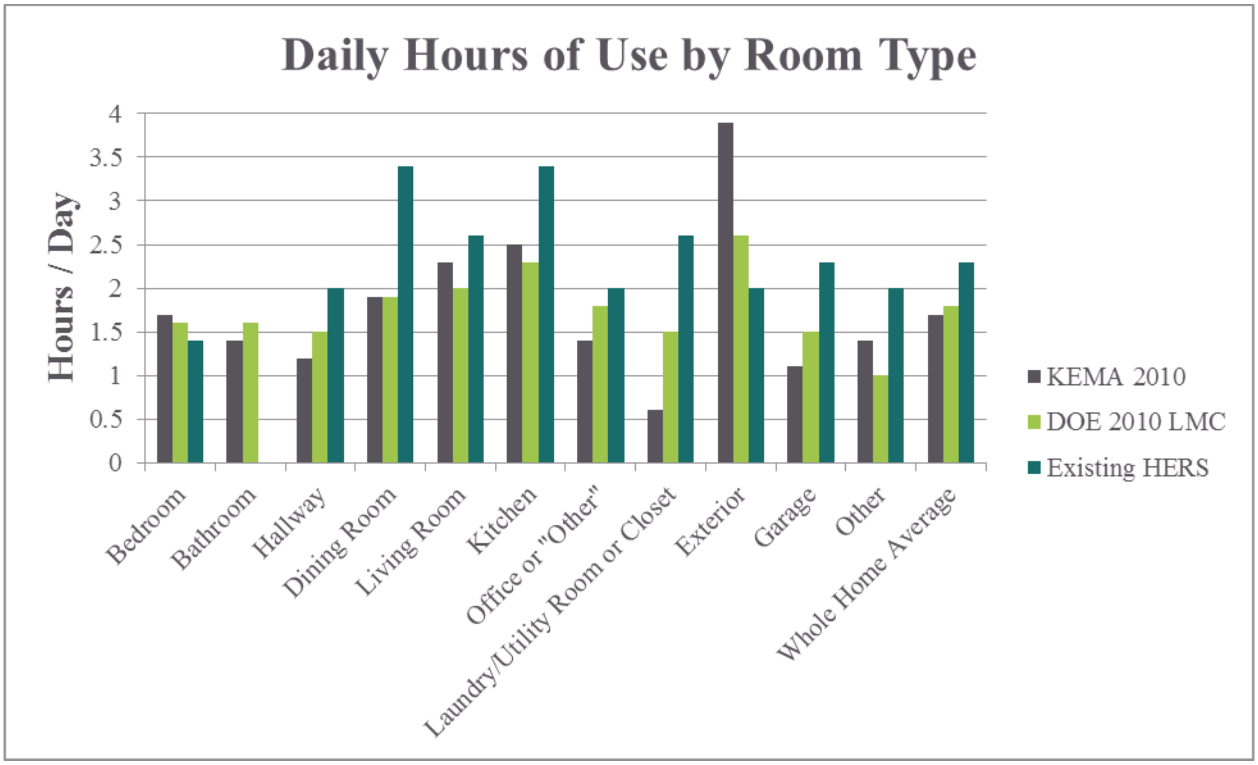

Figure 43: Hours of use by room type by data source

To determine the total lighting AEC of the home interior, exterior, and garage for each CFA bin, the Statewide CASE Team calculated and summed the lighting AECs of all their constituent rooms. The results are shown in Figure 44, and the calculations are as follows:

$$AEC_{L,CFA} = \sum_{R} AEC_{L,R}$$

$$AEC_{L,R} = (HOU_R) \times \left[\frac{(X_P)(ALF)_{L,R}}{(CLE_{L,P})} + \frac{(X_H)(\mathrm{ALF})L,_{R}}{(CLE_{L,H})} \right]$$

$$(ALF)_{L,R} = \sum_{R} \binom{\#\text{ of}}{\text{lamps}}_{L,R,F} \binom{\text{Lumens}}{\text{per lamp}}_{F}$$

$AEC_{L,CFA}$ = the annual energy consumption for the indexed CFA bin and location, where *Int* = interior, *Ext* = exterior, and *Gar* = garages;

$AEC_{L,R}$ = the annual energy consumption for the indexed location and room type, where *L* is the location as above and *R* is the room type;

HOU_R = hours of lighting use for the index room type;

X_W = the fraction of lamps that are portable or hard-wired, where *W* = *P* for portable and *W* = *H* for hard-wired;

ALF_R = the average luminous flux for the indexed location and room type, where *L* is the location as above and *R* is the room type;

$CLE_{L,W}$ = the combined luminous efficacy of portable or hard-wired lighting for the index location, where L is the location as above, $W = P$ for portable and $W = H$ for hard-wired;

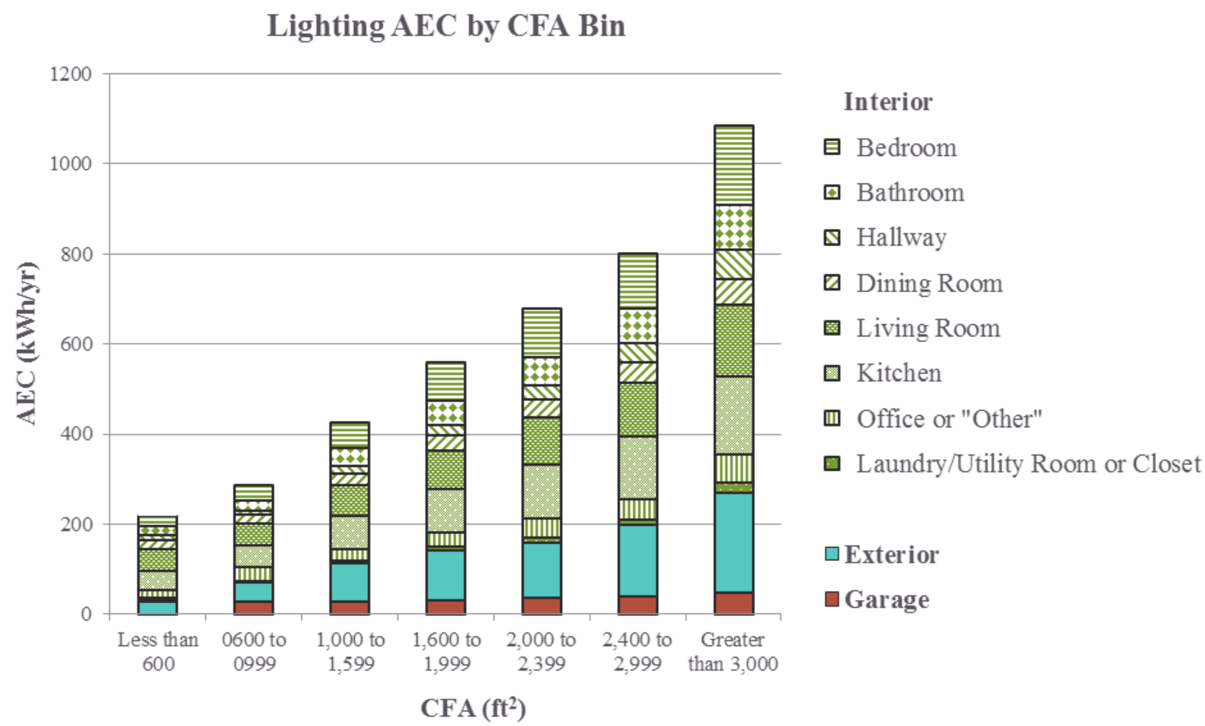

Figure 44: Calculated AEC of each CFA bin, segmented by room type

Using the calculated interior, exterior, or garage AEC of each bin, the Statewide CASE Team performed a linear regression to capture the relationship between AEC and CFA.

4.10.5 Results

The recommended algorithms for estimating interior, exterior, and garage lighting AEC based on CFA are presented in as well as Equation 8, Equation 9, and Equation 10.

The resulting algorithms are linear equations dependent on CFA and applicable to all dwelling units under 4,150 square feet of CFA. For dwelling units with more than 4,150 feet of total CFA, the software should evaluate the equations at 4,150 square feet. As discussed in Section 4.10.3, this cap to the AEC algorithms reflects the assumption that larger homes will tend to have a plateau in total lumen-hours, due to lower occupant density in larger homes.

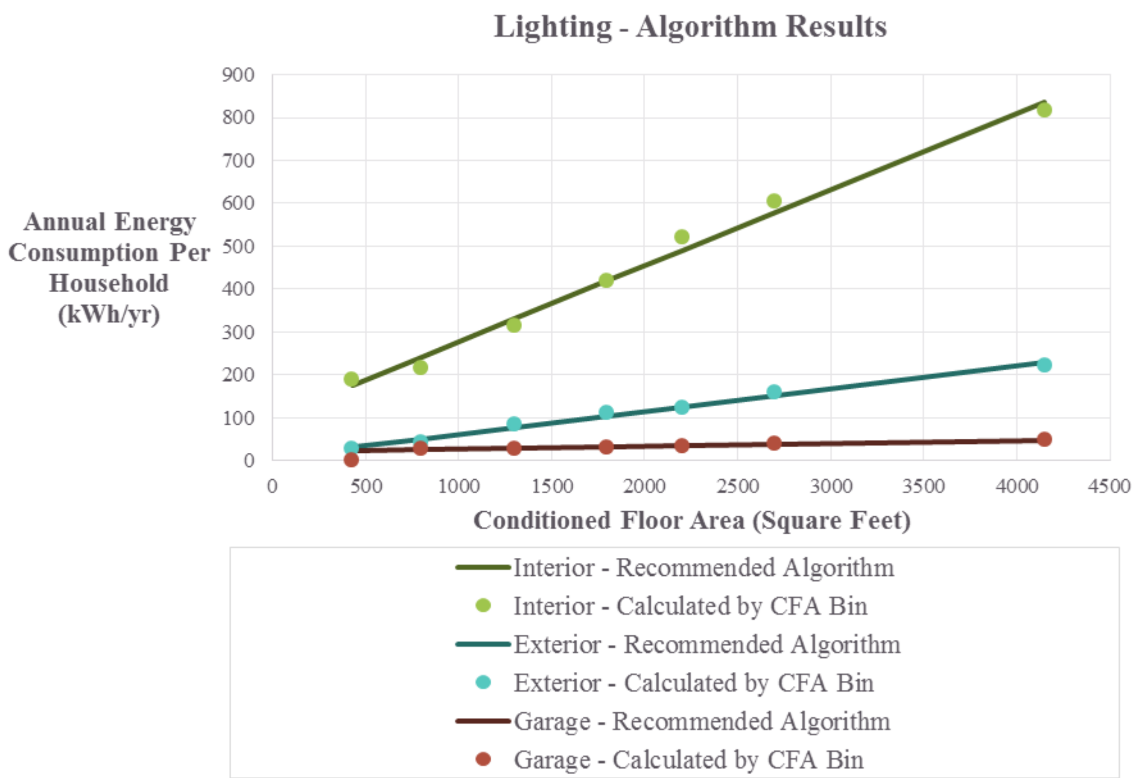

Figure 45: Per-household AEC of interior, exterior, and garage lighting as a function of CFA

Equation 8: Interior lighting AEC as a function of CFA

$$AEC_{Int} = 0.17(CFA) + 90$$

Equation 9: Exterior lighting AEC as function of CFA

$$AEC_{Ext} = 0.053(CFA) + 8$$

Equation 10: Garage lighting AEC as function of CFA

$$\boldsymbol{AEC_{Gar} = 0.0063(CFA) + 20}$$

Figure 46 and Figure 47 compare the recommended lighting algorithms to various benchmarks, described in Section 3.5.2.

The recommended interior lighting AEC algorithm estimates considerably less AEC than most of the other data sources plotted in Figure 46; however, the different models represent very different building stock from what the Statewide CASE Team intends to model:

- The RESNET 2013 standards are based on data from the 2002 DOE Lighting Market Characterization (Parker et al. 2011).
- The 1999 Heschong Mahone Group (HMG) study *Lighting Efficiency Technology Report: California Baseline* represents the estimated AEC of California existing homes,

but uses data that is will be fifteen to twenty years out of date for the 2016 Title 24 Code Cycle (HMG 1999).

- Building America's House Simulation Protocols aim to represent the typical lighting in American homes in 2010 (Wilson et al. 2014).
- The 2009 RASS CDA is California-specific but the CDA results are considerably out of date, since they are based on 2008 survey and whole-home metering data. Furthermore, the RASS CDA analysts were unable to statistically parse interior lighting and residual MELs; instead, the study authors conducted an engineering analysis to split the "miscellaneous category."
- The line marked as "Algorithm for 2013 Title 24 (high efficiency)" represents the 2008 California HERS Technical Manual interior lighting rulesets as applied to rated homes with high-efficiency hard-wired lighting (HERS 2008). The 2013 algorithms use the equations in the 2008 California HERS Technical Manual to estimate lighting AEC. Although the current algorithms do not use the high-efficiency HERS equations for new construction, the Statewide CASE Team compared against this benchmark as it represents a California-specific, high-efficacy scenario, albeit one based in 2008 data and efficiency levels. The 2008 HERS Technical Manual prescribes that in order for hard-wired luminaires to qualify as "high-efficiency," they must comply with the 2008 Title 24 definition, as defined in §150(k). One key portion of these high-efficiency requirements in 2008 Title 24 is that luminaires that use over 40 watts have an efficacy of at least 60 lumens/watt.
- The 2016 Title 24 requirement that all hard-wired lighting be high-efficacy represents a significant decrease in energy use. The Statewide CASE Team estimated that: most of lighting in the home is hard-wired (based on CLASS); the hard-wired lighting in a home will be mostly LED (given 2016 Title 24 requirements for new construction); and LEDs will have a luminous efficacy of 80 lumens/watt, which is likely a conservative estimate. Additionally, it is important to note that the Statewide CASE Team did not consider how lighting controls reduce average hours of use by room type relative to KEMA 2010 or account for Title 20 standards for certain types lamps that become effective in 2018.[65] These factors that will further reduce interior lighting AEC during the 2016 code cycle and thus support a substantially lower AEC estimate relative to the algorithms in the 2013 ACM.

[65] Specifically, the Statewide CASE Team did not consider the Title 20 standards for small diameter directional lamps (SDDL) and LED lamps, which will effectively require that these lamp types be high-efficacy.

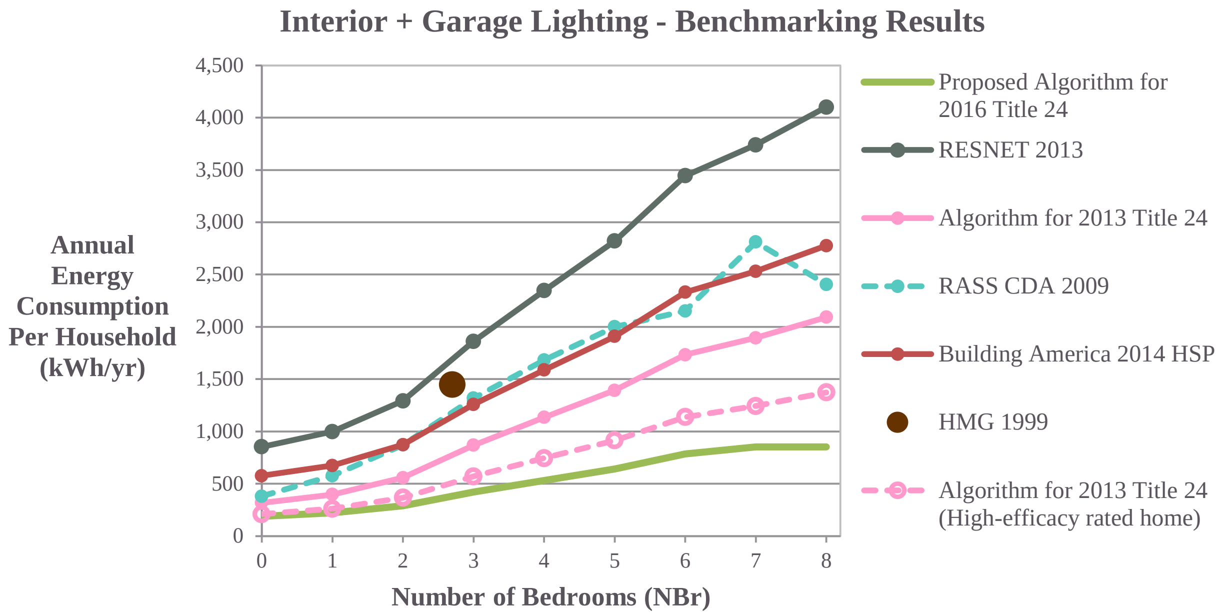

Figure 46: Comparison of interior and garage lighting AEC algorithm against various benchmarks

For the same reasons described above, the recommended exterior lighting algorithm estimates less AEC than most of the other data sources. The current (2013) algorithms for exterior lighting scale more steeply with home size than the proposed algorithms (estimating only 1.7 kWh/yr for average-sized 1-bedroom dwelling units). The high-efficiency rulesets from the 2008 HERS Technical Manual estimate less exterior lighting AEC than the proposed rulesets.

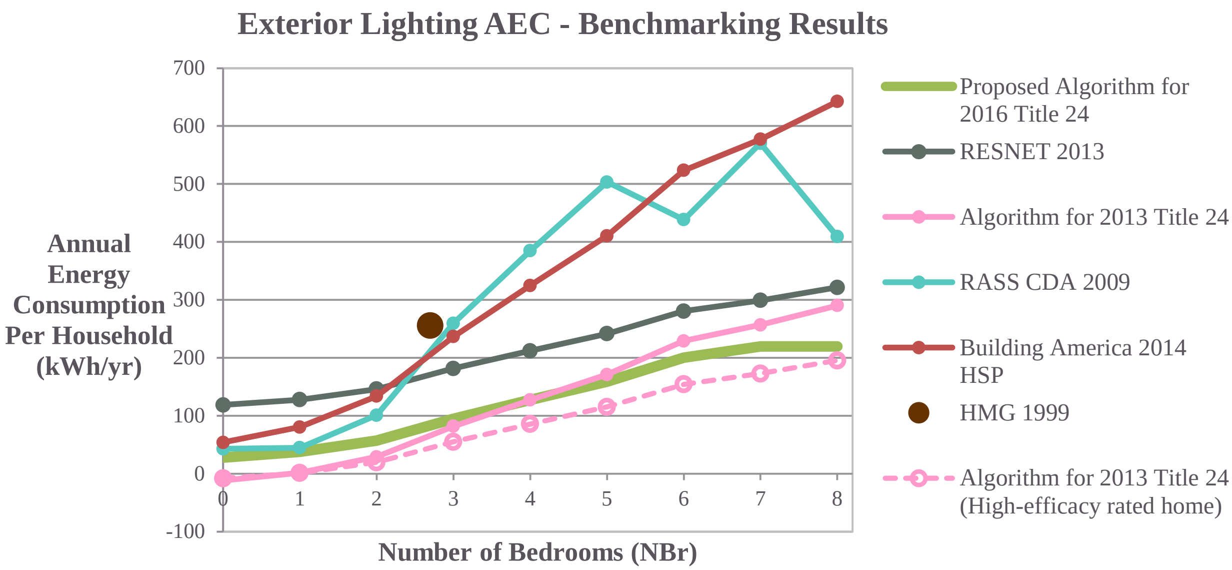

Figure 47: Comparison of exterior lighting AEC algorithm against various benchmarks

4.11 All Plug Loads and Lighting

4.11.1 Overview

This section presents the estimated AEC of all modeled plug loads and lighting combined, both for average-sized homes and as a function of NBr. The Statewide CASE Team compares the proposed AEC algorithms to the main benchmarks described in Section 3.5.2, with an emphasis on how the recommended AEC of each product category scales with home size, relative to the 2013 Title 24 algorithms.

Results are presented for gas and electric appliances. The electric energy consumption of gas appliances is not shown, both because gas appliances use very little electricity compared to the other product categories and because almost none of the data sources that the Statewide CASE Team typically uses for comparison have estimated values for electricity use.

Single-family and multi-family residences are shown separately because they have different typical sizes and because four of the modeled product categories have different algorithms for single-family and multi-family housing. The AEC algorithms for the end uses that are aligned with the Title 24 WH rulesets vary by house type (i.e. dishwashers, clothes washers, and clothes dryers), because CEC's WH usage assumptions vary by house type. Multi-family housing is assumed to have no AEC of non-primary refrigerators and separate freezers ("other refrigeration" in the figures below).

This section concludes with a summary of key takeaways of the whole-home results and comparisons.

4.11.2 Estimated AEC of Average-Sized Homes

Figure 48, Figure 49, Figure 50 and Figure 51 show the estimated AEC of all modeled plug loads and lighting for average-sized single-family and multi-family homes.

The Statewide CASE Team represented typical single-family housing as having three bedrooms based on the average NBr for single-family homes in RASS (3.1 bedrooms). Similarly, the Statewide CASE Team represented typical multi-family housing as having two bedrooms per unit, based on the average NBr for single-family homes in RASS (1.6 bedrooms).[66] AEC values are presented for electric and gas end uses.

Residual MELs have the highest estimated AEC of any of the modeled electric end uses by a wide margin, followed by electric clothes dryers and primary refrigerators. In smaller homes (zero-bedroom through two-bedroom), interior lighting is estimated to use less energy than televisions or electric ranges (i.e. electric ovens and cooktops). For homes with three or more bedrooms, interior lighting is a relatively higher end use because it scales more rapidly with NBr than television or cooking AEC.[67]

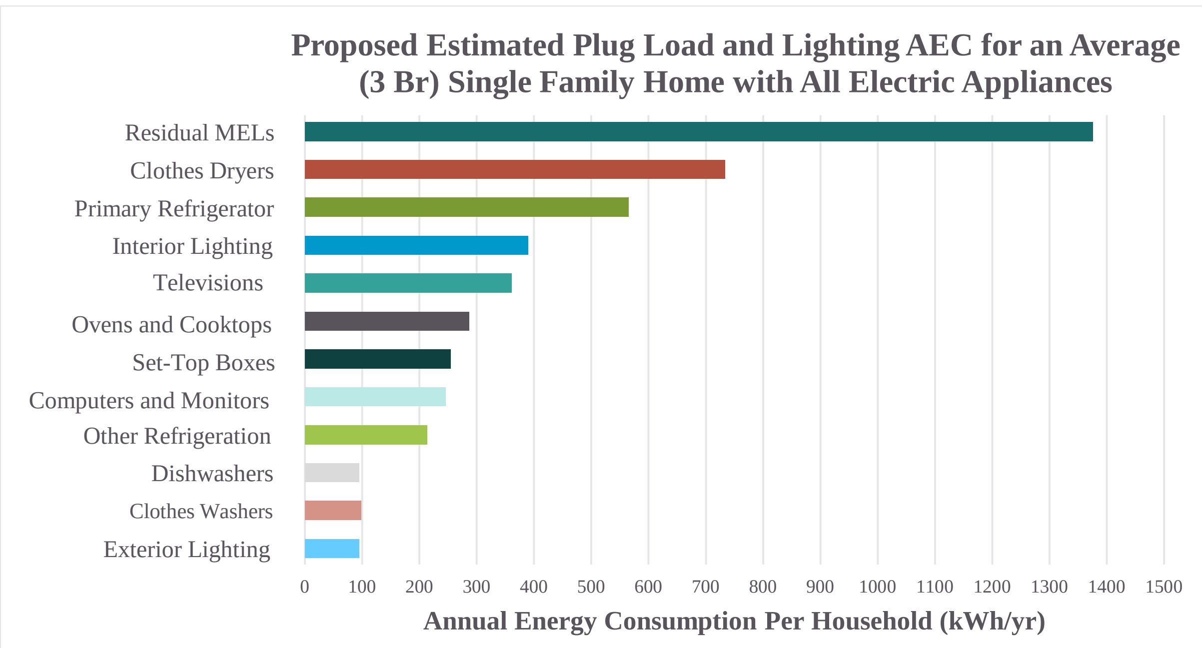

Figure 48: Estimated AEC of all electric end uses in an average-sized single-family home

[66] Although arguably 1 bedroom per unit may be more representative of typical new multi-family construction, the later figures in this section show the multi-family algorithms for a full range of home sizes.

[67] The Statewide CASE Team determined the lighting algorithms as a function of CFA, but then translated to NBr based on the average CFA in RASS in order to facilitate a comparison with the plug load end uses.

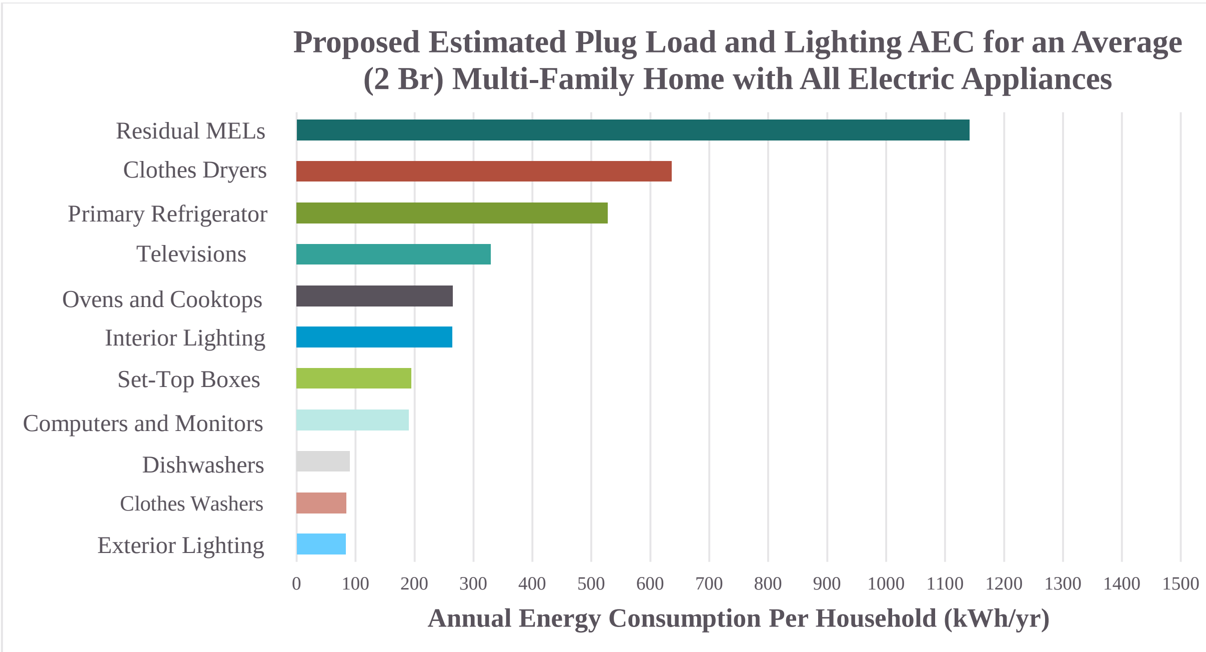

Figure 49: Estimated AEC of all electric end uses in an average-sized multi-family home

The Statewide CASE Team estimated that gas dryers will consume more therms than ovens and cooktops combined in homes with these devices.

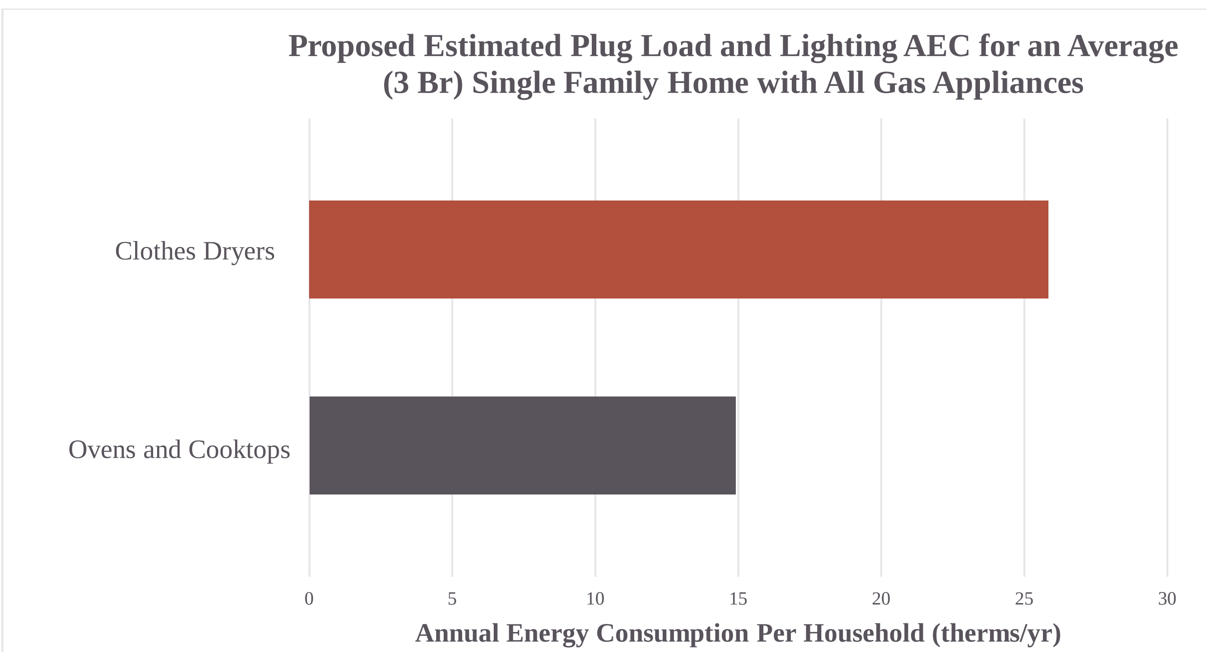

Figure 50: Estimated AEC of all gas end uses in an average-sized single-family home

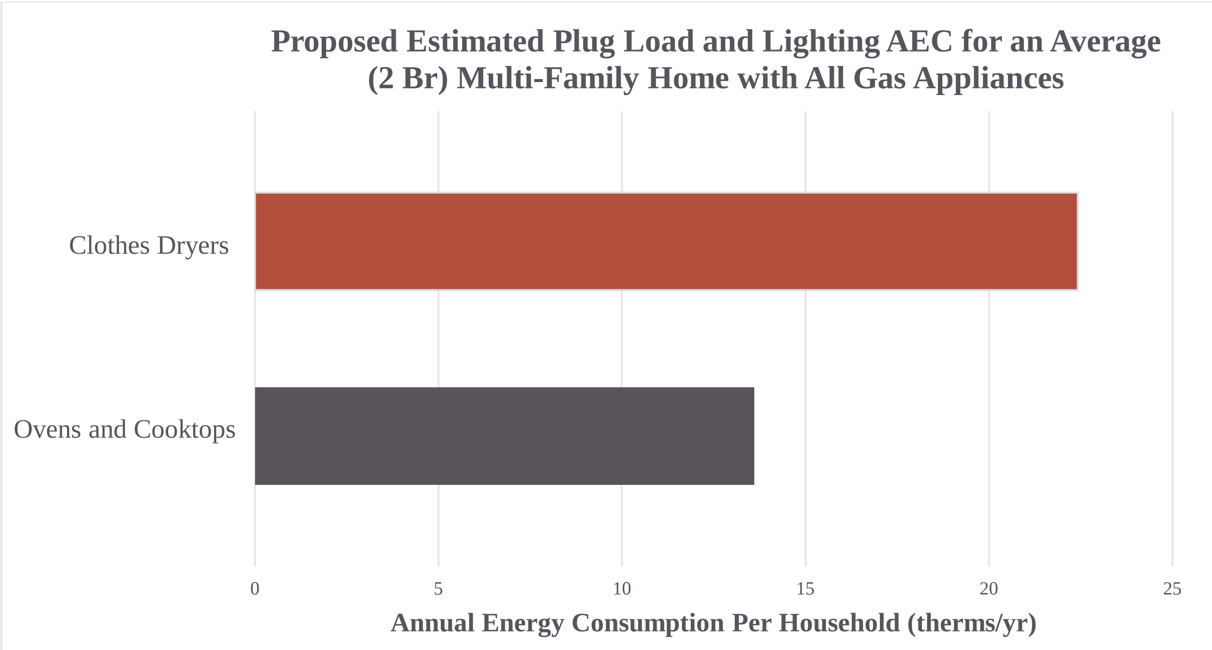

Figure 51: Estimated AEC of all gas end uses in an average-sized multi-family home

Figure 52, Figure 53, Figure 54, and Figure 55 compare the total plug load and lighting AEC estimated by the recommended algorithms to the main benchmarks described in Section 3.5.2. All comparisons assume a saturation of one device per household for ovens, cooktops, dishwashers, clothes washers, and clothes dryers. This serves to illustrate all the modeled end uses, but in reality these devices will not always be installed. For example, according to the RASS microdata, multi-family homes often do not have in-unit clothes washers and clothes dryers. Furthermore, even if these devices are installed, they will not always be of the fuel type specified in the following figures.

For an average-sized home with all of the white goods shown, the total plug load and lighting AEC (of both gas and electric) estimated by the recommended algorithms is not drastically different from the AEC estimated by the existing rulesets. The recommended algorithms estimate more electric AEC and slightly less natural gas AEC than the 2013 Title 24 code cycle algorithms.

The greatest difference for average-sized homes is the allocation of that AEC between end uses. The two greatest changes from the 2013 algorithms are a substantial decrease in interior lighting AEC and an estimated increase in the AEC of non-white good MELs (e.g. the combined total of residual MELs, televisions, set-top boxes, computers, and monitors relative to the 2013 AEC estimate for "miscellaneous").

Across the different energy models, the proportions of the constituent end uses are generally fairly similar. The most striking difference is the share of energy attributable to interior lighting. Given their underlying data sources, the interior lighting AEC estimates in Figure 52 and Figure 53 represent (from left to right): the 2002 DOE Lighting Market Characterization; typical lighting AEC in the U.S. in 2010; California lighting AEC in 2008; California lighting AEC in 2008 (again); and the lighting AEC of California homes built during the 2016 Title 24 code, which will be required by code to install high-efficiency hard-wired luminaries. Section 3.5.2 includes a more detailed discussion of these energy models.

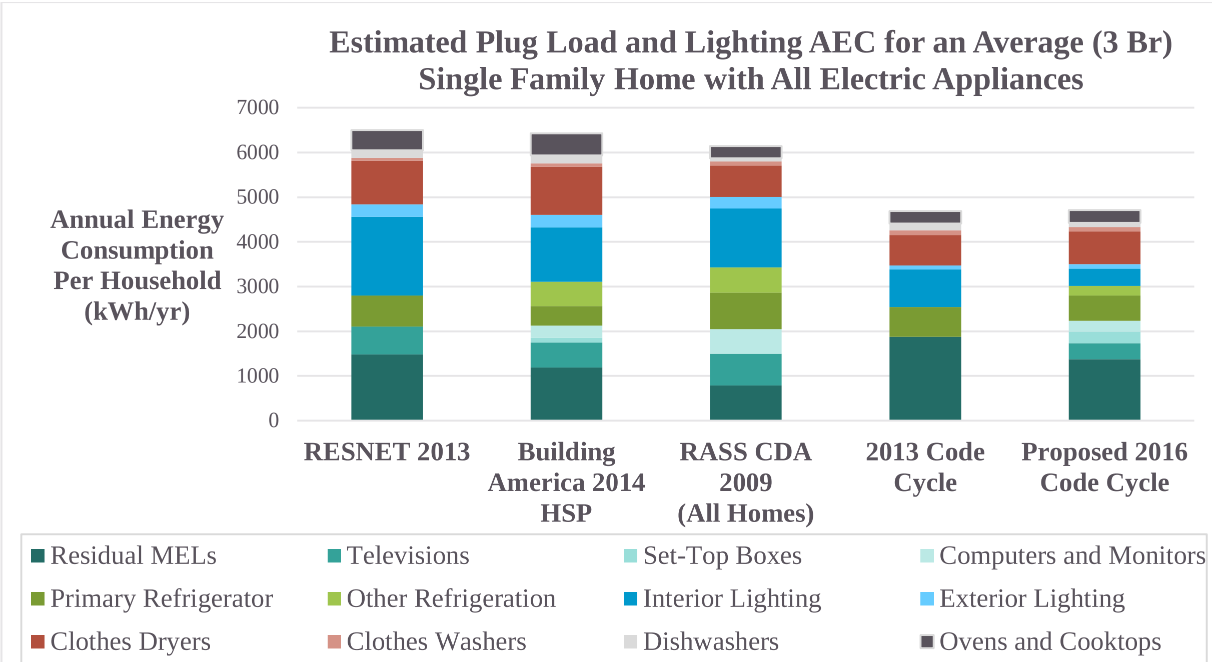

Figure 52: Benchmarking analysis of the estimated AEC of all plug loads and lighting (for an average-size single-family home with all electric appliances)

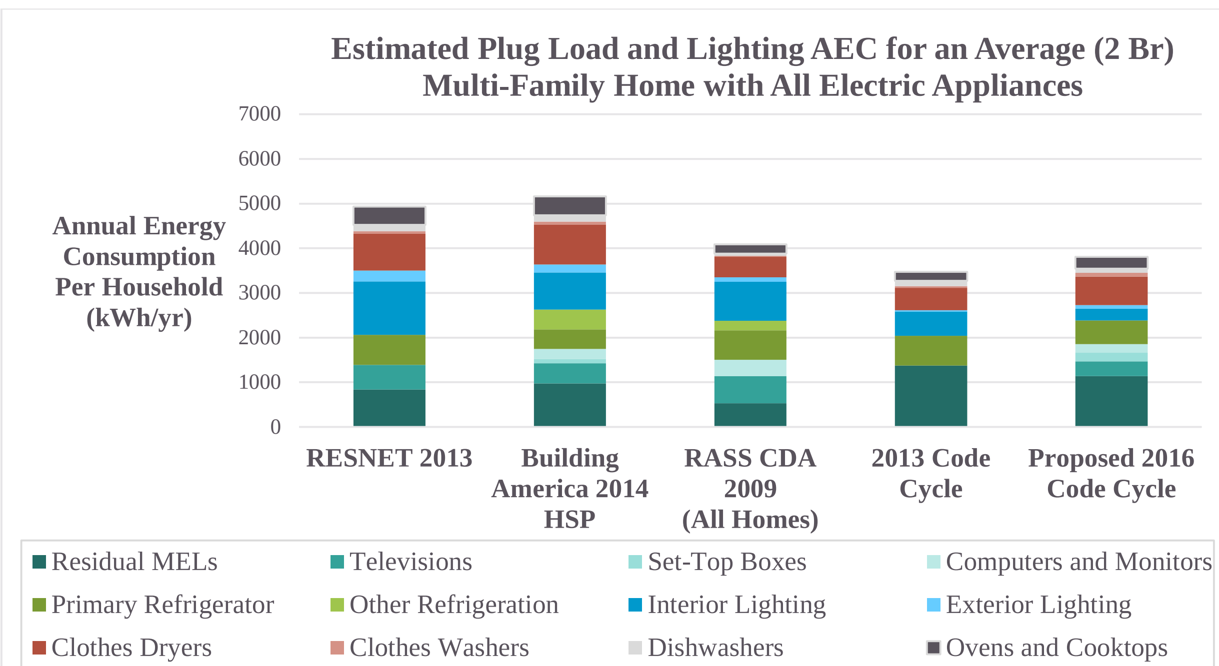

Figure 53: Benchmarking analysis of the estimated AEC of all plug loads and lighting (average-size multi-family home with all electric appliances)

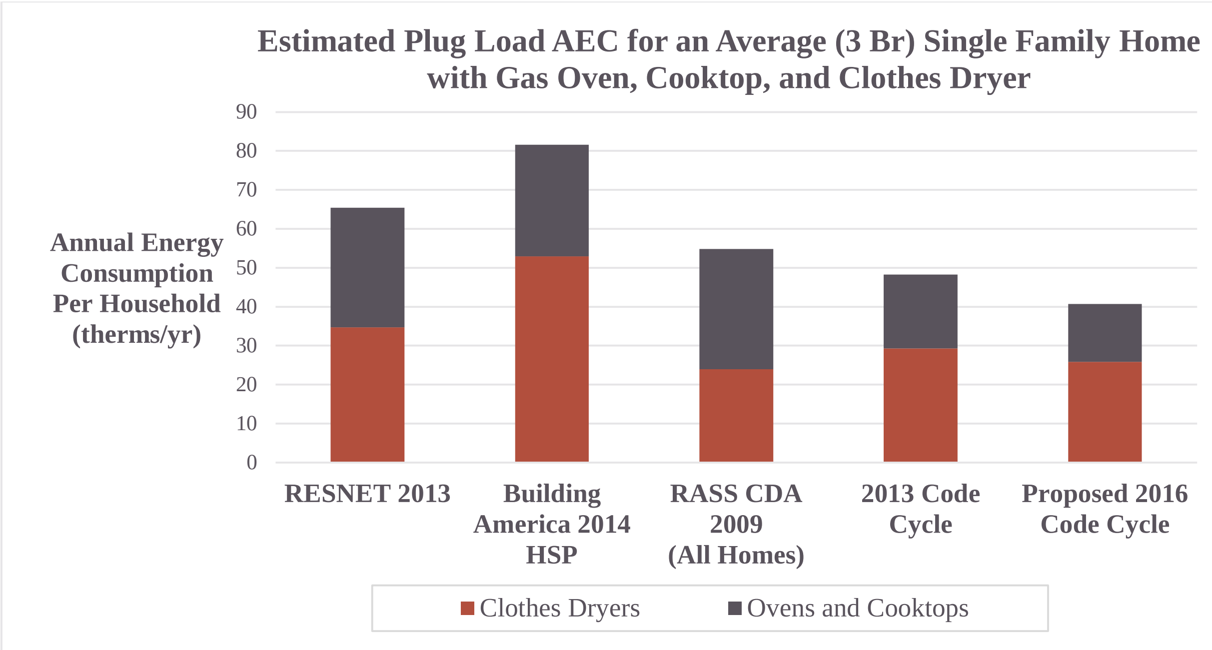

Figure 54: Benchmarking analysis of the estimated AEC of gas appliances (average-size single-family home with all gas appliances)

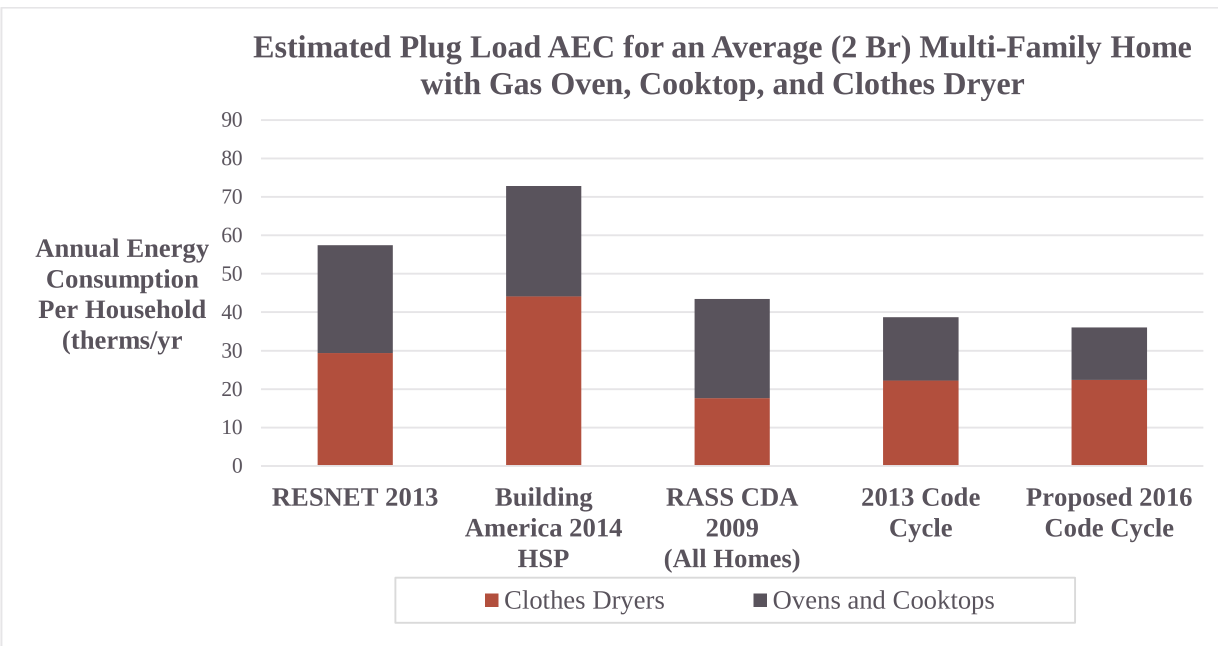

Figure 55: Benchmarking analysis of the estimated AEC of gas appliances (average-size multi-family home with all gas appliances)

4.11.3 Estimated AEC as a Function of NBr

Figure 56, Figure 57, Figure 58, and Figure 59 show the estimated AEC of all modeled plug loads and lighting as a function of NBr. Note that certain end uses, such as lighting and non-primary refrigerator and freezers, scale more rapidly with NBr, whereas others, such as ovens and cooktops are modeled to be less dependent on NBr.

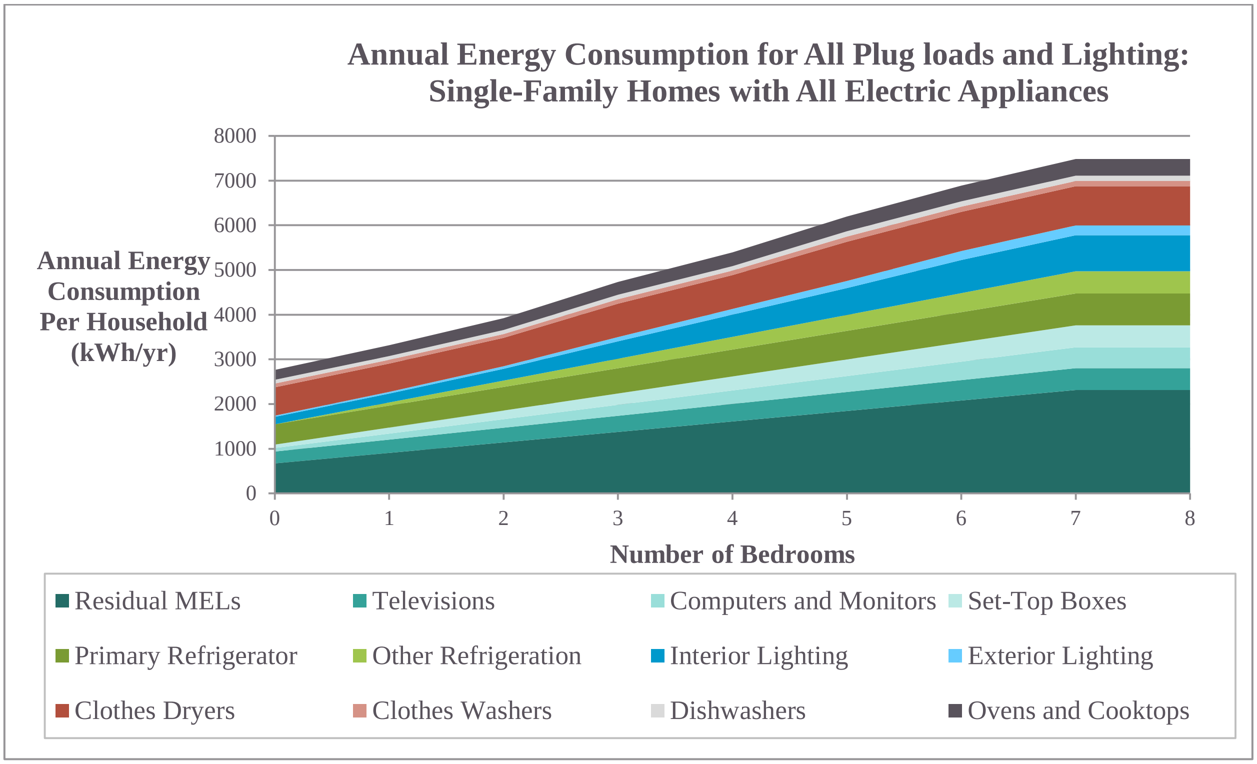

Figure 56: Estimated AEC of all plug loads and lighting as a function of NBr, single-family homes with all electric appliances

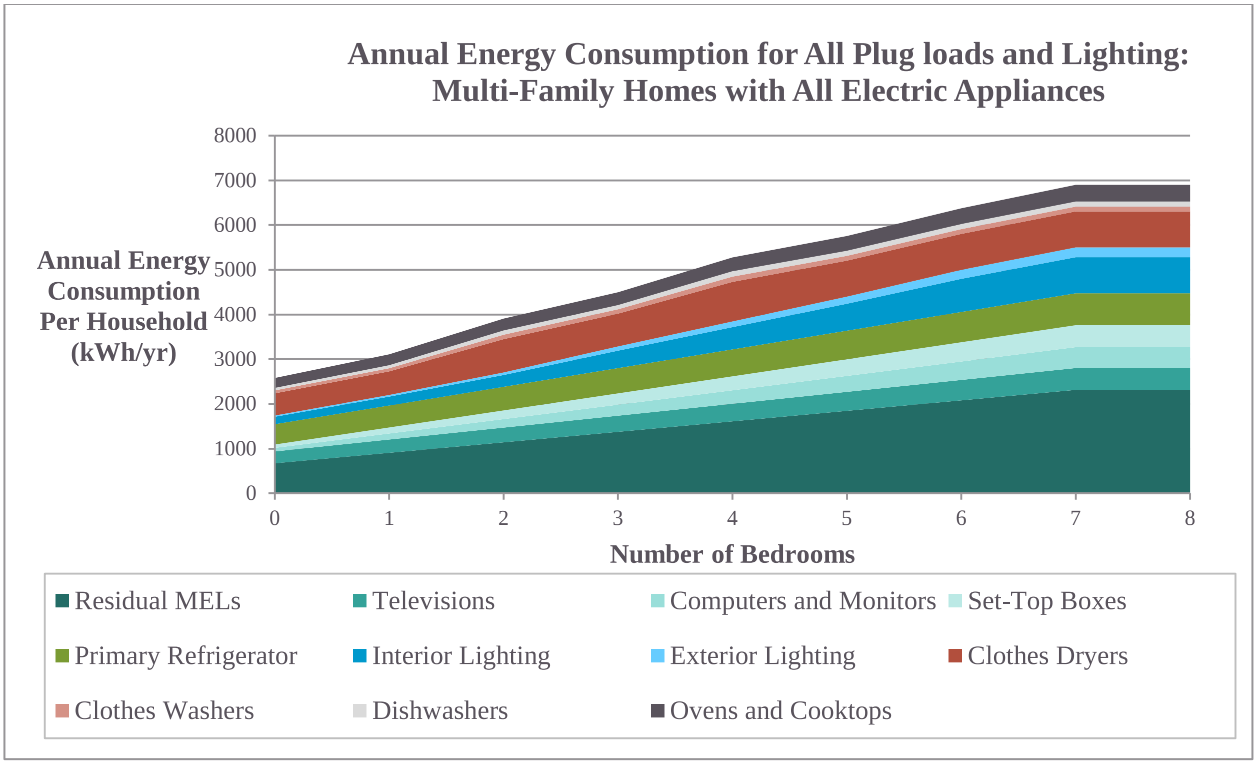

Figure 57: Estimated AEC of all plug loads and lighting as a function of NBr, multi-family homes with all electric appliances

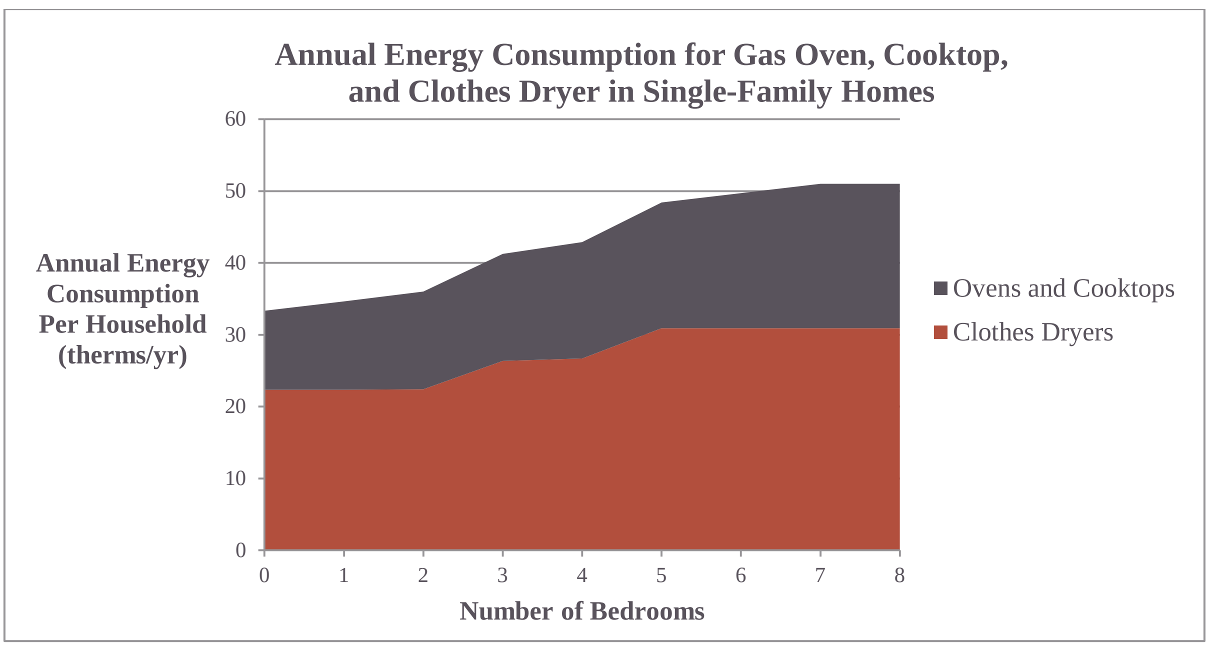

Figure 58: Estimated AEC of all gas appliances as a function of NBr, single-family homes with gas oven, cooktop, and clothes dryer

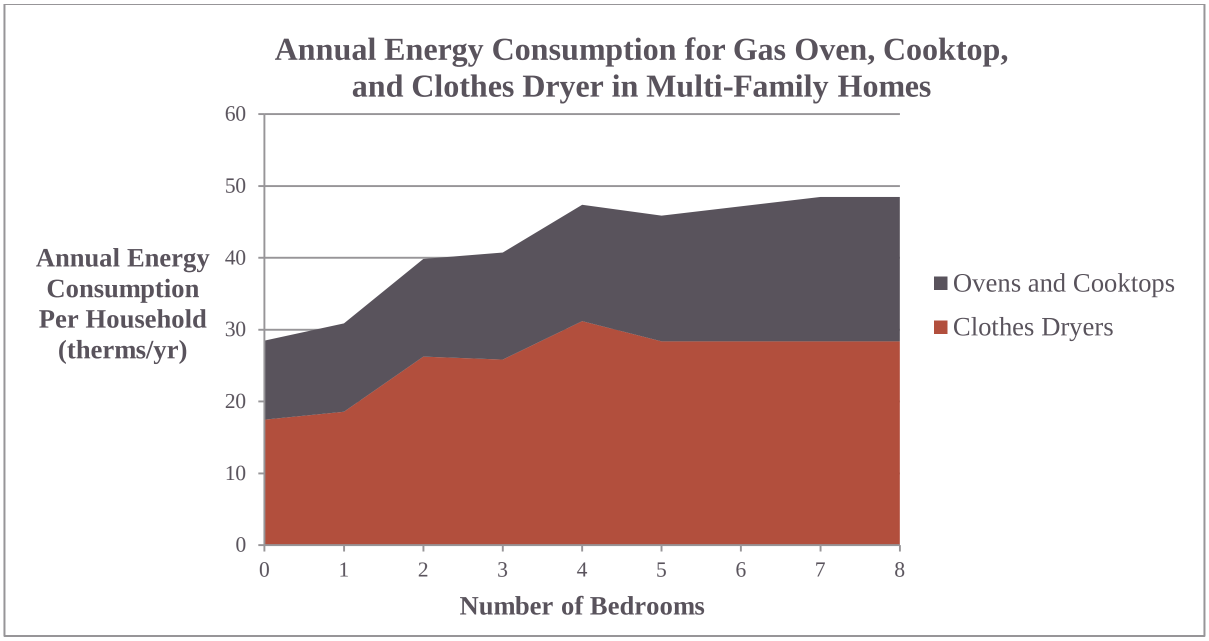

Figure 59: Estimated AEC of all gas appliances as a function of NBr, multi-family homes with gas oven, cooktop, and clothes dryer

Figure 60 and Figure 61 provide benchmarking analysis of how AEC is assumed to scale with NBr—comparing the estimated AEC of all modeled plug loads and lighting as a function of NBr to the main benchmarks described in Section 3.5.2.

For studio apartments (zero-bedroom homes), the proposed algorithms for electric and gas end uses produce similar AEC estimates to the 2013 rulesets. For all electric end uses combined, the recommended 2016 algorithms roughly tracks the existing 2013 algorithms until four–bedroom homes, at which point the existing algorithms estimate much more AEC. For all gas appliances combined, the recommend 2016 algorithms track the 2013 algorithms through two–bedroom homes, and then the existing algorithms estimate much higher AEC. In general, the recommended 2016 algorithms do not estimate as much AEC of large homes.

The RESNET 2013 standards for the reference home and the Building America House Simulation Protocols both estimate substantially more AEC than the recommended rulesets across all home sizes. However, these benchmarks were intended to represent nationwide patterns of energy use in existing buildings circa 2010.

At the visual scale of these benchmarking plots, the difference between the single-family and multi-family algorithms is minimal.

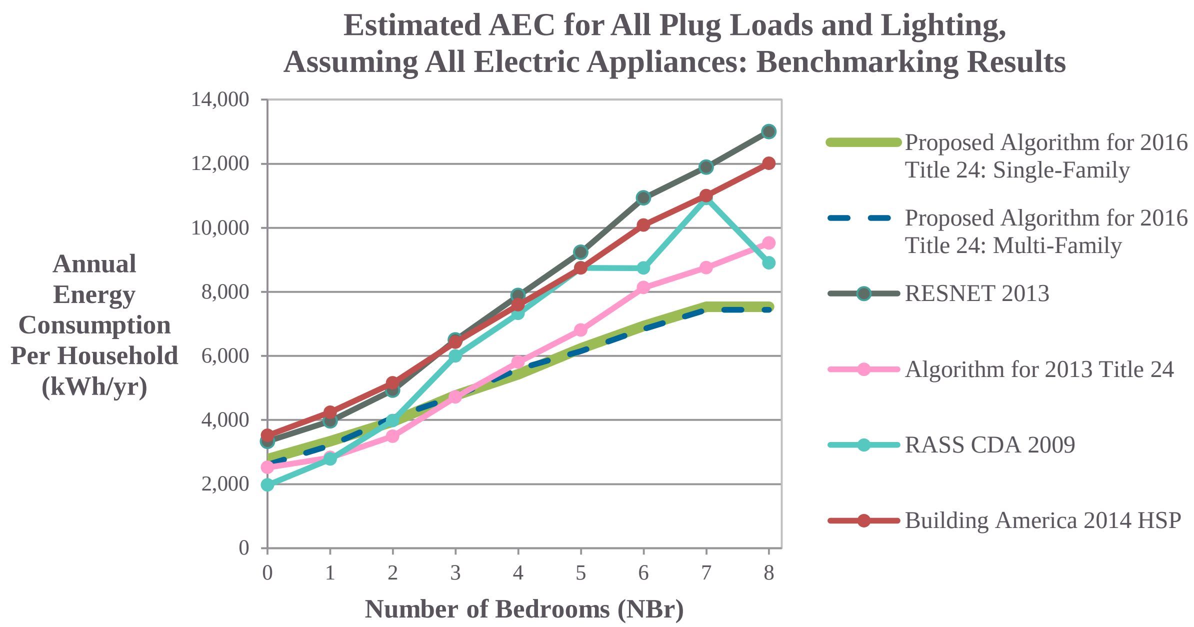

Figure 60: Benchmarking analysis of the estimated electric AEC of all plug loads and lighting as a function of NBr

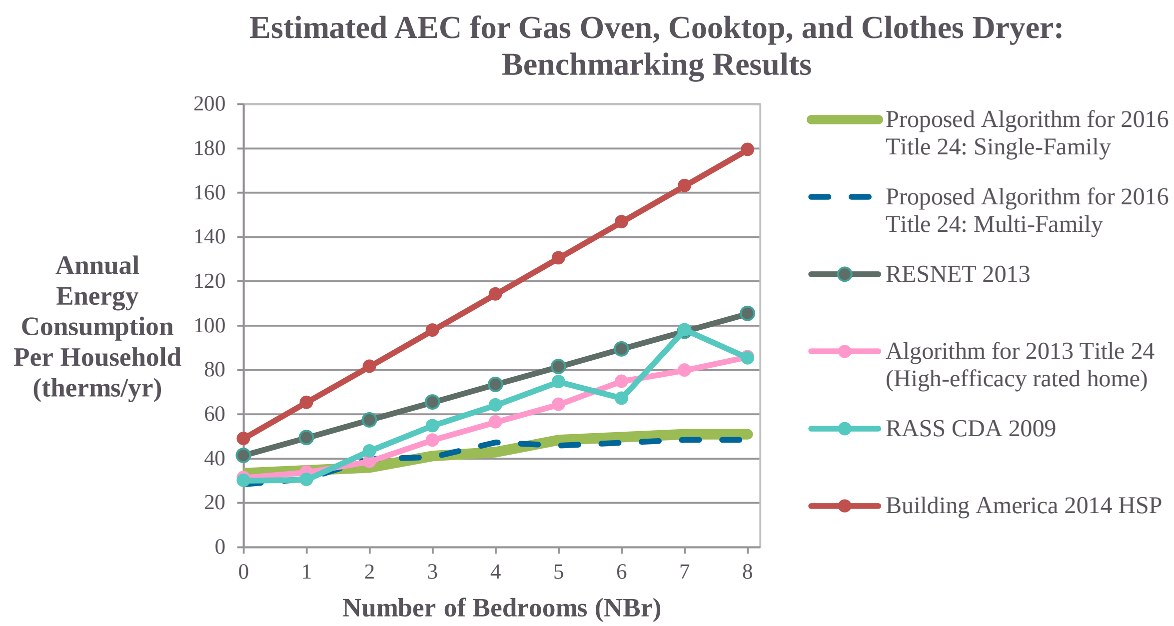

Figure 61: Benchmarking analysis of the estimated AEC of all gas appliances as a function of NBr

Figure 62, Figure 63, Figure 64, and Figure 65 provide a more detailed view of the differences between the recommended 2016 algorithms and the current 2013 algorithms, for each end use as a function of NBr. Bars above the horizontal axis indicate that the recommended 2016 algorithms estimate increased AEC of the given end use; bars below the horizontal axis indicate a decrease in AEC.

Figure 62 and Figure 63 illustrate the following differences between the proposed and existing equations for electric AEC:

- Interior lighting is estimated to use much less energy in average and large homes;
- The 2013 rulesets assumed only a primary refrigerator, but in the recommended 2016 algorithms single-family homes are assigned AEC of non-primary refrigerators and separate freezers ("other refrigeration")[68];
- The combined AEC from residual MELs and three individually modeled consumer electronics product categories is higher across all NBr—due to the growth of residual MELs[69];
- Electric oven/cooktop and clothes washer, and electric clothes dryer AEC is assumed to increase less rapidly with NBr; and
- Primary refrigerator AEC is assumed to scale with NBr instead of being constant across all homes sizes.

Figure 64 and Figure 65 illustrate the following differences between the proposed and existing equations for gas AEC:

- The proposed 2016 algorithms estimate less gas oven/cooktop AEC across all home sizes; and
- The proposed 2016 algorithms estimate less gas clothes dryer AEC of large homes.

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[68] AEC for other refrigeration is weighted according to the average saturation of non-primary refrigerators and freezers by NBr.

[69] The RASS CDA estimates for computers, televisions, and "miscellaneous" strongly informed the 2013 algorithms for "miscellaneous." The recommended 2016 algorithms estimate substantially less per-household AEC for computers and televisions than was estimated by the RASS 2009 CDA (see Figure 52). Therefore, the growth of combined AEC from residual MELs and consumer electronics is attributable to an increase in residual MELs AEC since 2008.

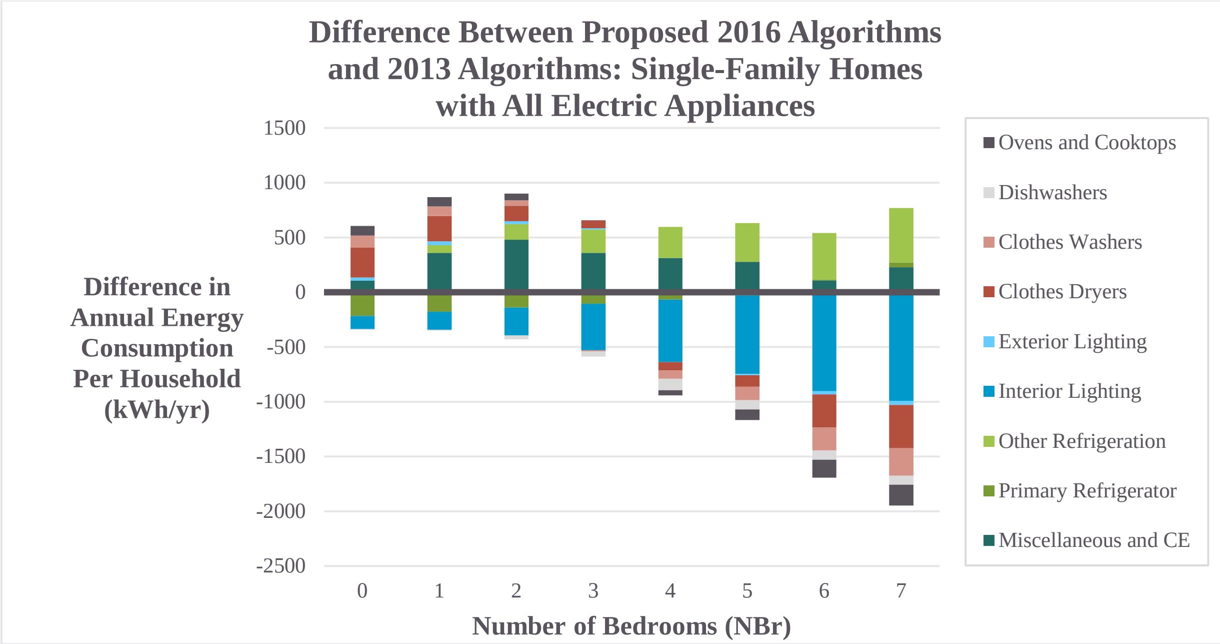

Figure 62: Difference between the proposed and existing algorithms by end use: single-family homes of varying NBr with all electric appliances

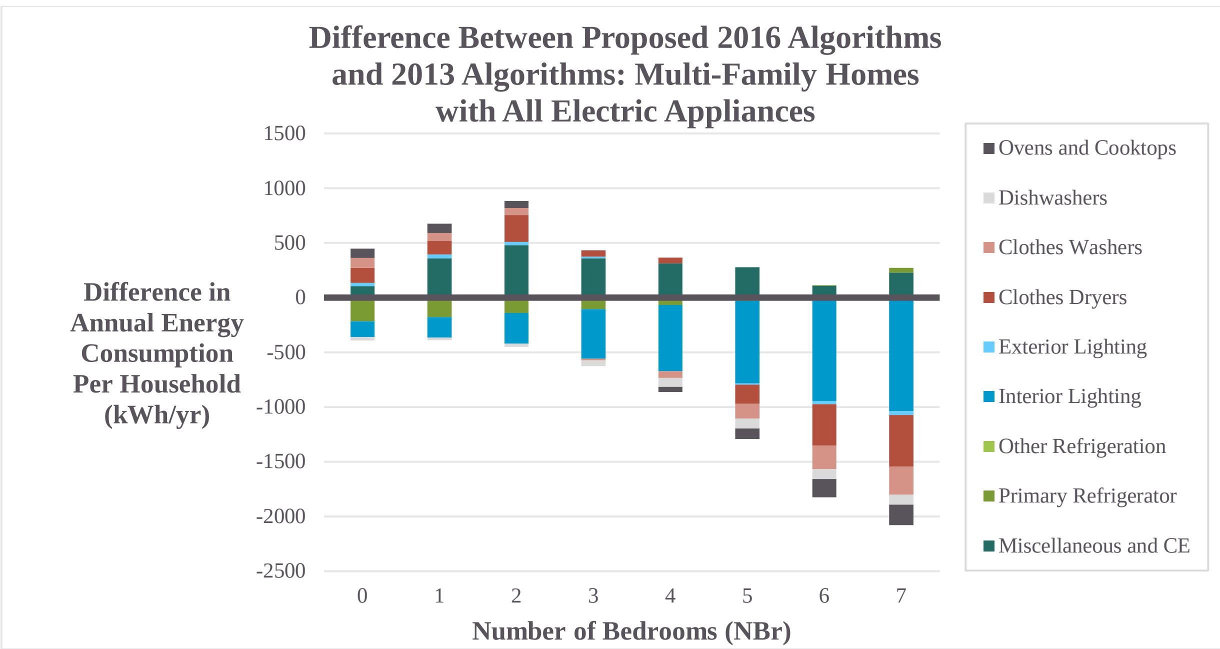

Figure 63: Difference between the proposed and existing algorithms by end use: multi-family homes of varying NBr with all electric appliances

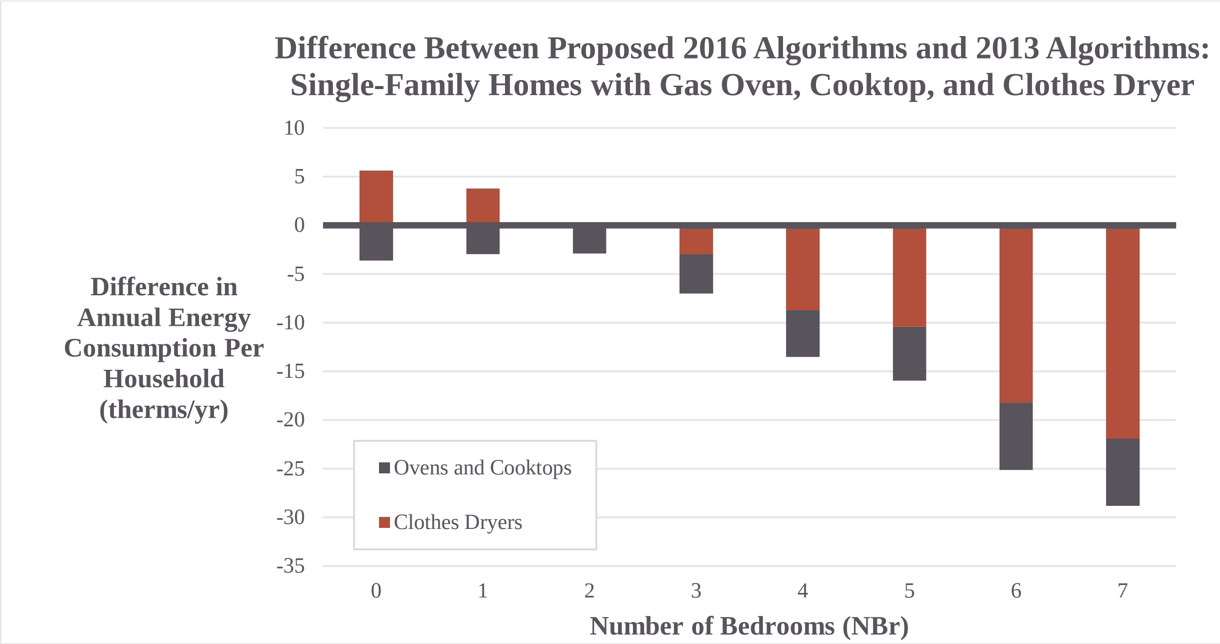

Figure 64: Difference between the proposed and existing algorithms by end use: multi-family homes of varying NBr with gas oven, cooktop, and clothes dryer

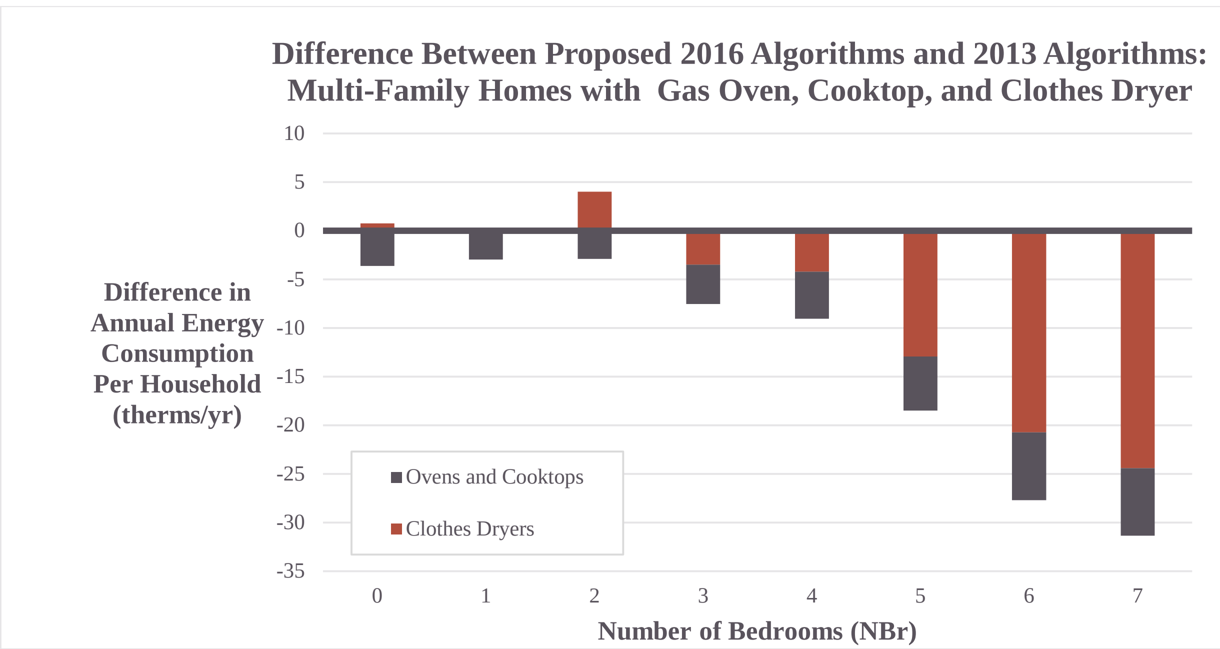

Figure 65: Difference between the proposed and existing algorithms by end use: multi-family homes of varying NBr with gas oven, cooktop, and clothes dryer

4.11.4 Key Takeaways

The Statewide CASE Team considers the following to be key takeaways from the preceding whole-home results and comparisons:

- By a wide margin, residual MELs have the highest estimated AEC of any of the modeled electric end uses, followed by electric clothes dryers (if present), and primary refrigerators;
- For average sized homes, the two greatest changes from the 2013 algorithms are a substantial decrease in interior lighting AEC and an estimated increase in the AEC of residual MELs;
- The recommended algorithms do not estimate as much AEC of large homes, compared to the 2013 rulesets.

5. ALGORITHMS TO CREDIT MORE EFFICIENT APPLIANCES

5.1 Overview

For a selection of federally-regulated major white goods, the Statewide CASE Team developed methods that allow builders to receive EDR credit for installing more efficient appliances than are required to be minimally compliant with federal standards. The motivations for creation high-efficiency algorithms were to:

- Encourage appropriately sized on-site renewable generation systems (avoid over generation in homes with highly efficient appliances);
- Allow builders to maximize the cost-effectiveness of their projects, choosing between investments in more efficient appliances or additional on-site renewable generation; and
- Incentivize the purchase and installation of efficient appliances.

For this update the Statewide CASE Team developed high-efficiency algorithms for primary refrigerators, clothes washers, and clothes dryers. The goals were to develop algorithms that would yield accurate estimates of AEC if actual equipment efficiency was known, and to establish a methodology that could use simple user inputs that can be reliably verified by on-site observation. Table 73 summarizes the user inputs that were used to determine the high-efficiency AEC algorithms. The following sections describe the high-efficiency algorithms in detail.

Table 73: List of appliances with proposed high-efficiency algorithms and basis for efficiency credit

Appliance	Additional Input for High-Efficiency Algorithm
Primary Refrigerator	Rated kWh/yr on the Energy Guide label
Clothes Washer	Compliance with the 2015 federal efficiency standards, as listed on the CEC Appliance Efficiency Database
Clothes Dryer	Remaining moisture content (RMC) of clothes after leaving the clothes washer, as listed on the CEC Appliance Efficiency Database

The Statewide CASE Team suggests that future updates to the models continue to expand the set of plug load and lighting end uses that have high-efficiency algorithms. In addition, the proposed high-efficiency algorithms could be further refined to include additional user inputs. For example, builders could specify whether the installed clothes washer is front-loading or top-loading.

5.2 Primary Refrigerators

The Statewide CASE Team proposes that builders be allowed to input the rated AEC from the Energy Guide label into the compliance software, if this information is known. Information from the Energy Guide label would override the default AEC assumption used in the primary refrigerator algorithm described in Section 4.1.5.

The Energy Guide label is required by the Federal Trade Commission (FTC) for all refrigerators sold in the US. Manufacturers must test their refrigerators in a DOE-certified third-party laboratory and print the reported AEC on an Energy Guide label that is affixed to products before they are shipped. The DOE test procedure used for the refrigerator Energy Guide label is the same as the extant federal test procedure. The assumptions underlying the rated AEC on the label are therefore the same as those underlying the default primary refrigerator algorithm, because the Statewide CASE Team relied on the federal standards to define the default AEC algorithm.[70]

For a given NBr, the EDR credit that builders can claim is capped. The intention of this limitation is to ensure that builders do not claim credit for refrigerators that are too small for the refrigeration needs of the household and that the claimed primary refrigerator AEC is a realistic long-term estimate for a home of that size. If the rated AEC on the Energy Guide label of the installed primary refrigerator is less than the minimum allowable AEC, the software tool will credit builders for installing the minimum allowable AEC.

The Statewide CASE Team calculated the minimum allowable AEC as a function of NBr. The minimum allowable AEC is an estimate of the AEC, as reported by the current federal standards test procedure for a refrigerator-freezer that is:

- Of average size, given the NBr in the home;
- A DOE product class 3 refrigerator-freezer—equipped with a top-mounted freezer and automatic defrost and without an automatic icemaker;[71] and
- 25 percent more efficient than the baseline of most recent federal efficiency standards.

To determine the average primary refrigerator size for a given NBr, the Statewide CASE Team used the estimated adjusted volume for the primary refrigerators reported in RASS that was already calculated as part of the primary refrigerator AEC methodology (see Section 4.1.4.2).

[70] Although this means that the Energy Guide label reflects the same unrealistic assumptions as the federal test procedure (such as no door openings), the benefit is that the AEC printed on the Energy Guide label can be justifiably compared to the default algorithm.

[71] The Statewide CASE Team's analysis of RASS data shows that top-mounted refrigerator-freezers with automatic defrost are the most common product class for a primary refrigerator. The federal efficiency standards prescribe a lower maximum AEC for top-mounted refrigerator-freezers than comparable bottom-mounted or side-by-side units.

The Statewide CASE Team conducted a linear regression analysis to capture the trend in how the adjusted volume of the survey-reported primary refrigerators varies with survey-reported NBr.[72] The resulting algorithm for estimating adjusted volume based on NBr is presented in Figure 66.

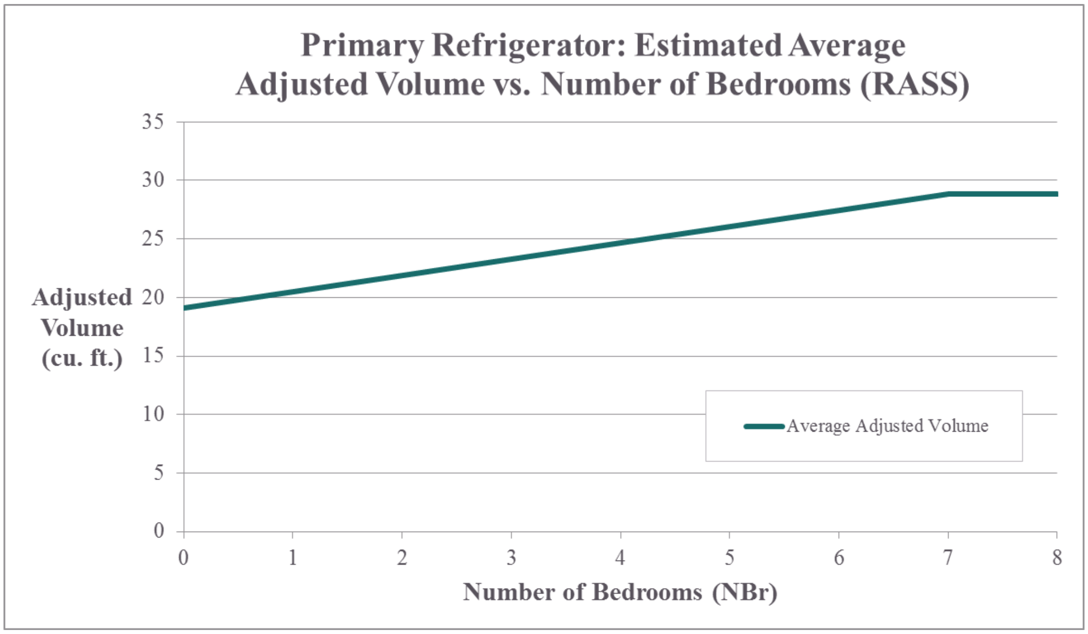

Figure 66: Algorithm to predict adjusted volume based on NBr (RASS)

The Statewide CASE Team applied the 2014 federal standard for the product class "3. Refrigerator-freezers—top-mounted refrigerator-freezers with automatic defrost and without an automatic icemaker" to the average adjusted volume algorithm. The resulting equation predicts based on NBr the code baseline AEC of an average-sized, class 3 refrigerator-freezer.

To calculate the maximum allowable AEC algorithm, the Statewide CASE Team multiplied this code baseline equation by 0.75, to allow for products that are 25 percent more efficient than 2014 code baseline.[73] Figure 67 presents the resultant minimum allowable AEC as a function of NBr, with the default AEC algorithm for primary refrigerators included to provide context.

[72] As described in Section 4.1.4.2, adjusted volume is the refrigerator size metric used by DOE to define the maximum allowable AEC for different refrigerator and freezer product classes.

[73] For reference, ENERGY STAR-qualified refrigerators are required to use 10 percent less kWh/yr than the federal minimum (https://www.energystar.gov/products/appliances/refrigerators/key_product_criteria).

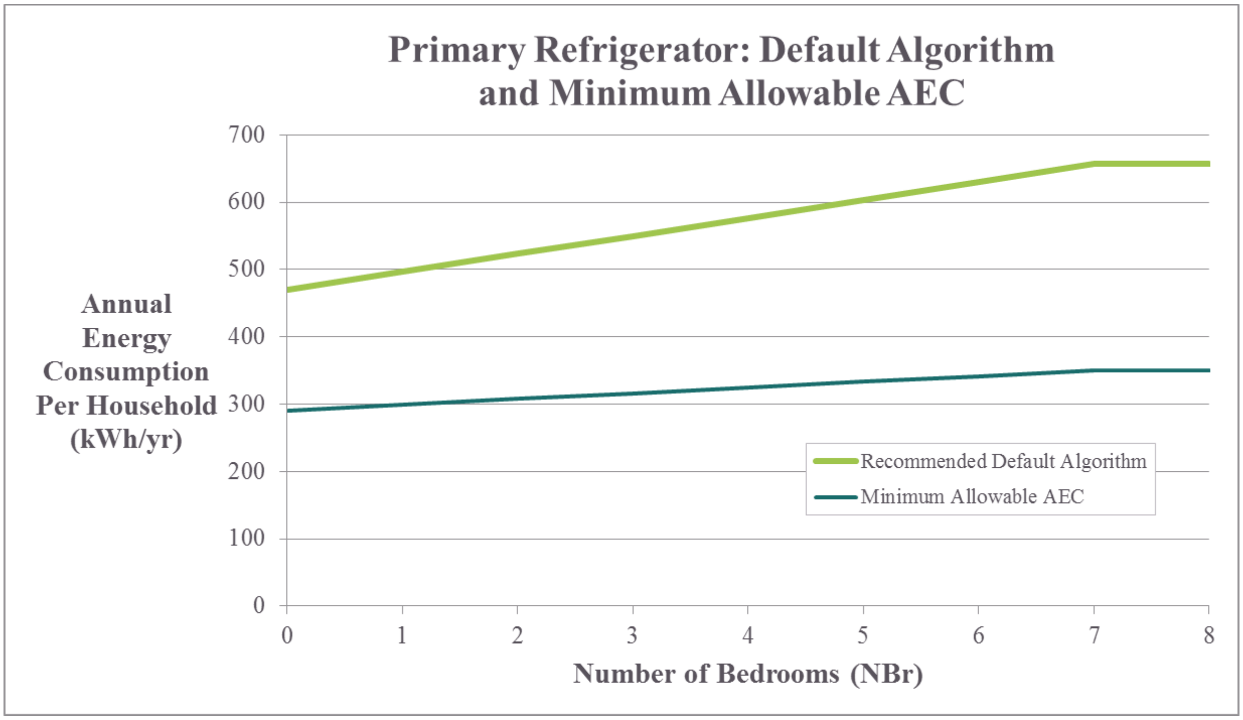

Figure 67: Minimum primary refrigerator AEC that builders may claim as a function of NBr

Table 74 presents the recommended default algorithm and minimum allowable AEC by NBr.

Table 74: Minimum primary refrigerator AEC that builders may claim by NBr

NBr	Recommended Default Algorithm	Minimum Allowable AEC	Resultant AEC Credit
0	470	291	179
1	496	299	197
2	523	308	215
3	550	316	234
4	577	325	252
5	603	333	270
6	630	341	289
7+	657	350	307

5.3 Clothes Washers

The Statewide CASE Team proposes that builders be allowed to receive EDR credit for installing a clothes washer that meets the 2015 federal efficiency standards clothes washers. Whereas the default algorithm assumes that only 29 percent of clothes washers in new homes will be manufactured after the effective date of the most recent standards (and the remaining

71 percent will only be required to meet the 2007 standards),[74] the high-efficiency clothes washer algorithm credits builders for installing modern clothes washers.

If the installed clothes washer meets the 2015 federal standards, as verified on-site by looking up the model number printed on the installed device in the California Appliance Efficiency Database, the estimated per cycle energy consumption of the clothes washer will be equal to 0.209 kWh/use instead of 0.259 kWh/use. Figure 68 and Figure 69 present the clothes washer algorithm for devices that meet the 2015 federal standards,[75] as well as the default AEC algorithm for clothes washers to provide context.

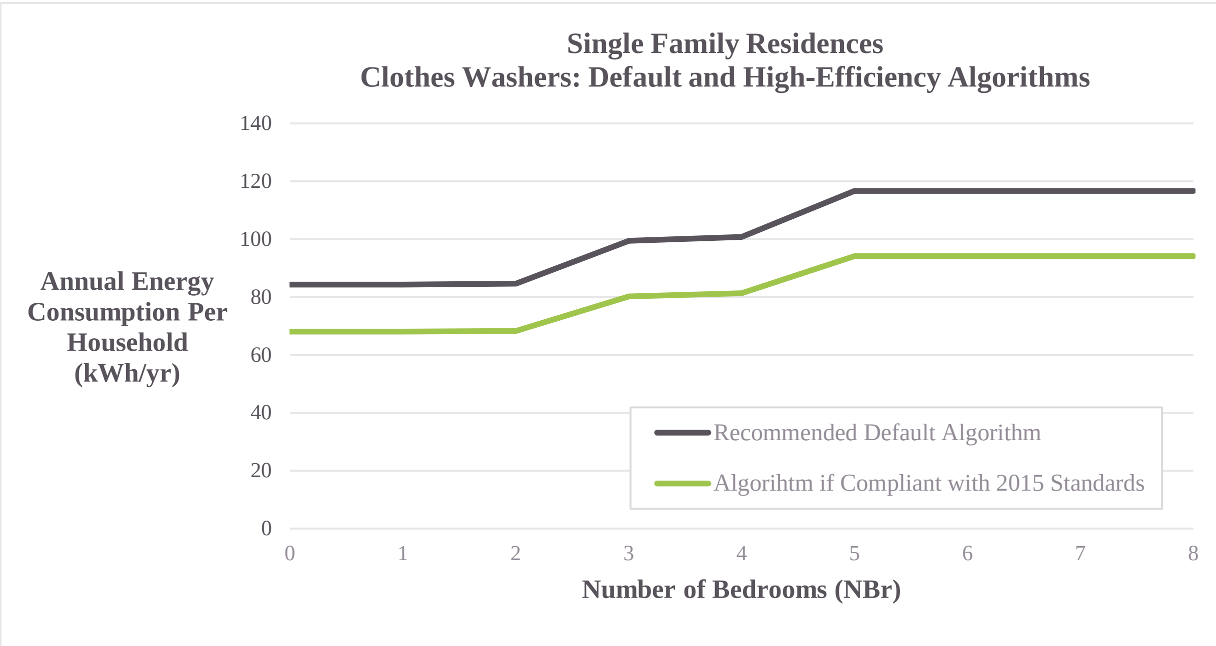

Figure 68: High-efficiency and default algorithms for clothes washers in single-family residences

[74] See Appendix A for details on how these proportions were determined using RASS data

[75] Technically, any clothes washer that meets the 2015 federal standard can receive credit, regardless of its age.

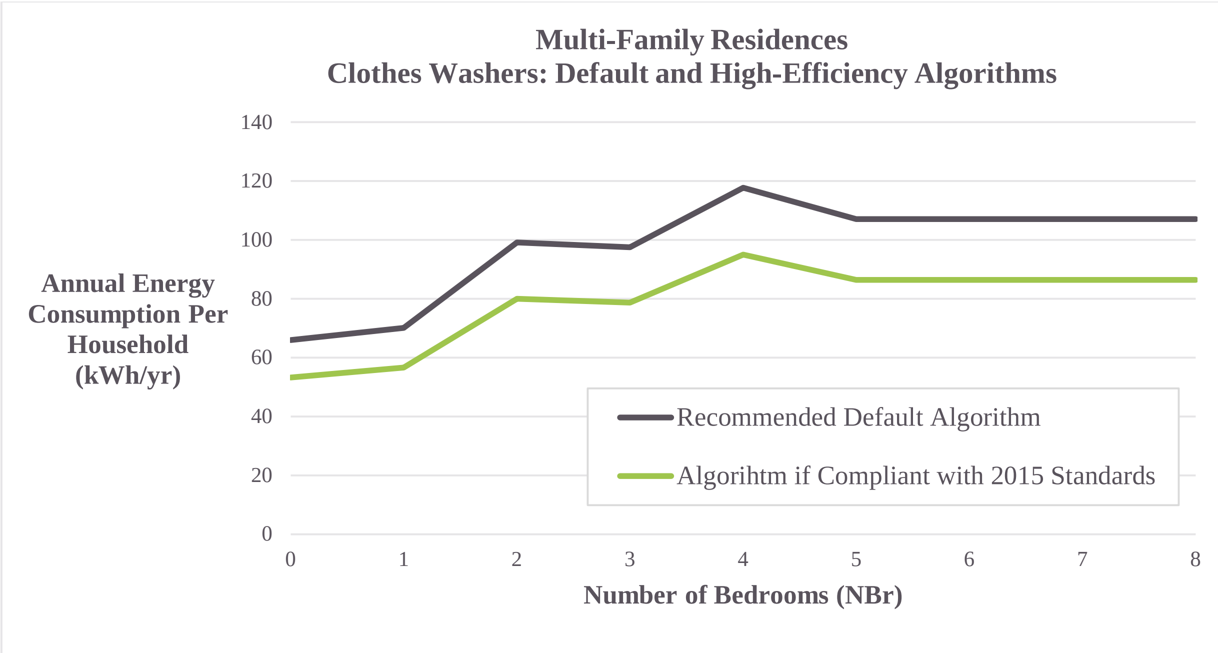

Figure 69: High-efficiency and default algorithms for clothes washers in multi-family residences

Table 75 presents the recommended default algorithm, high-efficiency clothes washer algorithm, and resultant AEC credit by NBr.

Table 75: High-efficiency and default algorithms for clothes washers

NBr	Single-Family			Multi-Family		
	Recommended Default Algorithm (kWh)	High-Efficiency Clothes Washer Algorithm[1] (kWh)	Resultant AEC Credit (kWh)	Recommended Default Algorithm (kWh)	High-Efficiency Clothes Washer Algorithm[1] (kWh)	Resultant AEC Credit (kWh)
0	84	68	16	66	53	13
1	84	68	16	70	57	13
2	85	68	17	99	80	19
3	100	80	20	98	79	19
4	101	81	20	118	95	23
5+	117	94	23	107	86	21

1. Applicable to clothes washers that meet the 2015 federal efficiency standards.

The AEC credit for clothes washer machine energy use is small compared with the potential credit for high-efficiency primary refrigerators; builders that install a high-efficiency clothes washer can also receive credit in the CEC HWH ruleset for reduced water use and water heating energy consumption.

5.4 Gas and Electric Clothes Dryers

The Statewide CASE Team proposes that builders be able to claim EDR credit for the clothes dryer if the installed clothes washer has a remaining moisture content (RMC) less than the default RMC assumed in the clothes washer algorithm methodology. This approach accounts for the fact that if clothes washers leave clothes less damp after washing, it reduces the amount of energy that the clothes dryer needs to input to evaporate the water content of the clothes. In fact, an EDR credit scheme based on clothes washer RMC is potentially much greater than one based on whether the clothes dryer meets the newest federal standard. In future updates to the AEC rulesets, both of these adjustment methods could be implemented in tandem.

The default RMC assumption for clothes washers is 50 percent. The RMC-adjusted clothes AEC can be roughly approximated as:

$$AEC_{RMC-Adjusted} = AEC_{Default} \times \frac{RMC_{Actual}}{50\%}$$

In other words, if the installed clothes washer leaves half as much moisture in the washed clothes as is assumed in the default equation (i.e. the actual RMC is 25 percent compared to the default assumption of 50 percent), the RMC-adjusted clothes dryer AEC will be roughly half the default clothes dryer AEC estimate. This result is based on the simplifying assumption that the clothes dryer active per use energy is proportional to the water content of the clothes, as discussed in Section 4.4.4.2. A more precise calculation of RMC-adjusted dryer AEC is provided at the end of this section.

Figure 70, Figure 71, Figure 72, and Figure 73 present the electric and gas clothes dryer algorithms for a selection of clothes washer RMC values, as well as the default AEC algorithm for clothes dryers to provide context. Note that if the builder installs a clothes washer with an RMC greater than 50 percent and opts to input this information, the estimated clothes dryer AEC would increase.

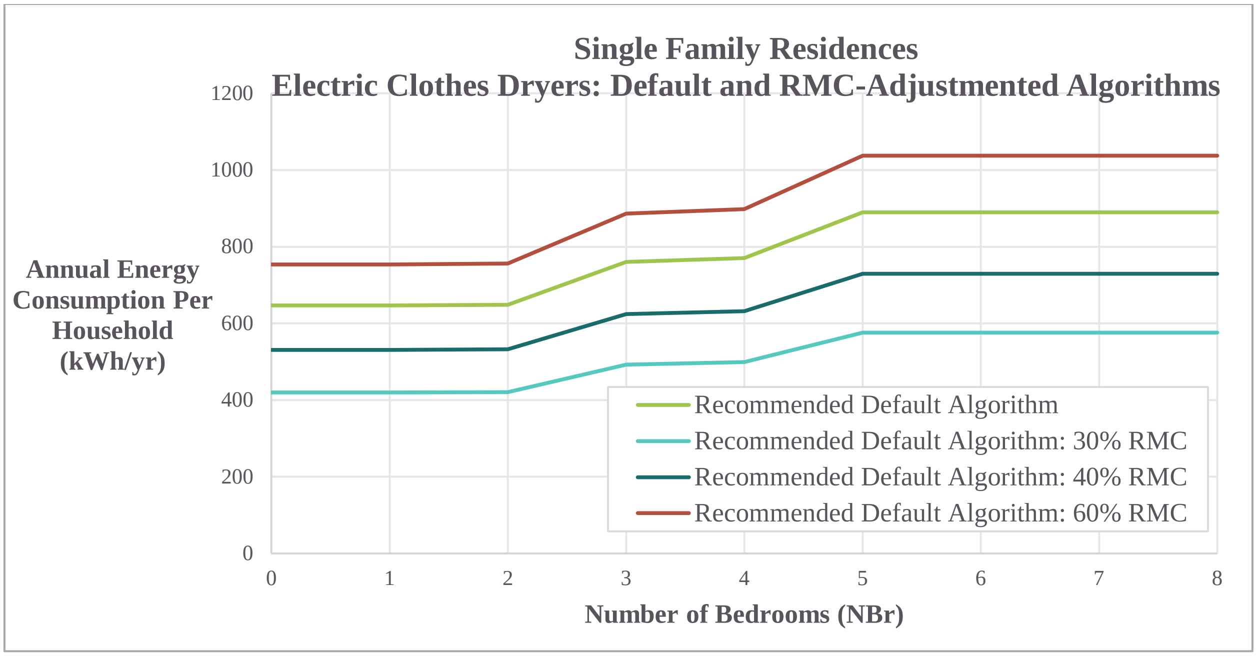

Figure 70: RMC-adjusted clothes electric dryer algorithm for single-family residences

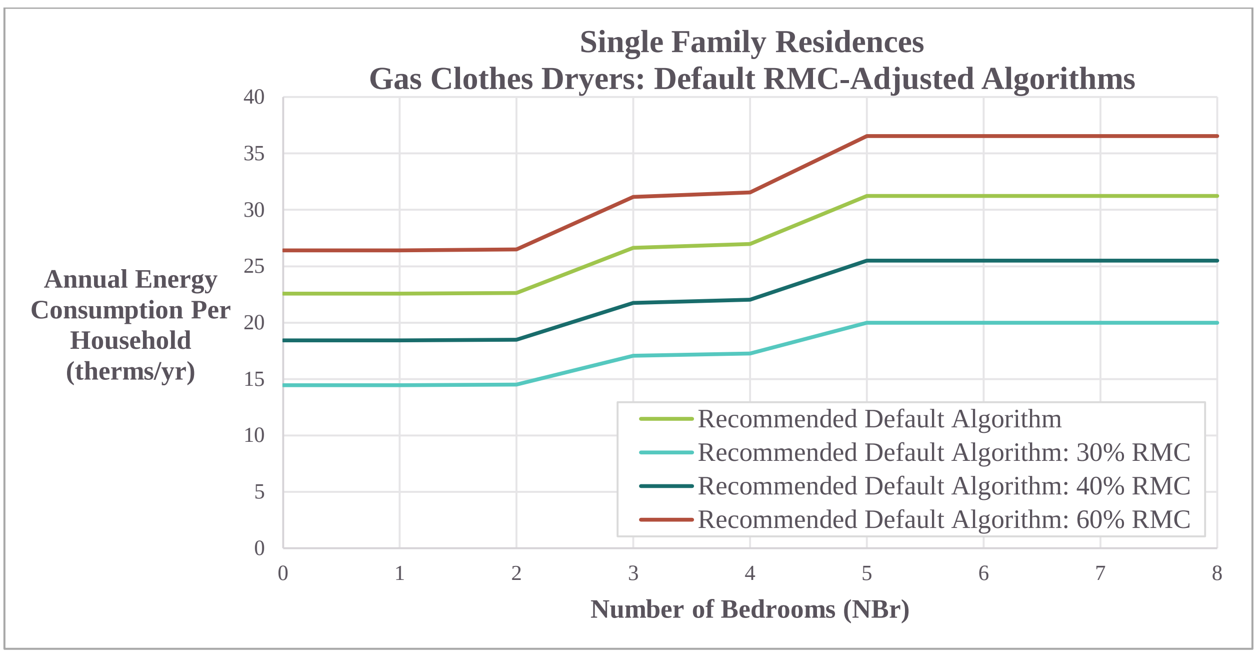

Figure 71: RMC-adjusted clothes gas dryer algorithm for single-family residences

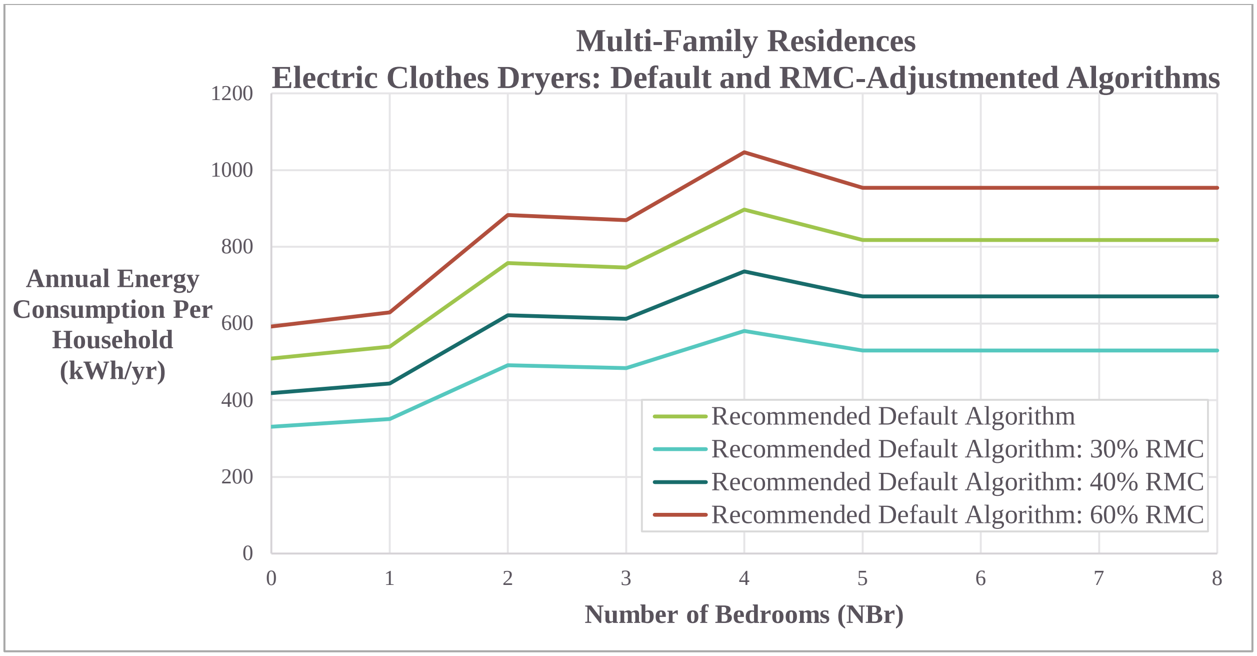

Figure 72: RMC-adjusted clothes electric dryer algorithm for multi-family residences

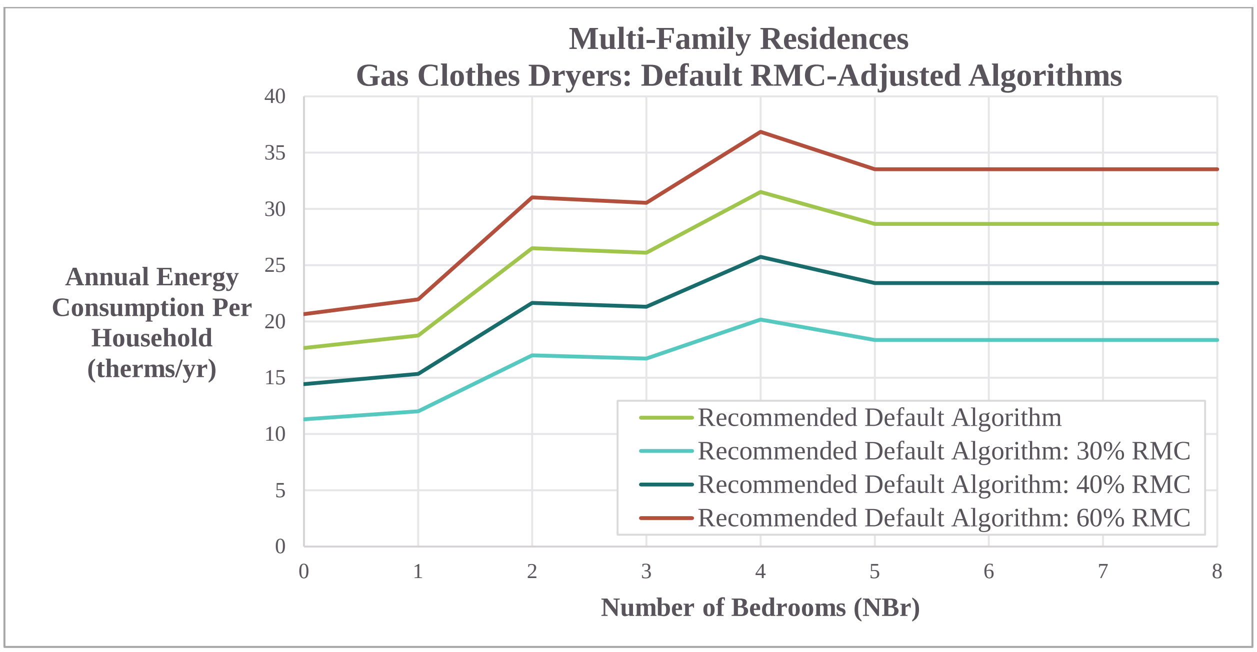

Figure 73: RMC-adjusted clothes gas dryer algorithm for multi-family residences

Table 76 and Table 77 present the recommended default algorithm, the RMC-adjusted algorithm assuming an RMC of 30 percent, and resultant AEC credits by NBr for electric and gas clothes dryers. For reference, the average RMC of front- and top-loading clothes washers listed on the CEC Appliance Efficiency Database that meet the 2015 federal standard is 31 percent and 46 percent, respectively.[76]

Table 76: RMC-adjusted gas clothes dryer AEC, assuming average percent RMC for a modern top-loading washer

NBr	Single-Family			Multi-Family		
	Recommended Default Algorithm (therms)	RMC-adjusted algorithm: 30% RMC (therms)	Resultant AEC Credit: 30% RMC (therms)	Recommended Default Algorithm (therms)	RMC-adjusted algorithm: 30% RMC (therms)	Resultant AEC Credit: 30% RMC (therms)
0	23	14	9	18	11	7
1	23	14	9	19	12	7
2	23	14	9	27	17	10
3	27	17	10	26	17	9
4	27	17	10	31	20	11
5+	31	20	11	29	18	11

Table 77: RMC-adjusted electric clothes dryer AEC, assuming average percent RMC for a modern top-loading washer

NBr	Single-Family			Multi-Family		
	Recommended Default Algorithm (kWh)	RMC-adjusted algorithm: 30% RMC (kWh)	Resultant AEC Credit: 30% RMC (kWh)	Recommended Default Algorithm (kWh)	RMC-adjusted algorithm: 30% RMC (kWh)	Resultant AEC Credit: 30% RMC (kWh)
0	647	420	227	508	331	177
1	647	420	227	540	351	189
2	649	421	228	757	491	266
3	760	493	267	746	483	263
4	770	499	271	897	581	316
5+	890	576	314	818	530	288

The following calculations demonstrate a more precise calculation of RMC-adjusted clothes dryer energy per use for a given RMC input from the user. The RMC-adjusted AEC can be calculated by determining the RMC-adjusted energy per use through the equations below and multiplying that by the assumed cycles per year in Table 78. (See Section 4.4.4.3 for the derivation of the annual cycle assumptions.)

$$\left(\frac{Energy}{Cycle}\right)_{Adjusted} \approx \left[\left(\frac{Energy}{Cycle}\right) - RMC_{adj}\right]\left(\frac{RMC_{Actual,Reported} - RMC_{Field,End}}{RMC_{Actual,CASE} - RMC_{Field,End}}\right) + RMC_{adj}$$

Energy / cycle = 2.21 kWh/cycle for electric, 0.077 therms/cycle for gas;
RMC_{adj} = 0.25 kWh/cycle, 0.00853 therms/cycle for gas;
RMC_{CASE} = 50.4 percent for electric, 50.3 percent for gas;

[76] Average RMCs are model-weighted means of the listed products.

$RMC_{UserInput}$ = RMC of the installed washer, inputted by the user and verified on-site.

Electric Dryer: RMC-adjusted kWh/use

$$\left(\frac{Energy}{Cycle}\right)_{Adjusted} \approx \left[\left(2.21\frac{kWh}{cycle}\right) - 0.25\frac{kWh}{cycle}\right]\left(\frac{RMC_{User,Input}}{50.4\%}\right) + 0.25\frac{kWh}{cycle}$$

$$\left(\frac{Energy}{Cycle}\right)_{Adjusted} \approx 0.0389\left(RMC_{User,Input}\right) + 0.25 \quad \frac{kWh}{cycle}$$

Gas Dryer: RMC-adjusted therms/use

$$\left(\frac{Energy}{Cycle}\right)_{Adjusted} \approx \left[\left(0.077\frac{therms}{cycle}\right) - 0.00853\frac{therms}{cycle}\right]\left(\frac{RMC_{User,Input}}{50.3\% - 0\%}\right) + 0.00853\frac{therms}{cycle}$$

$$\left(\frac{Energy}{Cycle}\right)_{Adjusted} \approx 0.00136\left(RMC_{User,Input}\right) + 0.00853 \qquad \frac{therms}{cycle}$$

Table 78: Annual clothes dryer cycles estimated based on NBr

NBr	Dishwasher Cycles Per Year	
	Single-Family	Multi-Family
0	290	227
1	290	241
2	291	341
3	342	335
4	346	405
5+	401	368

6. Load Profile Analysis

6.1 Overview

Understanding how energy usage is distributed over time (on an hourly, daily, and seasonal basis) for each of the modeled product categories is critically important to analyzing and understanding energy use impacts. These modeled load profiles for plug load and lighting affect the TDV calculations. Homes are defined as being ZNE if they have an EDR of zero, which means the TDV of the energy consumed on-site is equal to the TDV of the renewable energy generated on-site. Since plug loads and lighting represent such a large portion of whole-building energy use and TDV can have a measurable impact on how energy used or generated during a given hour of the year is valued, it is important for the MEL and lighting load profiles to be accurate.

The 2013 Residential ACM Reference Manual provides hourly load profiles for an average day (weekdays and weekends use the same load profiles) and seasonal adjustment factors for refrigeration, interior lighting, exterior lighting, and "equipment." The equipment category is used for all plug loads other than refrigeration. The 2013 Residential ACM also provides load profiles for people loads (i.e. internal gains from the body heat of occupants). The Statewide CASE Team has not proposed revisions to these factors (see Section 8.1.7).

Table 79 presents current hourly schedules for plug loads and lighting. The hourly schedules for equipment and interior lighting indicate two periods of increased energy use: a smaller peak in the morning and a larger peak the evening. Refrigeration energy use is assumed to be constant throughout the day and exterior lighting energy use is assumed to occur entirely from 8 p.m. to midnight.

Table 79: Hourly schedules for plug loads and lighting in the 2013 Residential ACM (percent of daily total)

Time	Refrigerators	People	Equipment	Interior Lighting	Exterior Lighting
0:00	4.2%	3.5%	3.7%	2%	0%
1:00	4.2%	3.5%	3.5%	2%	0%
2:00	4.2%	3.5%	3.4%	2%	0%
3:00	4.2%	3.5%	3.4%	2%	0%
4:00	4.2%	3.5%	3.2%	2%	0%
5:00	4.2%	5.9%	3.6%	3%	0%
6:00	4.2%	8.2%	4.2%	4%	0%
7:00	4.2%	5.5%	4.4%	4%	0%
8:00	4.2%	2.7%	3.7%	3%	0%
9:00	4.2%	1.4%	3.2%	3%	0%
10:00	4.2%	1.4%	3.3%	3%	0%
11:00	4.2%	1.4%	3.3%	3%	0%
12:00	4.2%	1.4%	3.2%	2%	0%
13:00	4.2%	1.4%	3.3%	2%	0%
14:00	4.2%	1.9%	3.5%	2%	0%
15:00	4.2%	2.7%	3.7%	3%	0%
16:00	4.2%	4.1%	4.4%	3%	0%
17:00	4.2%	5.5%	5.3%	4%	0%
18:00	4.2%	6.8%	5.8%	8%	0%
19:00	4.2%	8.2%	6.0%	12%	0%
20:00	4.2%	8.2%	6.2%	11%	25%
21:00	4.2%	7.0%	6.0%	10%	25%
22:00	4.2%	5.3%	5.2%	6%	25%
23:00	4.2%	3.5%	4.5%	4%	25%

The 2013 Residential ACM also provides a single set of monthly multipliers to adjust for seasonal variability. Table 80 presents current seasonal multipliers. The current rulesets apply the same seasonal adjustment factors to people, equipment, and interior lighting and indicate that energy use is highest in the winter and lowest in the summer. The current rulesets assume that there is no seasonal variation in energy use for refrigeration and exterior lighting.

Table 80: Seasonal Multipliers for plug loads and lighting in the 2013 Residential ACM (monthly multipliers).

Month	Refrigerators	People	Equipment	Interior Lighting	Exterior Lighting
Jan	1.0	1.2	1.2	1.2	1.0
Feb	1.0	1.1	1.1	1.1	1.0
Mar	1.0	1.0	1.0	1.0	1.0
Apr	1.0	0.9	0.9	0.9	1.0
May	1.0	0.8	0.8	0.8	1.0
Jun	1.0	0.8	0.8	0.8	1.0
Jul	1.0	0.8	0.8	0.8	1.0
Aug	1.0	0.9	0.9	0.9	1.0
Sep	1.0	1.0	1.0	1.0	1.0
Oct	1.0	1.1	1.1	1.1	1.0
Nov	1.0	1.2	1.2	1.2	1.0
Dec	1.0	1.2	1.2	1.2	1.0

The daily and seasonal load profile assumptions in the 2013 Residential ACM are not sufficiently granular to accurately model the unique usage patterns of different plug load and lighting product categories analyzed in this report. The Statewide CASE Team recommends that, to the extent possible given existing data, the rulesets be updated to use separate load profiles for each end use and separate hourly schedules for weekday and weekend days. To that end, the Statewide CASE Team has proposed updated hourly schedules and seasonal multipliers for all MEL and lighting product categories. Section 6.2 summarizes the main submetering studies and data sources that the Statewide CASE Team used to develop the proposed load profiles. Sections 6.3 and 0 summarize which data sources were used for each end use and provide the recommended load profile coefficients.

6.2 Data Sources for Load Profiles

The Statewide CASE Team recommends that dishwashers, clothes washers, and clothes dryers use the Title 24 WH ruleset load profiles. Using the Title 24 WH ruleset load profiles for these end uses serves the Statewide CASE Team's goal of aligning the plug load and WH rulesets.

Ideally, the other load profiles defined in the Residential ACM would be based on large, recent, California-specific submetering studies that measure the hourly energy use of each of the modeled end uses for at least a year. Unfortunately, this high standard of data is not presently available for the other plug load and lighting end uses. As such, the Statewide CASE Team recommends using data from recent submetering studies conducted in Florida and the Pacific Northwest to update the load profiles for most of the other modeled product categories. The Statewide CASE Team recognizes that there are potential pitfalls with relying on time-of-use data from studies that are not California-specific.[77] Given the known shortcomings of the

[77] There are many factors that could reduce the reliability of data from other regions to the extent that they differ by region and influence plug load and lighting load profiles. These factors include, but are limited to, differences in climate, hours of

current load profiles and the benefits of more granular load profiles derived from recent data, the Statewide CASE Team recommends using data from the following studies until more ideal data is available.

6.2.1 Florida Phased Deep Retrofit (PDR) Project Data

The Phased Deep Retrofit (PDR) project is a collaboration between Florida Power & Light (FPL) and the DOE Building America Partnership for Improved Residential Construction (Building America 2012). The purpose of this home energy-efficiency retrofit program is to gather data on the ability of shallow and deep retrofits to achieve and peak energy reductions, and to identify how energy efficiency in existing homes can best be improved.

The Statewide CASE Team used submetering data from PDR metering conducted by Florida Solar Energy Center (FSEC) from 2012–2013. FSEC performed home audits, and installed detailed metering equipment in 60 all-electric, single-family Florida residences for at least six months per home. FSEC provided PDR submetering data summarized by hour of the day and month of the year to support the creation of the hourly schedules and seasonal multipliers for ovens, cooktops, and televisions. The Statewide CASE Team derived the load profiles by determining the ratio of average metered energy use between the hours of the day and months of the year, respectively.

6.2.2 NEEA RBSA

NEEA submetered 101 single-family, all-electric homes in the Pacific Northwest as part of their 2014 RBSA. Each home was submetered at a device level (at 15-minute intervals) for a full year and light loggers were installed to measure hours of on-time in interior and exterior spaces. Submetered appliances include all of the individually-modeled plug load product categories in this CASE Report. Data was collected in 2012 and 2013 (NEEA 2014).

The Statewide CASE Team analyzed the publically-available submetering and light logging microdata to create hourly schedules for both weekday and weekend days as well as seasonal multipliers. To determine load profile factors for each end use sub-metered by NEEA, the Statewide CASE Team aggregated the data into one-hour increments. The Statewide CASE Team then averaged the data across all homes in the dataset, resulting in hourly load profiles for one full year for each load that was individually submetered in the study. Next, the Statewide CASE Team summed all related loads in the dataset to match the product categories analyzed in this report (e.g. all non-primary refrigeration loads were aggregated, all interior lighting loads were aggregated). Finally, the Statewide CASE Team derived hourly schedules and seasonal multipliers by calculating the average ratio of metered energy use between the hours of the day and months of the year, respectively.

daylight, economy, demographics, cultural practices, energy rates, efficiency regulations, and programs that promote efficiency and/or conservation.

6.3 Proposed Hourly Schedules

Table 81 summarizes the data sources for the recommended hourly schedules.

Table 81: Recommended hourly schedules data sources for each modeled end use

End Use	Data Source
Refrigerators and Freezers	PDR[1]
Dishwashers	CEC HWH ruleset
Clothes washers	CEC HWH ruleset
Clothes dryers	CEC HWH ruleset[1]
Ovens and cooktops	PDR
Televisions	PDR
Set-top boxes	NEEA RBSA
Computers and monitors	NEEA RBSA
Exterior lighting	NEEA RBSA
Interior and garage lighting	Existing hourly schedule (HMG 1999)
Residual MELs	Existing hourly schedule (BA HSP 2009)

1. With modification, as explained below.

Dishwashers and clothes washers have the same hourly schedule as modeled in the Title 24 WH ruleset. The Title 24 WH ruleset has a full annual water draw schedule. Both the plug load models and Title 24 WH rulesets for dishwashers and clothes washers assume that each water draw has corresponding machine energy use and water heating energy use. The Statewide CASE Team recommends that the timing of gas and electric clothes dryer energy use be the same as clothes washer energy use, but shifted one hour forward to account for the time between starting the clothes washer and clothes dryer loads.

The recommended hourly schedules for set-top boxes, computers and monitors, and exterior lighting are derived from the NEEA RBSA submetering and light logging data. The Statewide CASE Team relied on PDR submetering data for the refrigerators, televisions, ovens, and cooktops hourly schedules. As with clothes dryers, the recommended oven and cooktop hourly schedules are the same for gas and electric devices.

Both primary refrigerators and non-primary refrigerators rely on PDR data; however, the method is markedly different from the other end uses. The CEC used PDR submetering data and indoor temperature readings to develop an algorithm that adjusts estimated refrigerator and freezer energy use based on indoor temperature. For each hour of the year, the algorithm adjusts the energy use from the plug load algorithm up or down depending on the indoor temperature simulated by the compliance software in the space where the refrigerator or freezer is installed.[78] A simulated temperature of 78°F yields no adjustment to the estimated energy use for that hour, but warmer or cooler indoor temperatures produce an increase or decrease in estimated hourly energy use, respectively. Therefore, the hourly load profile for primary and non-primary refrigerator is defined by the simulated indoor temperatures instead of look-up tables like all other MELs and lighting loads.

The Statewide CASE Team recommends that interior lighting and garage lighting retain their current hourly schedules for the 2016 Title 24 code cycle. The current hourly schedule for interior and garage lighting is based on the 1999 HMG study *Lighting Efficiency Technology Report: California Baseline* (CEC 2008a). Specifically, the hourly schedules are based on the estimated fraction of fixtures in the home that are on during each hour of the day. The HMG study authors arrived at these fractions through analysis of light logging data from a sample 359 California homes (CEC 1999). For future updates to the lighting models, the DEER 2011 hourly schedule for residential CFLs may be a viable alternative (KEMA 2010a). Unfortunately, neither the 1999 HMG study nor the DEER 2011 load profiles have hourly schedules for exterior lighting.

The Statewide CASE Team also recommends that residual MELs retain their current hourly schedules for the 2016 Title 24 code cycle. The current hourly schedule for residual MELs is the hourly schedule for the "equipment" category. This hourly schedule originates from the 2008 Building America House Simulation Protocols (CEC 2008a), which in turn relied on data from a 1989 Pacific Northwest submetering study conducted by the End-Use Load and Consumer Assessment Program (ELCAP). The study, entitled *Description of Electric Energy Use in Single-Family Residences in the Pacific Northwest*, included both metering and submetering of 280 homes during two-year periods from 1984 to 1988. The Building America authors derived the residual MELs hourly schedule by the subtracting the electricity use of the major white goods in the ELCAP study from the electricity use for all equipment. Thus, the main strength of the residual MELs hourly schedule is that it is calculated as a residual using metered data, instead of being based on submetering data from a handful of "representative" MELs. Given the magnitude of residual MEL's AEC, how quickly the constituent end uses are evolving, and the age of ELCAP data, there is a pressing need for modern, California-specific data on residual MELs load profiles.

Figure 74 shows the hourly schedules assumed in the 2013 ACM. Figure 75 and Figure 76 show the Statewide CASE Team's recommendations for weekday and weekend hourly schedules for the 2016 Title 24 code cycle. The updated hourly schedules (oven and cooktop, major consumer electronics, and exterior lighting) reflect the variation between weekdays and weekends latent in their submetering data. Most end uses did not have a pronounced difference

[78] Primary refrigerators are assumed to be installed in the kitchen. Non-primary refrigerators and separate freezers are assumed to be installed in the garage in single-family housing with a garage. Multi-family housing is not assigned non-primary refrigerator and separate freezer AEC.

between weekends and weekdays. Ovens and cooktops have by far the greatest variation between weekdays and weekends, with a much higher evening peak on weekdays.[79]

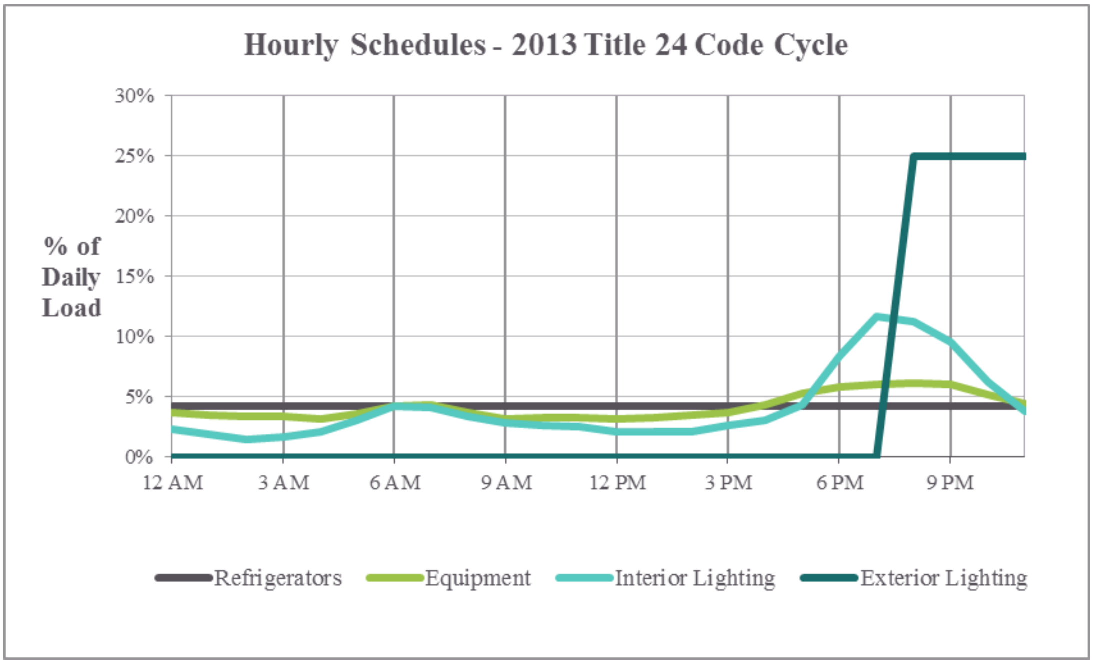

Figure 74: Current hourly schedules in the 2013 Residential ACM Reference Manual

[79] The Statewide CASE Team also analyzed NEEA submetering data for refrigerators, freezers, dishwashers, clothes washers and clothes dryers and found that dishwashers, clothes washers and clothes dryers have a difference in weekday and weekend hourly schedules.

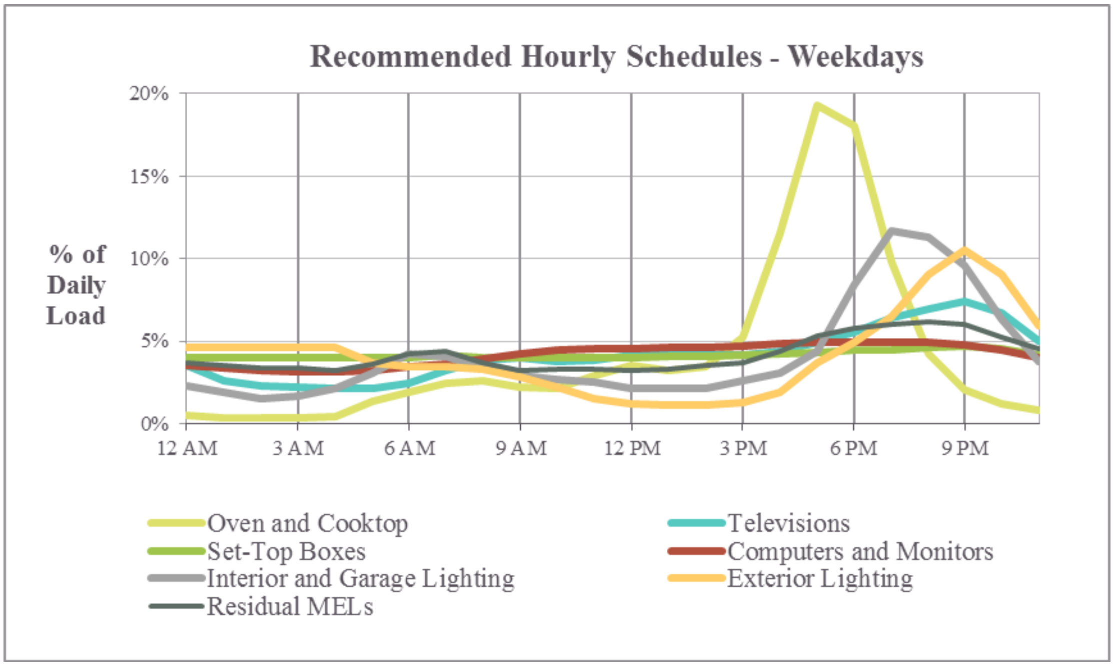

Figure 75: Recommended weekday hourly schedules

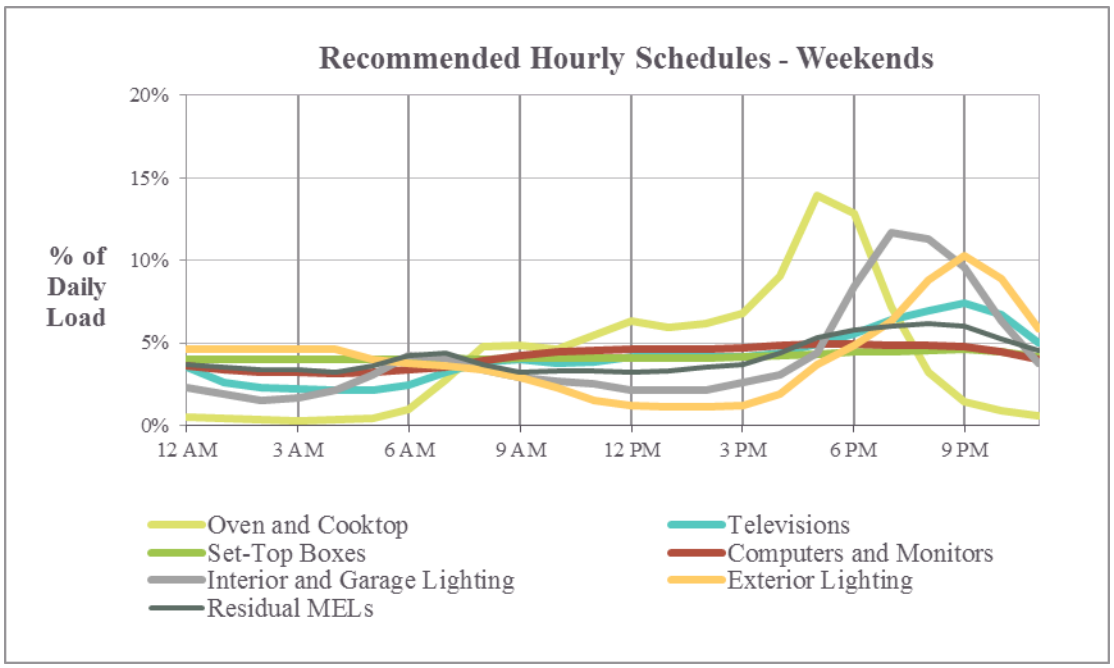

Figure 76: Recommended weekend hourly schedules

Table 82, Table 83,

Table 84, and Table 85 show the recommended hourly schedules for plug loads and lighting on weekdays and weekends.

Table 82: Recommended weekday schedules for appliances and other MELs

Time	Oven and Cooktop	Televisions	Set-Top Boxes	Computers and Monitors	Residual MELs
0:00	1%	4%	4%	4%	4%
1:00	0%	3%	4%	3%	4%
2:00	0%	2%	4%	3%	3%
3:00	0%	2%	4%	3%	3%
4:00	0%	2%	4%	3%	3%
5:00	1%	2%	4%	3%	4%
6:00	2%	2%	4%	3%	4%
7:00	2%	3%	4%	4%	4%
8:00	3%	4%	4%	4%	4%
9:00	2%	4%	4%	4%	3%
10:00	2%	4%	4%	4%	3%
11:00	3%	4%	4%	5%	3%
12:00	4%	4%	4%	5%	3%
13:00	3%	4%	4%	5%	3%
14:00	3%	4%	4%	5%	4%
15:00	5%	4%	4%	5%	4%
16:00	12%	4%	4%	5%	4%
17:00	19%	5%	4%	5%	5%
18:00	18%	6%	4%	5%	6%
19:00	10%	6%	4%	5%	6%
20:00	4%	7%	5%	5%	6%
21:00	2%	7%	5%	5%	6%
22:00	1%	7%	5%	4%	5%
23:00	1%	5%	4%	4%	5%
Total:	100%	100%	100%	100%	100%

Table 83: Recommended weekend schedules for appliances and other MELs

Time	Oven and Cooktop	Televisions	Set-Top Boxes	Computers and Monitors	Residual MELs
0:00	0%	4%	4%	4%	4%
1:00	0%	3%	4%	3%	4%
2:00	0%	2%	4%	3%	3%
3:00	0%	2%	4%	3%	3%
4:00	0%	2%	4%	3%	3%
5:00	0%	2%	4%	3%	4%
6:00	1%	2%	4%	3%	4%
7:00	3%	3%	4%	4%	4%
8:00	5%	4%	4%	4%	4%
9:00	5%	4%	4%	4%	3%
10:00	5%	4%	4%	4%	3%
11:00	5%	4%	4%	5%	3%
12:00	6%	4%	4%	5%	3%
13:00	6%	4%	4%	5%	3%
14:00	6%	4%	4%	5%	4%
15:00	7%	4%	4%	5%	4%
16:00	9%	4%	4%	5%	4%
17:00	14%	5%	4%	5%	5%
18:00	13%	6%	4%	5%	6%
19:00	7%	6%	4%	5%	6%
20:00	3%	7%	5%	5%	6%
21:00	1%	7%	5%	5%	6%
22:00	1%	7%	4%	4%	5%
23:00	1%	5%	4%	4%	5%
Total:	100%	100%	100%	100%	100%

Table 84: Recommended weekday schedules lighting

Time	Interior and Garage Lighting	Exterior Lighting
0:00	2%	5%
1:00	2%	5%
2:00	2%	5%
3:00	2%	5%
4:00	2%	5%
5:00	3%	4%
6:00	4%	3%
7:00	4%	3%
8:00	3%	3%
9:00	3%	3%
10:00	3%	2%
11:00	3%	2%
12:00	2%	1%
13:00	2%	1%
14:00	2%	1%
15:00	3%	1%
16:00	3%	2%
17:00	4%	4%
18:00	8%	5%
19:00	12%	7%
20:00	11%	9%
21:00	10%	11%
22:00	6%	9%
23:00	4%	6%
Total:	100%	100%

Table 85: Recommended weekend schedules lighting

Time	Interior and Garage Lighting	Exterior Lighting
0:00	2%	5%
1:00	2%	5%
2:00	2%	5%
3:00	2%	5%
4:00	2%	5%
5:00	3%	4%
6:00	4%	4%
7:00	4%	4%
8:00	3%	3%
9:00	3%	3%
10:00	3%	2%
11:00	3%	2%
12:00	2%	1%
13:00	2%	1%
14:00	2%	1%
15:00	3%	1%
16:00	3%	2%
17:00	4%	4%
18:00	8%	5%
19:00	12%	6%
20:00	11%	9%
21:00	10%	10%
22:00	6%	9%
23:00	4%	6%
Total:	100%	100%

6.4 Proposed Seasonal Multipliers

Table 86 summarizes the data sources underlying the seasonal multipliers recommended by the Statewide CASE Team.

Table 86: Recommended seasonal multipliers data sources for each modeled end use.

End Use	Data Source
Refrigerators and Freezers	PDR[1]
Dishwashers	CEC HWH ruleset
Clothes washers	CEC HWH ruleset
Clothes dryers	CEC HWH ruleset[1]
Ovens and cooktops	PDR
Televisions	PDR
Set-top boxes	NEEA RBSA
Computers and monitors	NEEA RBSA
Exterior lighting	Existing seasonal multipliers* (monthly hours of daylight)
Interior and garage lighting	Existing seasonal multipliers (monthly hours of daylight)
Residual MELs	Existing seasonal multipliers (monthly hours of daylight)

1. With modification, explained below.

Dishwashers, clothes washers, and clothes dryers will use load profiles from the Title 24 WH rulesets. Adding seasonal variation through monthly multipliers is not possible due to the structure of the Title 24 WH ruleset, which defines a detailed annual water draw schedule including the duration and flow rate of each use.

The recommended seasonal multipliers for set-top boxes and computers and monitors are derived from the NEEA RBSA submetering data. The Statewide CASE Team relied on PDR submetering data for the televisions, ovens, and cooktops seasonal multipliers. The recommended oven and cooktop seasonal multipliers are the same for gas and electric devices.

As described above in the context of hourly schedules, the Statewide CASE Team recommends that refrigerator energy use be adjusted based on simulated indoor temperatures for each hour of the year. This will result in a pattern of seasonal variation with more refrigeration energy use in the summer and less in the winter.

The Statewide CASE Team recommends that interior lighting, garage lighting, and residual MELs continue to use their current seasonal multipliers for the 2016 Title 24 code cycle. The current seasonal multipliers are derived from the hours of daylight in each month; the regression analysis used to justify the original adoption of those multipliers showed an inverse relationship between hours of daylight and energy use in California households.[80] The

[80] For lighting, this relationship is intuitive because daylight is a direct substitute or artificial lighting. The negative correlation between hours of daylight and the AEC of other electric loads may be explained by occupants spending more time indoors during the winter months.

Statewide CASE Team also recommends that exterior lighting use these seasonal multipliers instead of the current assumption of no seasonal variation. Light logging data from the NEEA RBSA shows that the average monthly hours of on-time for interior and exterior lighting have a similar pattern of variation, which approximates the seasonal multipliers in the 2013 Residential ACM.

Figure 77 shows the seasonal multipliers in the 2013 ACM. Figure 78 and Table 87 present Statewide CASE Team's recommendations for updated, 2016 seasonal multipliers. The end uses that rely on PDR and NEEA submetering data have differing patterns of seasonal variation, which are less intuitive than the hourly schedules. This may be because the factors that affect daily energy use are inherently more salient in our everyday lives than the factors that influence annual trends. However, in updates to the model, it would be valuable to verify whether the seasonal trends in the PDR and NEEA data can be reproduced in California-specific submetering studies.

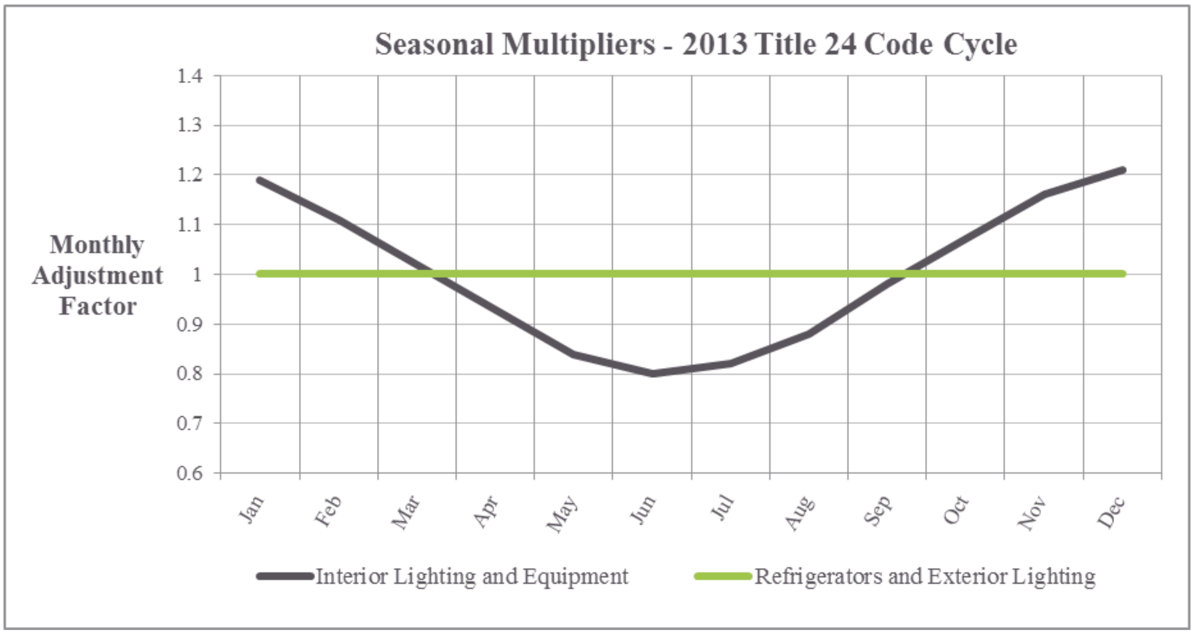

Figure 77: Current seasonal multipliers in the 2013 ACM

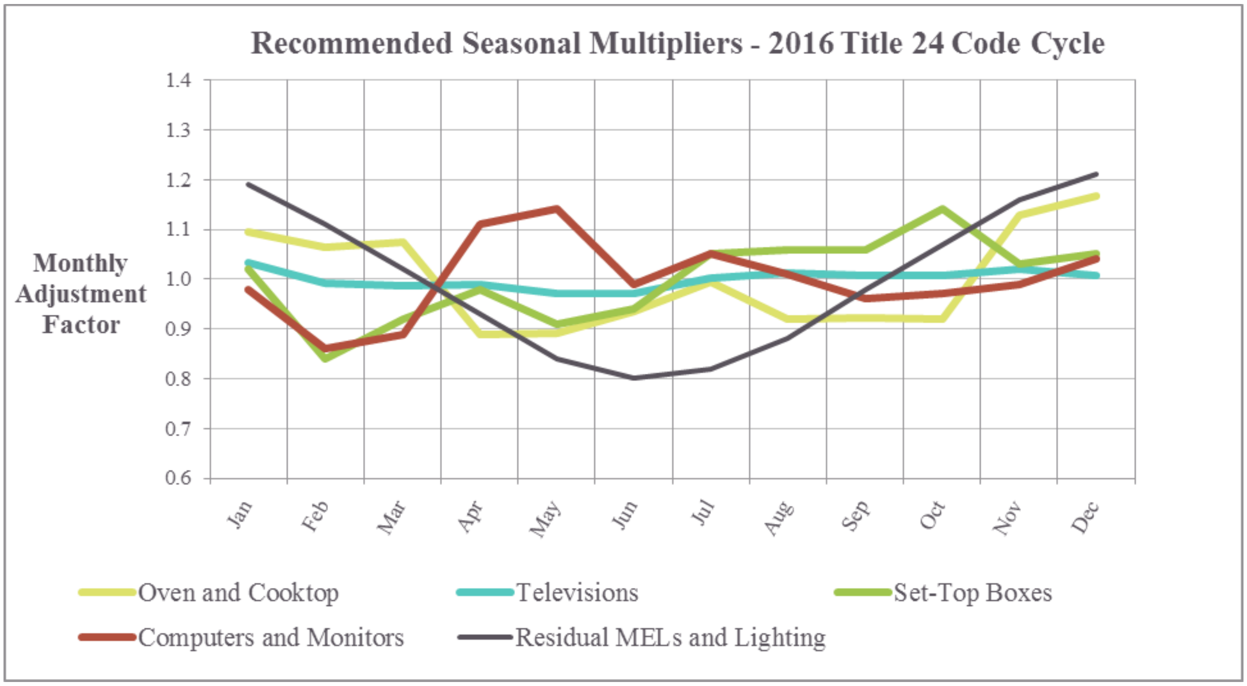

Figure 78: Recommended seasonal multipliers

Table 87: Recommended seasonal multipliers

Month	Oven and Cooktop	Televisions	Set-Top Boxes	Computers and Monitors	Residual MELs and
Jan	1.09	1.03	1.02	0.98	1.19
Feb	1.07	0.99	0.84	0.86	1.11
Mar	1.07	0.99	0.92	0.89	1.02
Apr	0.89	0.99	0.98	1.11	0.93
May	0.89	0.97	0.91	1.14	0.84
Jun	0.94	0.97	0.94	0.99	0.80
Jul	0.99	1.00	1.05	1.05	0.82
Aug	0.92	1.01	1.06	1.01	0.88
Sep	0.92	1.01	1.06	0.96	0.98
Oct	0.92	1.01	1.14	0.97	1.07
Nov	1.13	1.02	1.03	0.99	1.16
Dec	1.17	1.01	1.05	1.04	1.21

7. Summary of Results

7.1 Updated Annual Energy Consumption Rulesets

The Statewide CASE Team recommends that CEC update the following rulesets for estimating AEC of plug loads (white goods, major consumer electronics, and residual MELs) based on NBr. See Section 9 for additional details on the application of the rulesets—including when to assign AEC (e.g. depending on the presence of the device) and how to determine fuel type—and information on alternative algorithms to credit more efficient appliances.

Table 88: Recommended AEC rulesets for electric appliances

Product Category	Building Type (SF/MF/All)	Number of Bedrooms (NBr)							
		0	1	2	3	4	5	6	7+
Residual MELs	All	672	907	1,141	1,376	1,610	1,845	2,079	2,314
Clothes Dryers	SF	634	634	636	748	758	877	877	877
	MF	496	527	745	733	885	805	805	805
Primary Refrigerator	All	454	491	528	565	602	639	676	713
Other Refrigerators and Freezers	SF	0	71	142	213	284	355	426	497
	MF	0	0	0	0	0	0	0	0
Televisions	All	265	297	329	361	393	425	456	488
Ovens	All	138	154	170	186	202	218	234	250
Cooktops	All	84	89	95	101	106	112	118	124
Set-Top Boxes	All	76	135	194	254	313	373	432	491
Computers and Monitors	All	79	135	190	246	301	356	412	467
Clothes Washers	SF	84	84	85	99	101	117	101	117
	MF	66	70	99	97	118	107	107	107
Dishwashers	SF	83	83	91	100	99	119	119	119
	MF	56	68	96	94	121	114	114	114

Table 89: Recommended AEC rulesets for gas appliances

Fuel Usage Unit	Product Category	Building Type (SF/MF/All)	Number of Bedrooms (NBr)							
			0	1	2	3	4	5	6	7+
Therms	Clothes Dryers	SF	22	22	22	26	27	31	31	31
		MF	17	19	26	26	31	28	28	28
	Oven	All	6	7	8	9	10	11	12	13
	Cooktop	All	5	5	6	6	6	7	7	7
kWh	Clothes Dryers	SF	32	32	32	37	38	44	44	44
		MF	25	26	37	37	44	40	40	40
	Oven	Al	41	46	51	55	60	65	70	75

The following equations are used to estimate lighting AEC based on CFA. If CFA per home (or dwelling unit) is more 4,150 square feet, input 4,150 square feet into the equation:

Equation 11: Interior lighting AEC as a function of CFA

$$AEC_{Int} = 0.18(CFA) + 101$$

Equation 12: Exterior lighting AEC as function of CFA

$$AEC_{Ext} = 0.053(CFA) + 8$$

Equation 13: Garage lighting AEC as function of CFA

$$AEC_{Gar} = 0.0063(CFA) + 20$$

7.2 Load Profiles

7.2.1 Hourly Schedules

The Statewide CASE Team recommends the following hourly schedules to distribute total daily load over the course of the day (Table 90 and Table 91). The Statewide CASE Team also developed hourly schedules for refrigerators, freezers, dishwashers, clothes washers, and clothes dryers. Those coefficients are not included below because these product categories will be using alternate methodologies (see Section 6.3).

Table 90: Recommended hourly schedules – weekdays

Time	Oven and Cooktop	Televisions	Set-Top Boxes	Computers and Monitors	Residual MELs	Interior and Garage Lighting	Exterior Lighting
0:00	1%	4%	4%	4%	4%	2%	5%
1:00	0%	3%	4%	3%	4%	2%	5%
2:00	0%	2%	4%	3%	3%	2%	5%
3:00	0%	2%	4%	3%	3%	2%	5%
4:00	0%	2%	4%	3%	3%	2%	5%
5:00	1%	2%	4%	3%	4%	3%	4%
6:00	2%	2%	4%	3%	4%	4%	3%
7:00	2%	3%	4%	4%	4%	4%	3%
8:00	3%	4%	4%	4%	4%	3%	3%
9:00	2%	4%	4%	4%	3%	3%	3%
10:00	2%	4%	4%	4%	3%	3%	2%
11:00	3%	4%	4%	5%	3%	3%	2%
12:00	4%	4%	4%	5%	3%	2%	1%
13:00	3%	4%	4%	5%	3%	2%	1%
14:00	3%	4%	4%	5%	4%	2%	1%
15:00	5%	4%	4%	5%	4%	3%	1%
16:00	12%	4%	4%	5%	4%	3%	2%
17:00	19%	5%	4%	5%	5%	4%	4%
18:00	18%	6%	4%	5%	6%	8%	5%
19:00	10%	6%	4%	5%	6%	12%	7%
20:00	4%	7%	5%	5%	6%	11%	9%
21:00	2%	7%	5%	5%	6%	10%	11%
22:00	1%	7%	5%	4%	5%	6%	9%
23:00	1%	5%	4%	4%	5%	4%	6%

Time	Oven and Cooktop	Televisions	Set-Top Boxes	Computers and Monitors	Residual MELs	Interior and Garage Lighting	Exterior Lighting
Total:	100%	100%	100%	100%	100%	100%	100%

Table 91: Recommended hourly schedules – weekends

Time	Oven and Cooktop	Televisions	Set-Top Boxes	Computers and Monitors	Residual MELs	Interior and Garage Lighting	Exterior Lighting
0:00	0%	4%	4%	4%	4%	2%	5%
1:00	0%	3%	4%	3%	4%	2%	5%
2:00	0%	2%	4%	3%	3%	2%	5%
3:00	0%	2%	4%	3%	3%	2%	5%
4:00	0%	2%	4%	3%	3%	2%	5%
5:00	0%	2%	4%	3%	4%	3%	4%
6:00	1%	2%	4%	3%	4%	4%	4%
7:00	3%	3%	4%	4%	4%	4%	4%
8:00	5%	4%	4%	4%	4%	3%	3%
9:00	5%	4%	4%	4%	3%	3%	3%
10:00	5%	4%	4%	4%	3%	3%	2%
11:00	5%	4%	4%	5%	3%	3%	2%
12:00	6%	4%	4%	5%	3%	2%	1%
13:00	6%	4%	4%	5%	3%	2%	1%
14:00	6%	4%	4%	5%	4%	2%	1%
15:00	7%	4%	4%	5%	4%	3%	1%
16:00	9%	4%	4%	5%	4%	3%	2%
17:00	14%	5%	4%	5%	5%	4%	4%
18:00	13%	6%	4%	5%	6%	8%	5%
19:00	7%	6%	4%	5%	6%	12%	6%
20:00	3%	7%	5%	5%	6%	11%	9%
21:00	1%	7%	5%	5%	6%	10%	10%
22:00	1%	7%	4%	4%	5%	6%	9%
23:00	1%	5%	4%	4%	5%	4%	6%
Total:	100%	100%	100%	100%	100%	100%	100%

7.2.2 Seasonal Multipliers

The Statewide CASE Team recommends the following seasonal multipliers to adjust estimated energy use on a monthly basis (Table 92). The Statewide CASE Team also developed seasonal multipliers for refrigerators/freezers, dishwashers, clothes washers, and clothes dryers. Those coefficients are not included below because these product categories will be using alternate methodologies (see Section 6.4).

Table 92: Recommended Seasonal Multipliers

Month	Oven and Cooktop	Televisions	Set-Top Boxes	Computers and Monitors	Residual MELs and Lighting
Jan	1.09	1.03	1.02	0.98	1.19
Feb	1.07	0.99	0.84	0.86	1.11
Mar	1.07	0.99	0.92	0.89	1.02
Apr	0.89	0.99	0.98	1.11	0.93
May	0.89	0.97	0.91	1.14	0.84
Jun	0.94	0.97	0.94	0.99	0.80
Jul	0.99	1.00	1.05	1.05	0.82
Aug	0.92	1.01	1.06	1.01	0.88
Sep	0.92	1.01	1.06	0.96	0.98
Oct	0.92	1.01	1.14	0.97	1.07
Nov	1.13	1.02	1.03	0.99	1.16
Dec	1.17	1.01	1.05	1.04	1.21

8. Recommended Future Work

The recommended rulesets were developed using the best data available at the time with the expectation that more robust and recent data will become available in the future. Future iterations of these models should aim to incorporate recent field data and survey data and update the assumptions about mandatory and voluntary efficiency standards.

For example, using data from the upcoming RASS—scheduled for 2018—would be preferable to use of the 2009 RASS. RASS data can be extremely useful for gathering product inventory data from a large, diverse sample of California homes and quantifying the relationships to the characteristics of the house.

The key limitation of the RASS data is that it is self-reported, which limits the scope of variables that can ascertained (e.g. the efficiency and technical characteristics of devices), the precision of the data (e.g. responses are often in bins), and its accuracy (e.g. respondents may overestimate energy conservation behaviors). Therefore, there is a critical need for a large-scale, California-specific RBSA that includes a submetering (and possibly a light logging) component. Such an RBSA could help to address data gaps raised in this development of the recommended AEC algorithms, such as:

- What MELs product categories are becoming prominent sources of AEC and are not accounted for in the residual MELs methodology?
- What is the age distribution of non-builder supplied devices in new homes?
- How does the actual AEC of products relate to the AEC estimated by the federal test procedures, given real-world occupant behavior and usage patterns?
- How common are certain product types that have markedly high/low AEC per device (such as induction cooktop, UHD televisions, IP set-top boxes, gaming computers, incandescent/LED lighting), and what is their typical AEC per device?

- How do average lighting hours of use by room type vary with home size?
- How have increased lighting controls impacted lighting hours of use?

In addition, a California-specific RBSA is important for continuing to vet and improve the recommended load profiles. It could help answer research questions such as:

- How do Californians' daily, weekly, and seasonal energy use patterns differ from those of the households studied in the NEEA RBSA and Florida PDR?
- How have the load profiles for interior lighting evolved since the 1993-1994 light logging used to inform the current interior lighting hourly schedules (for example due to lighting controls)?
- What is the load profile of the residual MELs in total, when measured as the leftover electric AEC after subtracting major loads (and can we identify functional categories of MELs with distinct time-of-use patterns)?
- How accurate is the temperature adjustment algorithm for refrigerators and freezers, derived from Florida PDR data, when applied to devices in California homes?
- How accurately are clothes dryer load profiles estimated by shifting the WH ruleset draw schedule for clothes washers one hour forward?

In addition to answering these and other key research questions with additional data, the Statewide CASE Team has identified the following potential expansions to the modeling scope and methodology.

8.1.1 Separate Single-Family and Multi-Family Units

Single-family and multi-family units can be very different physically and can have very different energy usage characteristics. For example, according to the RASS microdata there are differences between single-family and multi-family in the average CFA for a given NBr, the average demographics of occupants, and the average number of products and their frequency of use.

Furthermore, the recommended algorithms have limitations in how they model multi-family homes. Most importantly, the recommended algorithms do not include a methodology to calculate the energy use of communal laundry facilities within multi-family buildings and assume that no multi-family units have secondary refrigerators or separate freezers. There are also challenges to applying the garage lighting ruleset to multi-family housing. Since the recommended rulesets are calculated at the level of the dwelling unit, excessive user inputs may be required for multi-family buildings comprised of many unique dwelling units. Although one solution would be to input the average bedrooms or floor area per unit, there are still challenges to accurately calculating internal gains for all the zones in the building without extensive user inputs.

Within the multi-family subset, low-income housing units may exhibit different energy usage characteristics as well. For example, preliminary data from recent submetering studies conducted by Redwood Energy demonstrate that low-income households living in multi-family housing tend to use far more cooking energy than statewide average and less energy from residual MELs (see Section 4.5.5 and Section 4.9.5).

The Statewide CASE Team believes that using the methodological framework presented in this report and existing data sources, it is possible to develop single-family and multi-family algorithms. If the proposed methods in the CASE Report are accepted, the Statewide CASE Team recommends expanding the analysis to evaluate the need for separate single-family and multi-family AEC rulesets, and possibly low-income housing rulesets.

8.1.2 Further Develop Residual MELs Methodology

Another improvement that could be made to the recommended algorithms would be to better characterize the composition and average AEC of residual MELs and how those factors scale with home size. Residual MELs are the product category with by far the largest AEC and are also the most challenging to model. In future updates to the model, it will be important to consider how RBSA metering and inventory data can be leveraged for this task. In particular, analysts should evaluate whether to keep using a purely bottom-up approach—modeling residual MELs as the sum of constituent end uses—or if this could be combined with a true "residual" approach—estimating residual MELs AEC as the leftover electric AEC after subtracting major loads.

There are many benefits to the bottom-up approach employed by the Statewide CASE Team Team that are important to retain. For example, modeling all of the constituent MELs makes it easier to create functional categories of MELs, each with its own assumed growth rate, scaling with home size, and time-of-use patterns. [81] However, a key drawback of the bottom-up approach is that it potentially requires current data on every conceivable MEL product category. It would be very difficult to keep a purely bottom-up approach up-to-date with saturation and efficiency patterns consistently changing.

Taking a "residual" approach instead would be extremely useful for ensuring that the whole-home electric AEC is accurate, which is a main goal of the present work from a ZNE perspective. If a sufficiently large and diverse sample of new ZNE homes were submetered, measuring all loads except for the residual MELs, the total residual MELs AEC could be estimated with much greater confidence than is afforded by the Statewide CASE Team's bottom-up approach. This total could then be disaggregated into functional categories using a bottom-up engineering approach for the sake of analyses such as forecasting growth rates, targeted program design, identification of efficiency standards opportunities.

8.1.3 Provide Builders with Additional Options to Receive Credit for More Efficient Appliances

For this update to the modeling rulesets, the Statewide CASE Team developed high-efficiency algorithms for primary refrigerators, clothes washers, and clothes dryers. The goals were to

[81] Furthermore, a bottom-up approach yields more useful data for targeted program design and identification of efficiency standards opportunities.

develop algorithms that would yield accurate estimates of AEC if actual equipment efficiency were known, and to establish a methodology that could use simple user inputs that can be reliably verified by on-site observation. The Statewide CASE Team suggests that future updates to the models continue to expand the set of plug load and lighting end uses that have high-efficiency algorithms. In addition, the proposed high-efficiency algorithms could be further refined to include additional user inputs. For example, builders could provide inputs such as:

- Configuration of the clothes washer (front-loading or top-loading);
- Rated efficiency of the clothes dryer (or at least whether it meets the most recent federal efficiency standards);
- Gas, electric resistance heating, or induction cooktop;
- Self-cleaning or standard oven; or
- Information on the luminous efficacy or lighting technology type (e.g. LED, CFL) of the hard-wired lighting.

8.1.4 Expand Scope to Cover Existing Homes

In developing these ruleset recommendations, the Statewide CASE Team focused only on new homes constructed in 2017. These models cannot be used to effectively estimate energy use of existing homes because they do not factor in appliance vintages outside of what is likely to be encountered in homes constructed in 2017. By developing relationships between appliance vintage and appliance efficiency and adjusting the assumed age distribution of the non-builder supplied white goods, these rulesets could be modified to be able to estimate existing home energy use as well.

8.1.5 Explicitly Model Per-Household AEC from Standby Loads

To some extent, the recommended algorithms already calculate AEC from standby and active mode AEC. Given the high fraction of residential electricity consumption caused by wasteful standby loads, it may be helpful to explicitly distinguish between standby and active mode AEC in future modeling results in order to support targeted efficiency measures that address this issue (NRDC 2015a).

8.1.6 Account for Trends in Energy Use Over Time

Plug load and lighting energy use is always changing as products become more efficient and as new technologies and end uses enter the market. The current rulesets represent energy in homes built during the 2016 Title 24 code cycle, but take the simplifying approach of targeting the effective year of 2017. The Statewide CASE Team proposes that future update cycles should attempt to develop rulesets that include a time component that would allow raters to factor in the date that the building is completed.

One form this could take is a series of scaling factors that account for improvements in product efficiency, based on historical trends. Such an approach would require a robust dataset on recent, market-weighted efficiency trends. Even with a robust dataset, it may be challenging to reliably forecast change, and would increase the barriers to updating the model and analyzing the full set of results (i.e. by home size, home type, product category, and also construction year).

A more simplified approach would be to have certain algorithms account for construction year based on the effective dates of mandatory efficiency standards that occur within the modeled Title 24 code cycle and are projected to have a large impact on the AEC of the product category.

8.1.7 Update People Loads Rulesets

The Statewide CASE Team did not recommend updates to the rulesets used to estimate the magnitude and timing of internal gains from occupants. Future updates to the modeling rulesets may be able to use data from the 2018 RASS to develop a relationship between NBr and number of occupants and then combine that with California-specific load profiles to estimate how many occupants are typically in homes of varying sizes and when they tend to be at home.

9. PROPOSED LANGUAGE

The proposed changes to the Residential ACM Reference Manual are provided below. Changes to the 2013 documents are marked with underlining (new language) and ~~strikethroughs~~ (deletions).

9.1 Standards

There are no proposed changes to the Standards.

9.2 Reference Appendices

There are no proposed changes to the Reference Appendices.

9.3 ACM Reference Manual

1.1 Appliances, Miscellaneous Energy Use and Internal Gains

Full details of the assumptions for lighting and appliance loads are found in the Codes and Standards Enhancement Initiative (CASE) Plug Loads and Lighting Modeling (Statewide Utility C&S Team 2016, see Appendix D).

1.1.1 Background

~~This model is derived from the 2008 HTM (California Energy Commission, HERS Technical Manual, California Energy Commission, High Performance Buildings and Standards Development Office. CEC-400-2008-012). This is a major change from the 2008 RACM in that internal gains are built up from models for refrigerator, people, equipment and lights instead f the simple constant plus fixed BTU/ft2 used there. The HTM derived model has been used in the 2013 Development Software throughout the 2013 revision process.~~

~~This model has another significant change beyond the HTM model with the addition of latent gains required as input for the new CSE air conditioning model. There was no information on latent gains in either the 2008 RACM or the HTM. The latent model here was created by applying the best available information on the latent fraction of internal gains to the HTM gains model.~~

Rulesets for all plug loads (including appliances and miscellaneous electric loads (MELs)) and lighting loads were updated in 2016. The CASE report describes the methodology, data sources, and assumptions used to develop the rulesets. The updated methodology replaces the rulesets from the 2013 *Residential Alternative Calculation Method (ACM) Reference Manual* (ACM Reference Manual), which in turn referenced the 2008 California Home Energy Rating System (HERS) Technical Manual.

The rulesets were modified to reflect efficiency levels assuming 2017 federal code baseline or 2017 projected market average performance, depending on whether or not a product is regulated by federal energy efficiency standards. Miscellaneous loads were disaggregated so that the three largest loads in this group—televisions, set-top boxes, and computers and monitors—are modeled individually. The remaining miscellaneous loads are modeled in aggregate. Garage lighting is also disaggregated from interior lighting. Assumptions about how energy use scales with building size were updated for all plug load and lighting end uses.

Updated load profiles were proposed for the majority of the modeled plug load and lighting end uses. The proposed updates include revisions to both the hourly schedules and seasonal multipliers. The updated load profiles are based on the water heating models described in section 2.9 of the ACM Reference Manual for the applicable end uses and otherwise on recent submetering studies.

1.1.2 Approach

~~The approach here is to calculate the Appliances and Miscellaneous Energy Use (AMEU) for the home and use that as the basis for the internal gains. This will facilitate future expansion of the procedure to calculate a HERS Rating~~.

Rulesets for all modeled end uses reflect the estimated energy consumption of those devices in new homes built during the 2016 Title 24 Code Cycle. The plug load rulesets estimate annual energy consumption (AEC) as a function of number of bedrooms (BRperUnit) and the lighting rulesets estimate AEC as a function of conditioned floor area (CFAperUnit). The relationship between AEC and BRperUnit for dishwashers, clothes washers, and clothes dryers was based on the usage assumptions in the water heating model. The relationship between all other plug load AEC and BRperUnit was generally derived from the 2009 Residential Appliance Saturation Survey (RASS), through a statistical and engineering analysis that applied modern efficiency assumptions to estimate what the AEC of plug loads within homes included in the 2009 RASS would be if they were built during the 2016 Title 24 code cycle. The relationship between lighting AEC and CFAperUnit was derived using a similar analysis completed on the RASS data but using data from the 2012 California Lighting and Appliance Saturation Survey.

With additional user inputs, the default AEC equations for primary refrigerators, clothes washers, and clothes dryers can be modified to reflect the efficiency of the devices that are actually installed in the building. That is, the modeled energy use can be adjusted downward if more efficient devices are installed (the software tool can also adjust energy use upward if devices are less efficient).

Updated load profiles are derived from the following data sources:

- **Dishwashers, clothes washers, and clothes dryers:** updated to be consistent with the usage patterns assumed by water heating models described in section 2.9 of the ACM Reference Manual.
- **Ovens, cooktops, and televisions:** based on data from the Phased Deep Retrofit (PDR) study conducted by the Florida Solar Energy Center (FSEC), which submetered 60 Florida homes in 2012.
- **Set-top boxes, computers, and monitors:** based on the Northwest Energy Efficiency Alliance (NEEA) Residential Building Stock Assessment (RBSA), released in 2014. This study monitored 100 homes in the Pacific Northwest over the course of one year, submetering major end uses at 15 minute intervals.
- **Exterior lighting:** the proposed hourly schedule for exterior lighting is derived from the NEEA RBSA light logging data; the proposed exterior lighting seasonal multipliers are no longer constant, but instead equivalent to the interior and garage seasonal multipliers.

Load profiles for interior lighting, garage lighting, and residual MELs were not updated in 2016. The current hourly schedules for interior lighting are based on the 1999 Heschong Mahone Group (HMG) study "Lighting Efficiency Technology Report: California Baseline." The current hourly schedule for residual MELs is derived from the 2008 Building America House Simulation Protocol, which in turn relied on data from a 1989 Pacific Northwest submetering study conducted by the End-Use Load and Consumer Assessment Program (ELCAP).

Refrigerators and freezers use PDR data to adjust estimated energy use on an hourly basis depending on the modeled indoor temperature (using the Title 24 compliance software) in the space where the refrigerator is installed.

1.1.3 Problems

~~The procedure here (also used in the 2013 development program) does not work correctly for multifamily buildings unless all of the units are the same (CFA and number of bedrooms). I don't believe this problem was considered in developing the HTM. I believe that the only~~

~~exactly correct solution involves simulating each unit as a separate zone with a different internal gain. For now we will ignore this problem and assume that average values are OK. The HTM equations are FUBAR if there is a gas range and electric oven. The allocation of internal gain to zones is not specified in either the RACM or the HTM. A proposed approach is presented here.~~

The plug load and lighting rulesets have some limitations. The rulesets generally do not account for differences in energy use patterns between single-family and multi-family housing. For example, they do not account for the energy use of laundry equipment in multi-family residences that is installed in common areas—only laundry equipment in the dwelling units.

The plug load and lighting rulesets were developed to apply to new homes built during the 2016 Title 24 Code Cycle, and thus should not be used for estimating energy use for existing homes.

1.1.4 Inputs

~~Units~~	~~Number of dwelling units in the building.~~
~~BRperUnit~~	~~Bedrooms/Dwelling units rounded to an integer~~
~~CFA~~	~~Conditioned Floor Area in the building~~
~~CFAperUnit~~	~~CFA/Dwelling units~~

~~New CBECC input at the building level: an Appliances Input Screen (for a single conditioned zone, most of these default, we are assuming that MF buildings will be done as one zone):~~

~~Refrigerator/Freezer~~	~~Efficiency (Choice of Default = 669 kWh/year, no other choices at this time), Location (Choice of zones if multiple conditioned zones). // HTM assumes all Dwelling units have refrigerators. Different for additions and alterations when we get to them.~~
~~Dishwasher~~	~~Efficiency (Choice of Default, no other choices at this time), Location (Choice of zones if multiple conditioned zones). // HTM assumes all Dwelling units have refrigerators. Different for additions and alterations when we get to them.~~
~~Clothes Dryer~~	~~Location (Choice of zones if multiple zones, No Dryer space or hookup provided) Dryer power (Choice Electric, Gas or other) //Assuming gas for now~~
~~Clothes Washer~~	~~Location (Choice of zones if multiple zones), No Washer space or hookup provided)~~
~~Range/Oven~~	~~Location (Choice of zones if multiple conditioned zones, No Range~~Range~~/Oven space and hookup provided) Range/Oven power (Choice Electric, Gas or other) Assumes gas for now.~~

1.1.4.1 AEC Inputs and Algorithms

Table 1 summarizes the user inputs that determine the plug load and lighting annual energy consumption (AEC) estimates. The variable 'BRperUnit' refers to the number of bedrooms in a single-family home or the number of bedrooms in each dwelling unit of a multi-family building. Similarly, 'CFAperUnit' refers to the conditioned floor area per dwelling unit. AEC equations are to be applied to each dwelling unit within a multi-family building, not the building as a whole. Users also specify the zone where certain major appliances are located; however, this affects the modeled internal gains from equipment and lighting, not their estimated energy use of the plug load or lighting load and is therefore not included in the table below. The Optional inputs are not implemented in CBECC-Res 2016.2, but may be allowed in future releases.

Table 1: User Inputs Affecting Estimated Plug Load and Lighting Energy Use

End Use	User Inputs that Determine Estimated Energy Use	Notes
Primary Refrigerator/ Freezer	- BRperUnit - Optional: rated annual kWh usage from the Energy Guide label of the installed device	- Default kWh can be overridden with the rated annual kWh usage input on the Energy Guide label; however, there is a maximum allowable kWh credit dependent on BRperUnit - Energy use adjusted on an hourly basis depending on the indoor temperature in the kitchen simulated in the software.
Non-Primary Refrigerators and Separate Freezers	- BRperUnit - Single-family or multi-family housing	- Assumed to be installed in the garage in new, single-family homes - Assumed to be absent in multi-family dwelling units
Dishwasher	- BRperUnit - Presence of device - Single-family or multi-family	- Ruleset estimates machine energy use only - Energy use is only included if user indicates the device will be present - Assumed different usage patterns in single family and multi-family when developing algorithms
Clothes Washer	- BRperUnit - Presence of device - Single-family or multi-family - Optional: whether installed device will comply with the 2015 federal efficiency standards (credit for installing new or nearly-new device)	- Ruleset estimates machine energy use only - Energy use is only included if user indicates the device will be present - Assumed different usage patterns in single family and multi-family when developing algorithms - Default energy use can be reduced if the user specifies the device will meets the 2015 federal standard, which can be determined by looking up the model on the California Appliance Efficiency Database
Clothes Dryer	- BRperUnit - Presence of device - Fuel type (natural gas, propane, or electric) - Single-family or multi-family - Optional: percent remaining moisture content (RMC) of the clothes washer	- Energy use is only included if user indicates the device will be present - User can select fuel type. If user indicates natural gas is available at the site (see Section 2.2.10 of RACM), then the default fuel type is natural gas. If user indicates that natural gas is not available at the site then the default fuel type is electric. User cannot select natural gas as the fuel type if natural gas is not available at the site. - Default energy use can be reduced if the user specifies

		that the installed clothes washer has a rated RMC of less than 50 percent
Oven	- BRperUnit - Presence of device - Fuel type (natural gas, propane, or electric)	- Energy use is only included if user indicates the device will be present - User can select fuel type, but default assumption is natural gas if user indicates that natural gas is available on-site and electric if user indicates natural gas is not available on-site
Cooktop		
Televisions	BRperUnit	
Set-Top Boxes		
Computers and Monitors		
Residual MELs		
Interior Lighting	CFAperUnit	
Exterior Lighting		
Garage Lighting	- CFAperUnit - Presence of garage	- Energy use is only included if user indicates there is a garage present - Garage lighting is assigned to multi-family buildings if there is at least once garage present - Carport lighting is covered under the exterior lighting ruleset

Table 2 summarizes the proposed AEC algorithms for plug load and lighting. These linear equations take the following general form where the homes size metric is BRperUnit for plug loads and CFAperUnit for lighting:

$$y = mx + b$$

Where: y = Estimated AEC measured in kWh/yr or therms/yr
m = how AEC changes with home size
x = home size as measured in BRperUnit for plug loads or CFAperUnit for lighting
b = minimum energy use (energy use at y-intercept)

BR-based equations are capped at 7 bedrooms, meaning that units with eight or more bedrooms have the same estimated AEC as a 7-bedroom unit. CFA-based equations are capped at 4,150 square feet. For those end uses that list 'presence of device' as a user input in Table 2, the AEC equation is only applied if the device is present. Similarly, for the AEC equations for end uses that can be gas or electric are only applied according to the user-specified fuel type. Gas algorithms apply to devices that use natural gas or propane.

Table 2: Algorithms for Plug Load and Lighting Annual Energy Use

End Use	Standard Design Fuel Type	kWh or therms	Intercept	Slope	Per-Unit BR or CFA
Primary Refrigerator/Freezer	Electricity	kWh	454	37.0	BR

Non-Primary Refrigerators and Separate Freezers (Single-Family only)	Electricity	kWh	0	71.0	BR
Oven	Electricity	kWh	138	16	BR
Oven	Gas	therms	6	0.95	BR
Oven	Gas	kWh	41	4.79	BR
Cooktop	Electricity	kWh	84	5.68	BR
Cooktop	Gas	therms	5	0.30	BR
Cooktop	Gas	kWh	0	0	BR
Televisions	Electricity	kWh	265	31.8	BR
Set-Top Boxes	Electricity	kWh	76	59.4	BR
Computers and Monitors	Electricity	kWh	79	55.4	BR
Residual MELs	Electricity	kWh	672	235	BR
Interior Lighting	Electricity	kWh	100	0.1775	CFA
Exterior Lighting	Electricity	kWh	8	0.0532	CFA
Garage Lighting	Electricity	kWh	20	0.0063	CFA

Table 3 and Table 4 summarize the AEC algorithms for dishwashers, clothes washers and clothes dryers. These rulesets only include machine energy use from dishwashers and clothes washers. Energy use for heating the water before it enters these devices is accounted for in the water heating model.

Table 3: Single-Family Residences Algorithms for Dishwasher, Clothes Washer, and Clothes Dryer Annual Energy Use

BRperUnit	Dishwashers (kWh/yr)	Clothes Washers (kWh/yr)	Electric Clothes Dryers (kWh/yr)	Natural Gas Clothes Dryers	
				Natural Gas Use (therms/yr)	Electricity Use (kWh/yr)
0	83	84	634	22	32
1	83	84	634	22	32
2	91	85	636	22	32
3	100	99	748	26	37
4	99	101	758	27	38
5+	119	117	877	31	44

Table 4: Multi-Family Dwelling Units Algorithms for Dishwasher, Clothes Washer, and Clothes Dryer Annual Energy Use

BRperUnit	Dishwashers (kWh/yr)	Clothes Washers (kWh/yr)	Electric Clothes Dryer (kWh/yr)	Gas Clothes Dryers	
				Natural Gas Usage (therms/yr)	Electricity Usage (kWh/yr)
0	56	66	496	17	25
1	68	70	527	19	26
2	96	99	745	26	37
3	94	97	733	26	37

4	121	118	885	31	44
5+	114	107	805	28	40

1.1.4.2 AEC Algorithms for High-Efficiency Appliances

As indicated in Table 5, if allowed in the software, users could override the default AEC rulesets for the primary refrigerator, clothes washer and clothes dryer if the software user has additional information about the device that will be installed.

For the primary refrigerator, the default AEC ruleset could be replaced with the rated AEC listed on the refrigerator's Energy Guide label. If using this option, the user will input AEC measured in kWh per year, and that value will replace the AEC value for the primary refrigerator calculated using the equation in Table 5. The default AEC of the primary refrigerator cannot be adjusted below a certain value, which is dependent on BRperUnit as described in the following equation:

$$MinPrimaryRefrigAEC\,\frac{kWh}{yr} = \left(8.4\,\frac{kWh}{BRperUnit yr} \times BRperUnit\right) + 291\,\frac{kWh}{yr}$$

Users could reduce the estimated primary refrigerator AEC to this value, but no lower.

Table 5: Minimum primary refrigerator AEC that builders may claim by BRperUnit

BRperUnit	Default Primary Refrigerator AEC (kWh/yr)	Minimum Allowable Primary Refrigerator AEC (kWh/yr)
0	470	291
1	496	299
2	523	308
3	550	316
4	577	325
5	603	333
6	630	341
7+	657	350

For clothes washers, if allowed in the software, the user could specify that the installed clothes washer meets the 2015 federal standards (as documented on the CEC Appliance Efficiency Database). This effectively provides credit if the clothes washer is new or nearly new. Table 6 presents the AEC values used if the washer is compliant with the 2015 federal standards.

Table 6: Minimum allowable high-efficiency AEC for clothes washers

BRper Unit	Single Family		Multi-Family	
	Default AEC (kWh/yr)	High-Efficiency Clothes Washer AEC[1] (kWh/yr)	Default AEC (kWh/yr)	High-Efficiency Clothes Washer AEC[1] (kWh/yr)

0	84	68	66	53
1	84	68	70	57
2	85	68	99	80
3	100	80	98	79
4	101	81	118	95
5+	117	94	107	86

[1] Applicable to clothes washers that meet the 2015 federal efficiency standards

For clothes dryers, if allowed in the software, the user could specify the percent remaining moisture content (RMC) of the installed *clothes washer* (as documented on the CEC Appliance Efficiency Database) to override the default clothes dryer AEC ruleset. The RMC-adjusted clothes dryer AEC should be calculated using the equations provided below. For natural gas dryers the RMC-adjusted AEC modifies natural gas use but does not impact electricity use.

Electric Dryer: RMC-adjusted AEC (kWh/yr)

$$RMCadjusted\ AEC\ \frac{kWh}{yr} = 12.67\ \frac{kWh}{yr} + \left[\left(3.80\frac{kWh}{cycle}\left(RMC_{User,Input}\right) + 0.25\ \frac{kWh}{cycle}\right) \times \frac{cycles}{yr}\right]$$

Gas Dryer: RMC-adjusted AEC (therms/yr)

$$RMCadjusted\ AEC\ \frac{therms}{yr} = \left[0.136\frac{therms}{cycle}\left(RMC_{User,Input}\right) + 0.00853\ \frac{therms}{cycle}\right] \times \frac{cycles}{yr}$$

Table 7: Annual clothes dryer cycles estimated based on BRperUnit

BRperUnit	Clothes Dryer Cycles Per Year	
	Single-Family	Multi-Family
0	290	227
1	290	241
2	291	341
3	342	335
4	346	405
5+	401	368

1.1.4.3 Load Profiles

Dishwashers and clothes washer loads are specified in the water heating load profiles. Clothes dryers have the same usage assumptions as clothes washers, but shifted one hour later.

The estimated energy use for refrigerators is adjusted for each hour of the year depending on the simulated indoor temperature in the thermal zone where the refrigerator or freezer is installed (user input). Multi-family housing is assumed to have no energy use for non-primary refrigerators or separate freezers.

The following tables summarize the hourly load profiles and seasonal multipliers for the remaining plug load and lighting end uses.

Table 8: Hourly Multiplier – Weekdays

Hour	Oven and Cooktop	Televisions	Set-Top Boxes	Computers and Monitors	Residual MELs	Interior and Garage Lighting	Exterior Lighting
1	.005	.035	.040	.036	.037	.023	.046
2	.004	.026	.040	.033	.035	.019	.046
3	.004	.023	.040	.032	.034	.015	.046
4	.004	.022	.040	.032	.034	.017	.046
5	.004	.021	.040	.031	.032	.021	.046
6	.014	.021	.040	.032	.036	.031	.037
7	.019	.025	.040	.034	.042	.042	.035
8	.025	.032	.041	.036	.044	.041	.034
9	.026	.038	.040	.039	.037	.034	.033
10	.022	.040	.040	.043	.032	.029	.028
11	.021	.038	.040	.045	.033	.027	.022
12	.029	.038	.040	.045	.033	.025	.015
13	.035	.041	.040	.046	.032	.021	.012
14	.032	.042	.040	.046	.033	.021	.011
15	.034	.042	.041	.046	.035	.021	.011
16	.052	.041	.041	.047	.037	.026	.012
17	.115	.044	.042	.048	.044	.031	.019
18	.193	.049	.043	.049	.053	.044	.037
19	.180	.056	.044	.049	.058	.084	.049
20	.098	.064	.045	.049	.060	.117	.065
21	.042	.070	.046	.049	.062	.113	.091
22	.020	.074	.047	.048	.060	.096	.105
23	.012	.067	.045	.044	.052	.063	.091
24	.010	.051	.045	.041	.045	.039	.063

Table 9: Hourly Multiplier – Weekends

Hour	Oven and Cooktop	Televisions	Set-Top Boxes	Computers and Monitors	Residual MELs	Interior and Garage Lighting	Exterior Lighting
1	.005	.035	.041	.036	.037	.023	.046
2	.004	.027	.041	.034	.035	.019	.046
3	.003	.022	.040	.033	.034	.015	.045
4	.003	.021	.041	.033	.034	.017	.045
5	.003	.020	.040	.032	.032	.021	.046

6	.005	.020	.040	.033	.036	.031	.045
7	.010	.022	.040	.033	.042	.042	.044
8	.027	.029	.040	.035	.044	.041	.041
9	.048	.037	.041	.038	.037	.034	.036
10	.048	.043	.042	.042	.032	.029	.030
11	.046	.042	.042	.044	.033	.027	.024
12	.055	.039	.041	.045	.033	.025	.016
13	.063	.040	.041	.046	.032	.021	.012
14	.059	.042	.041	.047	.033	.021	.011
15	.062	.045	.041	.047	.035	.021	.011
16	.068	.048	.042	.048	.037	.026	.012
17	.091	.051	.042	.049	.044	.031	.019
18	.139	.052	.043	.049	.053	.044	.038
19	.129	.056	.044	.048	.058	.084	.048
20	.072	.061	.044	.048	.060	.117	.060
21	.032	.065	.045	.048	.062	.113	.083
22	.014	.069	.045	.047	.060	.096	.098
23	.009	.064	.044	.044	.052	.063	.085
24	.005	.050	.039	.041	.045	.039	.059

Table 10: Seasonal Multipliers

Month	**Oven and Cooktop**	**Televisions**	**Set-Top Boxes**	**Computers and Monitors**	**Residual MELs and Lighting**
Jan	1.094	1.032	1.02	0.98	1.19
Feb	1.065	.991	.84	0.87	1.11
Mar	1.074	.986	.92	0.89	1.02
Apr	0.889	.99	.98	1.11	.93
May	0.891	.971	.91	1.14	.84
Jun	0.935	.971	.94	0.99	.8
Jul	0.993	1.002	1.05	1.05	.82
Aug	0.92	1.013	1.06	1.01	.88
Sep	0.923	1.008	1.06	0.96	.98
Oct	0.92	1.008	1.14	0.97	1.07
Nov	1.128	1.02	1.03	0.99	1.16
Dec	1.168	1.008	1.050	1.04	1.2

~~Assumes CSE Meters are set up elsewhere:~~

~~Mtr_Elec~~

~~Mtr_NatGas~~

~~Mtr_Othewr //PropaNE~~

~~Write Constants to the CSE input:~~

~~#redefine Intgain_mo choose1($month, 1.19,1.11,1.02,0.93,0.84,0.8,0.82,0.88,0.98,1.07,1.16,1.21) //The monthly internal gain multiplier (same as 2008 RACM).~~

~~#redefine Lights_hr hourval(0.023,0.019,0.015,0.017,0.021,0.031,0.042,0.041,0.034,0.029,0.027,0.025,\~~

~~0.021,0.021,0.021,0.026,0.031,0.044,0.084,0.118,0.113,0.096,0.063,0.038) // Changed 0.117 to 0.118 to add to 1~~

~~#redefine OutdoorLights_hr hourval(0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0.25,0.25,0.25,0.25) // #redefine People_hr hourval(0.035,0.035,0.035,0.035,0.035,0.059,0.082,0.055,0.027,0.014,0.014,0.014,\~~

~~0.014,0.014,0.019,0.027,0.041,0.055,0.068,0.082,0.082,0.070,0.053,0.035)~~

~~#redefine Equipment_hr hourval(0.037,0.035,0.034,0.034,0.032,0.036,0.042,0.044,0.037,0.032,0.033,0.033,\~~

~~0.032,0.033,0.035,0.037,0.044,0.053,0.058,0.060,0.062,0.060,0.052,0.045)~~

1. ~~Setup the gains that are distributed across the zones per CFA of the zone and write to CSE input: Calculations are generally more complicated in future for HERS~~
    a. ~~//Lights Returns Btu/day-CFA - based on ElectricityInteriorLights = (214+ 0.601×CFA)×(FractPortable + (1-FractPortable)×PAMInterior) //HTM Eqn 11, p. 30~~
        ~~#define FractPortable .22 //fixed for now, variable later for HERS~~
        ~~#define Paminterior 0.625 //fixed for now, variable later for HERS~~
        ~~#Redefine LightsGainperCFA (((214. + 0.601 * CFAperUnit) * (FractPortable + (1- FractPortable) * Paminterior) * 3413. / 365) * DwellingUnits /CFA)~~
    b. ~~People Returns BTU/day-CFA - 100% is internal gain 57.3% sensible, 42.7% latent Based on HTM and BA existing bldgs Sensible 220, Latent 164 BTU~~
        ~~#redefine PeopleperUnit (1.75 + 0.4 * BRperUnit)~~
        ~~#Redefine PeopleGainperCFA ((3900/0.573) * PeopleperUnit * DwellingUnits / CFA)~~
    c. ~~Misc Electricity Returns BTU/day-CFA - 100% is internal gain~~
        ~~#Redefine MiscGainperCFA ((723. + (0.706 * CFAperUnit))* DwellingUnits * 3413. / 365.)/CFA~~
2. ~~Setup the gains that are point sources located in a particular zone and write to CSE input. Calculations are generally more complicated in future for HERS~~

a. ~~Refrigerator. In the HTM all Standard Design refrigerators use the same amount of electricity (669 kWh/year) regardless of the size of dwelling unit or number of bedrooms. The proposed use is based on the energy label of the actual refrigerator installed or if that is not available the default. For existing home HERS calculations the default is (775 kWh/year). Refrigerators run at a constant power 24 hours per day, regardless of the interior air temperature or number of times the door is opened.~~

    ~~Returns BTU/day - 100% is internal gain. Installed refrigerator rating is input for proposed in HERS later~~

    ~~#Redefine RefrigeratorGain (DwellingUnits * 669. * (3413. / 365.))~~

b. ~~Dishwasher. 0 based choose returns BTU/day // uses Table based in INTEGER bedrooms per dwelling.~~

    ~~#Redefine DishwasherGain (choose (BRperUnit,90,90,126,126,126,145,145,174,174,174,default 203) * DwellingUnits * 3413. / 365.)~~

c. ~~Stove and Oven – Assumes both are gas with electonic igniter Returns BTU/day - Full Energy Use, 90% is internal Gain define CookGain (((31. + (.008 * CFAperUnit))* 0.43* 0.9)* DwellingUnits * 100000. / 365.) //Added the 0.43 for the electronic ignition 12/4 BAW~~

d. ~~Clothes Washer - // Returns BTU/day~~

    ~~#Redefine WasherGain ((-64 + 0.108 * CFAperUnit) * DwellingUnits * 3413. / 365.)~~

e. ~~Clothes Dryer - Assumes gas with electonic igniter Returns BTU/day - Full energy Use, 30% is internal gain~~

    ~~define DryerGAin (13. + (.01 * CFAperUnit))* DwellingUnits * 100000. / 365. //Added the 0.43 for the electronic ignition //120831~~

f. ~~Exterior Lights Returns Btu/day - based on HTM Eqn 14~~

    ~~#define PamExterior 0.49 //fixed for now, variable later for HERS~~

    ~~#Redefine ExtLightGain (-81+ 0.152 × CFA)×PAMExterior * 3413. / 365)~~

3. ~~For each conditioned zone: //Write GAIN objects inside each conditioned zone~~

    ~~GAIN Lights(zone) gnPower= LightsGainperCFA*CFA(Zone)*Lights_hr*Intgain_mo gnFrRad=0.4 gnEndUse=Lit gnMeter= Mtr_Elec~~

    ~~GAIN People(zone) gnPower= PeopleGainperCFA*CFA(Zone)*People_hr*Intgain_mo gnFrRad=0.3 gnFrLat=0.427 // Free Energy so not metered~~

    ~~GAIN Misc(zone) gnPower= MiscGainperCFA*CFA(Zone)*Equipment_hr*Intgain_mo gnFrRad=0.3 gnFrLat=0.03 gnEndUse=Rcp gnMeter= Mtr_Elec~~

    ~~Write any of the following if the source is located in this zone:~~

    ~~GAIN Refrigerator gnPower= RefrigeratorGain/24 gnFrRad=0 gnEndUse=Refr gnMeter= Mtr_Elec // No *Intgain_mo, change fro 2013 DevProg~~

~~GAIN Dishwasher gnPower= DishwasherGain*Equipment_hr*Intgain_mo gnFrRad=0 gnFrLat=0.25 gnEndUse=Dish gnMeter= Mtr_Elec //~~
~~GAIN Cooking gnPower= CookGain*Equipment_hr*Intgain_mo gnFrRad=0 gnFrLat=0.67 gnEndUse=Cook gnMeter= Mtr_NatGas gnFrZn=.9 //~~
~~GAIN Washer gnPower= WasherGain*Equipment_hr*Intgain_mo gnFrRad=0 gnEndUse=Wash gnMeter= Mtr_Elec //~~
~~GAIN Dryer gnPower= DryerGAin*Equipment_hr*Intgain_mo gnFrRad=0 gnFrLat=0.5 gnEndUse=Dry gnMeter= Mtr_NatGas gnFrZn=.3 //~~

~~Write the following to the 1st zone only (one gain per building):~~

~~GAIN ExtLights gnPower= ExtLightGain*OutdoorLights_hr gnFrZn=.0 gnEndUse=Ext gnMeter= Mtr_Elec // outside lights, no internal gain~~

4. ~~For each unconditioned zone write the following if the source is located in this zone: //Garage or Basement Maybe 2nd refrigerator in garage later?~~

~~GAIN Washer gnPower= WasherGain*Equipment_hr*Intgain_mo gnFrRad=0 gnEndUse=Wash gnMeter= Mtr_Elec //~~
~~GAIN Dryer gnPower= DryerGAin*Equipment_hr*Intgain_mo gnFrRad=0 gnFrLat=0.5 gnEndUse=Dry gnMeter= Mtr_NatGas gnFrZn=.3 //~~

~~3.6 Seasonal Algorithm~~

~~These are constant control rules. You could substitute values for defined terms in some cases like Winter_Vent Winter_Cool Summer_heat and Sumr_Vent_Temp~~

~~//Thermostats and associated controls~~

~~//Heat Mode~~

~~#redefine SZ_Heat_hr hourval(65,65,65,65,65,65,65,68,68,68,68,68,68,68,68,68,68,68,68,68,68,68,68,65)~~

~~#redefine Liv_Heat_hr hourval(65,65,65,65,65,65,65,68,68,68,68,68,68,68,68,68,68,68,68,68,68,68,68,65)~~

~~#redefine Slp_Heat_hr hourval(65,65,65,65,65,65,65,68,65,65,65,65,65,65,65,65,65,65,65,65,65,68,68,65)~~

~~#redefine Winter_Vent 77~~

~~#redefine Winter_Cool 78 //Cool Mode~~

~~#redefine SZ_Cool_hr hourval(78,78,78,78,78,78,78,83,83,83,83,83,83,82,81,80,79,78,78,78,78,78,78,78)~~

~~#redefine Liv_Cool_hr hourval(83,83,83,83,83,83,83,83,83,83,83,83,83,82,81,80,79,78,78,78,78,78,78,83)~~

~~#redefine Slp_Cool_hr hourval(78,78,78,78,78,78,78,83,83,83,83,83,83,83,83,83,83,83,83,83,83,78,78,78)~~

~~#redefine Summer_Heat 60~~

~~#redefine Sumr_Vent_Temp 68 // // Summer Winter mode switch based on 7 day average temp. Winter<=60>Summer~~

~~#redefine Coolmode select(@weather.taDbAvg07 >60., 1,default 0)~~

~~#redefine HeatSet select(@weather.taDbAvg07 >60., Summer_Heat, default SZ_Heat_hr)~~

~~#redefine CoolSet select(@weather.taDbAvg07 >60., SZ_Cool_hr, default Winter_Cool)~~

~~#redefine Tdesired select(@weather.taDbAvg07 >60., Sumr_Vent_Temp, default Winter_Vent)~~

~~// Window interior shade closure~~

~~#define SCnight 0.8 // when the sun is down. 80%~~

~~#define SCday 0.5 // when the sun is up 50%~~

~~#define SCcool 0.5 // when cooling was on previous hour. 50%?~~

9.4 Compliance Manuals

There are no proposed changes to the Compliance Manuals.

9.5 Compliance Forms

There are no proposed changes to the Compliance Forms.

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APPENDIX A: AGE OF NON-BUILDER SUPPLIED WHITE GOODS

To determine the age distribution of the non-builder-supplied white goods (i.e. refrigerators, clothes washers, clothes dryers) in newly-constructed homes, the Statewide CASE Team used the data available in RASS 2009 and RASS 2003. The Statewide CASE Team performed the analysis on both 2009 and 2003 survey data and found similar age distributions for devices in new homes.

The Statewide CASE Team used these age distributions to adjust the energy use calculations of Sections 4.1, 4.3, and 4.4 to account for lower efficiency in older devices.

For all homes in RASS, the data provides the survey-reported ages of refrigerators and clothes washers. For the rulesets presented in this report, the Statewide CASE Team assumes that clothes dryers are paired with clothes washers, and thus follow the same age distribution.

The survey-reported ages of the appliances are grouped in bins as follows.

- **Refrigerator age (years):**
  - Less than 2
  - 2 to 7
  - 8 to 10
  - 11 to 20
  - More than 20
- **Clothes Washer age (years):**
  - Less than 1
  - 1 to 5
  - 6 to 8
  - 9 to 15
  - 16 to 30
  - Over 3

RASS data do not specifically indicate the age of the appliance for when the home was newly-purchased. Thus, the Statewide CASE Team filtered the data by the survey-reported year in which the home was built and the number of years the home was occupied by the survey respondent, creating a subset representative of newly-constructed homes. RASS groups the built years of the home in bins, but allowed the respondent to select specifically the number of years in which they had lived in the home. The Statewide CASE Team filtered the RASS data to include only homes that were built in the most recent 3-year age bins (2005-2008 for the RASS 2009 and 2000-2003 for RASS 2003), and then applied a sub-filter to the data to retain only homes in which the residents reported living in the home for exactly 3 years, thus identifying the households that moved into their home when it was newly built. For RASS 2009, the sub-filtered sample includes only homes built in 2005 that residents moved into in

2005, since residents cannot live at the home before it was built. For RASS 2003, the sub-filtered sample only includes homes built in 2000 that residents began occupying in 2000. These subsets contained several hundred homes.

By also subtracting 3 years from the survey-reported appliance ages, the outcome variable of the analysis becomes the age of the device when the residents moved into the newly constructed home. The resulting plots based on the survey-reported data for refrigerator and clothes washer ages are shown for RASS 2009 and RASS 2003 in the subsequent figures.

The Statewide CASE Team used these age distributions to determine the fraction of appliances in homes built in 2017 will be required to meet the most recent federal efficiency standards and what fraction will only be required to meet the prior standards. Since the effective dates of the most recent and/or prior standards may have occurred in the middle of the survey-reported age bin, the Statewide CASE Team assumed a uniform distribution throughout each age bin. For example, respondent reported that their refrigerator was “8 to 10” years old at the time of the survey, the Statewide CASE Team assumed it was equally likely to be 8, 9, or 10 years old (and therefore equally likely to have been 5, 6, or 7 years old when the home was newly built, 3 years before the survey).

If appliances were purchased after move-in (i.e. the survey-reported device age was less than 3 years), the Statewide CASE Team assumed the residents had replaced their previous refrigerator or clothes washer, and that the age of the replaced appliance age was equal to effective useful life (EUL) of the appliance, effectively making them compliant with only the older standard. For simplicity, the Statewide CASE Team assumed that the small fraction of appliances that are even older than the “older” standard would meet that standard.

The results from this analysis, as well as the average values, which were the values used in the models for this report, are shown in the Table below. As can be seen, the RASS 2009 and RASS 2003 values are close, and thus it is reasonable to assume this distribution will continue to hold for 2017 homes. The resulting distribution plots are also shown in the figures below.

Table A-1: The resulting fractions of newly-constructed homes that meet newer and older standards based on RASS 2009, RASS 2003, and an average value

		RASS 2009	RASS 2003	Average
Refrigerators	New Standard (2014)	43.9	41.1	42.5
	Older Standard (2001)	56.1	58.9	57.5
Washer/Dryer	New Standard (2015)	28.6	29.0	28.8
	Older Standard (2007/1994)	71.4	71.0	71.2

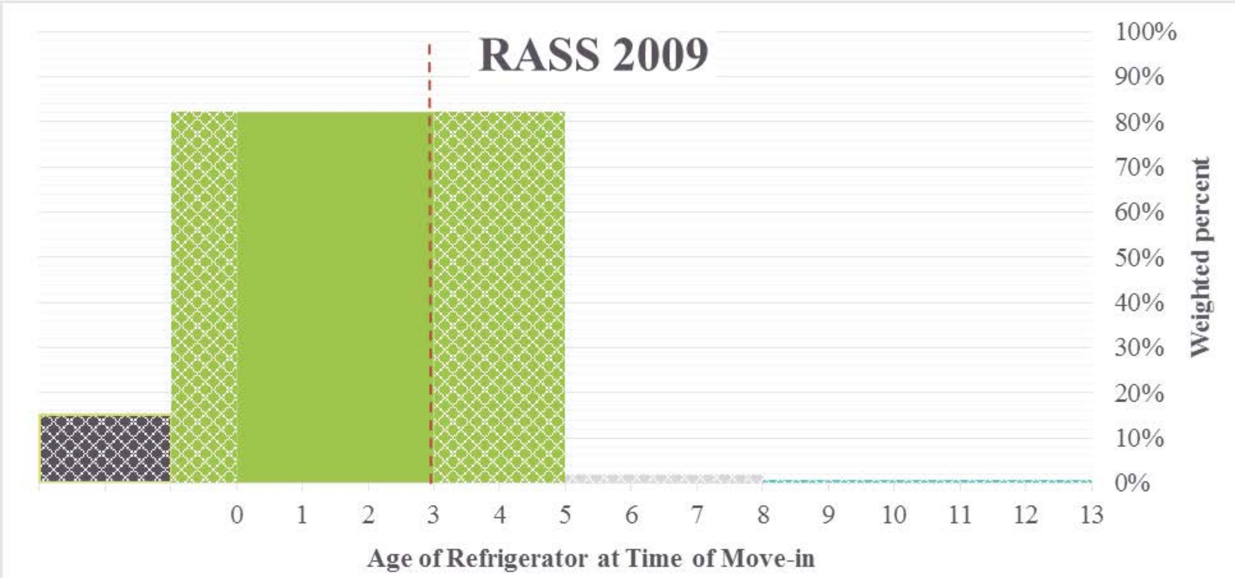

Figure A-1: Refrigerator age distribution for newly-constructed homes based on RASS 2009

Note: The colors denote the survey ages, the patterned background denotes portions attributed to the older standard, and the red line denotes the date of the newer standard.

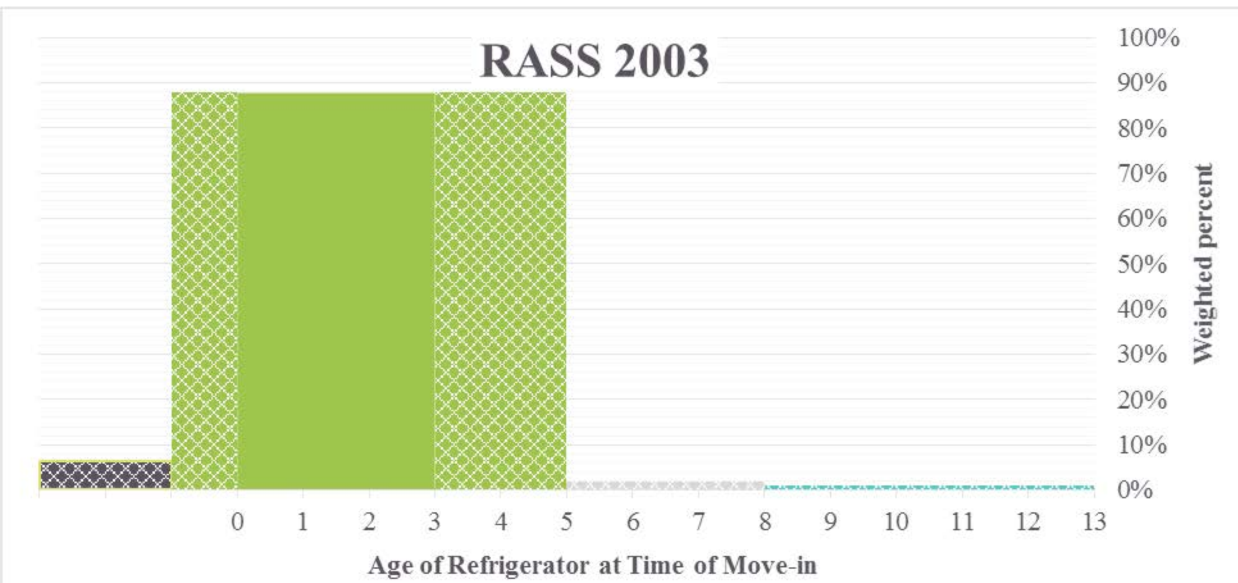

Figure A-3: Refrigerator age distribution for newly-constructed homes based on RASS 2003

Note: The colors denote the survey ages, the patterned background denotes portions attributed to the older standard, and the red line denotes the date of the newer standard.

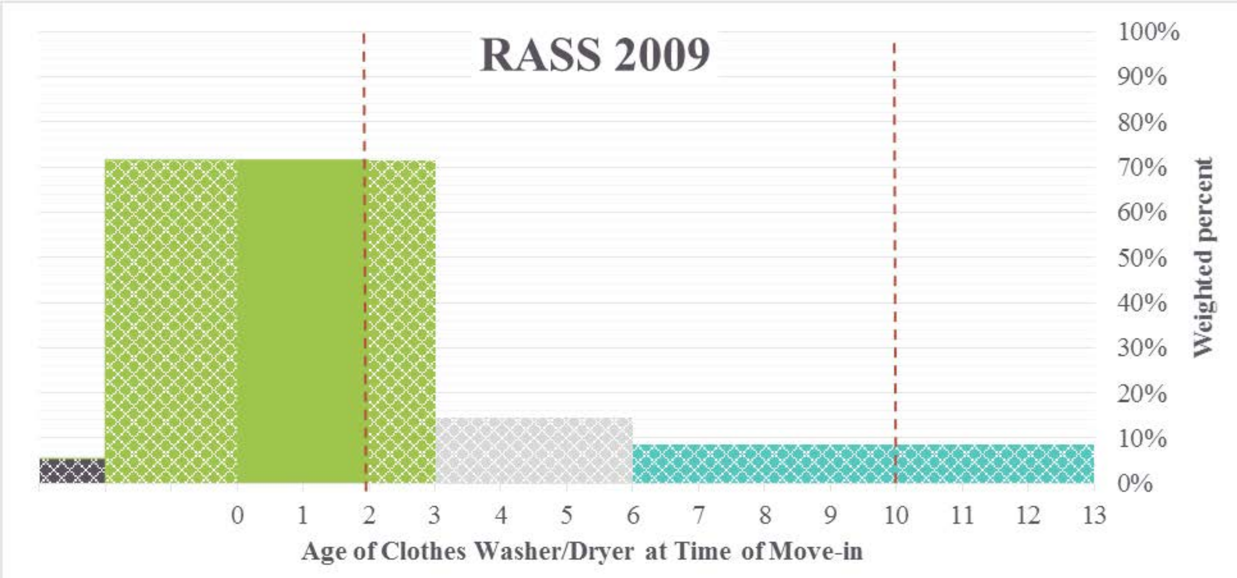

Figure A-3: Clothes washer (and dryer) age distribution for newly-constructed homes based on RASS 2009

Note: The colors denote the survey ages, the patterned background denotes portions attributed to the older standard, and the red line denotes the date of the newer and older standards.

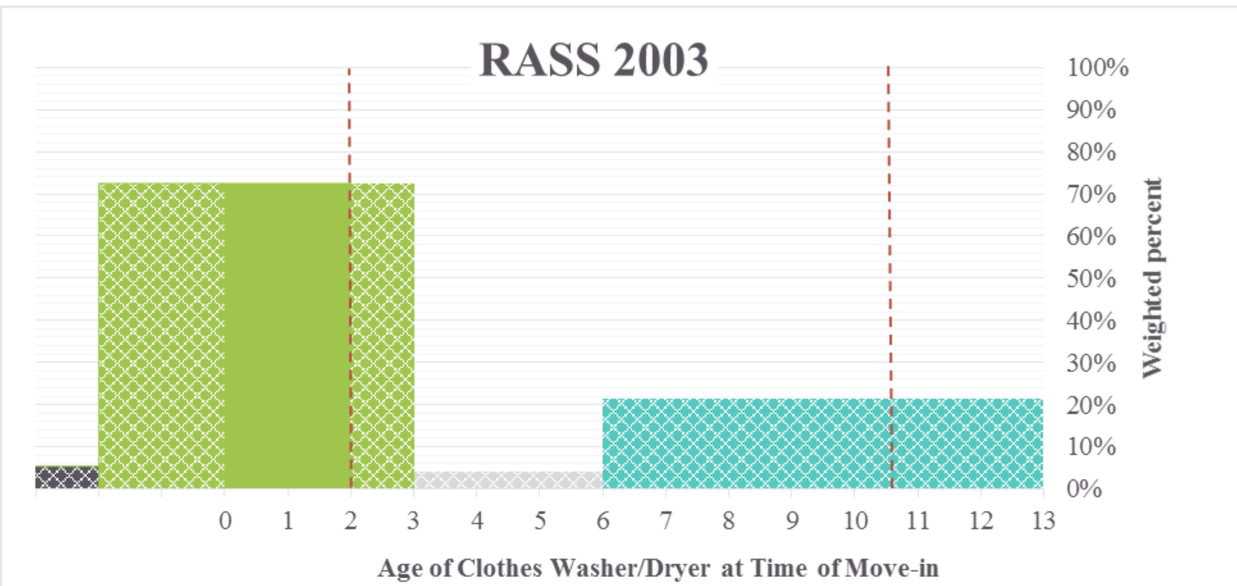

Figure A-4: Clothes washer (and dryer) age distribution for newly-constructed homes based on RASS 2003

Note: The colors denote the survey ages, the patterned background denotes portions attributed to the older standard, and the red line denotes the date of the newer and older standards.

APPENDIX B: REFRIGERATOR AND FREEZER DOE PRODUCT CLASS ASSIGNMENT

The following tables indicate how the Statewide CASE Team mapped the different permutations of RASS self-reported refrigerator and freezer characteristics to the product classes defined in the 2014 federal standards.

The DOE TSD provides a full description and technical specifications for each product class of residential refrigeration equipment (DOE 2011a).

Table B-1: Assignment of RASS refrigerator types to DOE product classes

RASS Survey-Report Refrigerator Characteristics				DOE Product Class
Door Style	**Defrost**	**TTD Ice**	**Compact**	
Top-mounted	Manual	Yes	No	1. Refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.
Top-mounted	Manual	No	No	1. Refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.
Side-by-side	Manual	Yes	No	1. Refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.
Side-by-side	Manual	No	No	1. Refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.
Bottom-mounted	Manual	Yes	No	1. Refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.
Bottom-mounted	Manual	No	No	1. Refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.
Top-mounted	Manual	Yes	Yes	11. Compact refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.
Top-mounted	Manual	No	Yes	11. Compact refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.
Top-mounted	Auto	Yes	Yes	11. Compact refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.
Top-mounted	Auto	No	Yes	11. Compact refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.
Single-door	Auto	Yes	Yes	11. Compact refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.
Single-door	Auto	No	Yes	11. Compact refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.
Side-by-side	Manual	Yes	Yes	11. Compact refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.
Side-by-side	Manual	No	Yes	11. Compact refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.
Side-by-side	Auto	Yes	Yes	11. Compact refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.
Side-by-side	Auto	No	Yes	11. Compact refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.
Bottom-mounted	Manual	Yes	Yes	11. Compact refrigerator-freezers and refrigerators other

RASS Survey-Report Refrigerator Characteristics				DOE Product Class
Door Style	Defrost	TTD Ice	Compact	
				than all-refrigerators with manual defrost.
Bottom-mounted	Manual	No	Yes	11. Compact refrigerator-freezers and refrigerators other than all-refrigerators with manual defrost.
Single-door	Manual	Yes	Yes	11A.Compact all-refrigerators—manual defrost.
Single-door	Manual	No	Yes	11A.Compact all-refrigerators—manual defrost.
Bottom-mounted	Auto	Yes	Yes	15. Compact refrigerator-freezers—automatic defrost with bottom-mounted freezer.
Bottom-mounted	Auto	No	Yes	15. Compact refrigerator-freezers—automatic defrost with bottom-mounted freezer.
Single-door	Manual	Yes	No	1A. All-refrigerators—manual defrost.
Single-door	Manual	No	No	1A. All-refrigerators—manual defrost.
Single-door	Auto	Yes	No	3A. All-refrigerators—automatic defrost.
Single-door	Auto	No	No	3A. All-refrigerators—automatic defrost.
Top-mounted	Auto	No	No	3I. Refrigerator-freezers—automatic defrost with top-mounted freezer with an automatic icemaker without through-the-door ice service.
Side-by-side	Auto	No	No	4I. Refrigerator-freezers—automatic defrost with side-mounted freezer with an automatic icemaker without through-the-door ice service.
Bottom-mounted	Auto	Yes	No	5A. Refrigerator-freezer—automatic defrost with bottom-mounted freezer with through-the-door ice service.
Bottom-mounted	Auto	No	No	5I. Refrigerator-freezers—automatic defrost with bottom-mounted freezer with an automatic icemaker without through-the-door ice service.
Top-mounted	Auto	Yes	No	6. Refrigerator-freezers—automatic defrost with top-mounted freezer with through-the-door ice service.
Side-by-side	Auto	Yes	No	7. Refrigerator-freezers—automatic defrost with side-mounted freezer with through-the-door ice service.

Table B-2: Assignment of RASS freezer types to DOE product classes

RASS Survey-Report Freezer Characteristics			DOE Product Class
Freezer Style	Defrost	Compact	
Chest	Manual	No	10. Chest freezers and all other freezers except compact freezers.
Chest	Auto	No	10A. Chest freezers with automatic defrost.
Upright	Manual	Yes	16. Compact upright freezers with manual defrost.
Upright	Auto	Yes	17. Compact upright freezers with automatic defrost.
Chest	Auto	Yes	18. Compact chest freezers.
Chest	Manual	Yes	18. Compact chest freezers.
Upright	Manual	No	8. Upright freezers with manual defrost.
Upright	Auto	No	9. Upright freezers with automatic defrost without an automatic icemaker.

APPENDIX C: LIST OF RESIDUAL MELS

The following is a list of the 114 MELs product categories that the Statewide CASE Team did not individually model. The Statewide CASE Team used this list calculate the total national energy use of these MELs in households. See Section 4.9 for details on the calculations.

Table C-1: Full list of residual MELs considered in the report

End-Use	Source	AEC (GWh/yr)
Microwaves	SCE	14,705
DVD/Blu-Ray Players	SCE	8,500
Video Game Consoles	SCE	7,950
Cordless Phones	SCE	7,275
Audio Receivers	SCE	6,400
Compact Audio	SCE	6,312
Air Cleaners/Humidifiers	SCE	6,000
Iron	SCE	5,620
Toasters	SCE	5,353
Vacuum Cleaners	SCE	5,183
Printer Devices	SCE	4,900
Waterbed Heater	SCE	4,730
Coffee Machines	SCE	4,257
VCRs	SCE	4,213
Hair Dryer	SCE	4,160
Doorbell	BA	3,952
Ground Fault Circuit Interrupter (GFCI)	BA	3,202
Home Theater in a box	SCE	2,458
Garage Door Openers	SCE	2,300
Power Strips	SCE	2,300
Digital Photo Frames	SCE	2,200
Toaster Oven	SCE	2,110
Modems	SCE	2,108
Routers	SCE	2,000
Radio	SCE	1,933
Tabletop Fans	SCE	1,800
Computer Speaker	SCE	1,800
Security System	SCE	1,650
Slow cooker	SCE	1,300
Waffle Iron	BA	1,085
Telephone Answering Machine	SCE	1,067
Food Waste Disposers	SCE	1,000
Hot Plate	BA	951
Marine/Automotive/RV Chargers	DOE	940
Rice cookers	SCE	900
External Storage Device	SCE	800
Standing Fans	SCE	800
Uninterruptible Power Supplies	DOE	712
MP3 Docking Station	SCE	700
Mobility Scooters	DOE	637

End-Use	Source	AEC (GWh/yr)
Toy Ride-On Vehicles	DOE	620
Carbon Monoxide Detector	BA	616
Mobile Phone	SCE	600
Rechargeable Toothbrushes	DOE	585
Sump Pump	BA	522
Wheelchairs	DOE	471
Fax Machine (stand-alone)	SCE	450
Smartphone	DOE	407
Deep Fryer	BA	402
Projectors	SCE	400
Stand Alone DVR	SCE	400
Portable Audio	SCE	400
Smoke Detectors	BA	388
Portable Video Game Systems	DOE	303
Caller ID Equipment	SCE	300
Wine coolers	SCE	300
Bluetooth Headsets	DOE	295
Electric Grill	BA	241
Electric Scooters	DOE	228
DIY Power Tools (External)	DOE	226
DIY Power Tools (Integral)	DOE	206
Electric Griddle	BA	201
Popcorn Popper	BA	201
Electric Lawn Mowers	SCE	200
Scanner (stand-alone)	SCE	200
Netbooks	DOE	192
Baby Monitors	DOE	158
Sleep Apnea Machines	DOE	154
Aquarium Accessories	DOE	150
Motorized Bicycles	DOE	137
Instant Hot Water Dispenser	BA	134
Robotic Vacuums	DOE	128
Broiler	BA	107
Shavers	DOE	102
Camcorder	SCE	100
Electric Hedge Trimmers	SCE	100
Professional Power Tools	DOE	87
VoIP Adapters	DOE	70
Curling Iron	BA	67
Irrigation Timers	DOE	60
Media Tablets	DOE	54
Food Slicer	BA	54
Electric Knife	BA	54
Indoor Fountains	DOE	52
Wireless Charging Stations	DOE	51
Pager	SCE	50
Digital Camera	SCE	40
Medical Nebulizers	DOE	38
In-Vehicle GPS	DOE	37
Water Softeners/Purifiers	DOE	28

End-Use	Source	AEC (GWh/yr)
E-Books	DOE	28
Universal Battery Chargers	DOE	23
Beard and Moustache Trimmers	DOE	15
Hair Clippers	DOE	10
Flashlights/Lanterns	DOE	10
Golf Carts	DOE	9
Personal Digital Assistants	DOE	6
Blood Pressure Monitors	DOE	6
Consumer Two-Way Radios	DOE	5
RC Toys	DOE	4
Rechargeable Water Jets	DOE	4
Wireless Speakers	DOE	3
Pre-Amps	DOE	3
Wireless Headphones	DOE	3
Portable O2 Concentrators	DOE	3
Rechargeable Garden Care Products	DOE	2
Guitar Effects Pedals	DOE	2
Can Openers	DOE	2
Keyboards	DOE	1
Air Mattress Pumps	DOE	1
Breast Pumps	DOE	< 1
Handheld GPS	DOE	< 1
Blenders	DOE	< 1
Mixers	DOE	< 1
	Count	**Total AEC**
BA HSP	16	12,177
DOE BCEPS TSD	52	7,271
SCE Meta-Analysis	46	128,324

Note: SCE refers to the 2014 Southern California Edison Meta-Analysis of Residential Loads (SCE 2014). DOE refers to the 2012 Department of Energy Technical Support Document for Battery Chargers and External Power Supplies (DOE 2012f). BA refers to the 2014 Building America House Simulation Protocols (Wilson et al. 2014).

APPENDIX D: FORECAST OF LAMP SHIPMENT AND STOCK SHARES IN 2017

The shipment and stock forecasts below are used as a proxy for estimating the relative portion of the lamp type present in a 2017 newly constructed home, as discussed in Section 4.10. The Statewide CASE Team based these forecasts on the 2016 Department of Energy Technical Support Document for General Service Lamps (DOE TSD GSL). Below is a step-by-step explanation of the forecast methodology and the resulting market share values of each lamp type.

Estimating Shipments

DOE TSDs typically contain projected lamp shipments. However, due to the "Appropriations Rider", which prevents DOE from using appropriated funds for amending standards pertaining to incandescent or halogen lamps, the 2016 TSD only includes a forecast of LED and CFL lamps. Moreover, the forecasts are national projections, and thus require some manipulation to reflect the effects of California Title 20 standards.

1. Historic 2010-2013 shipment data for the four lamp types were determined by DOE in the 2014 General Service Lamps Preliminary Technical Support Document (GSL PTSD). DOE references the Cadeo group for this shipment data.
2. The 2010-2015 market shares of shipment data were obtained from NEMA. The data was adjusted to match the Cadeo data from Step 1.
3. The 2015-2020 shipments of LED and CFL lamps were estimated from DOE 2015 GSL TSD National Impacts Analysis (NIA). Here, the 2018, 2019, and 2020 shipment data was taken to equal the 2020, 2021, and 2022 DOE shipment data, respectively. This is because while DOE predicts that the federal standard for GSLs will eliminate halogen and incandescent lamp shipments starting 2020, California Title 20 regulation will initiate the phase out 2 years earlier, in 2018.
4. The 2015 shipment data of halogen and incandescent lamps were derived using the data from Step 2 and Step 3.
5. The 2018-2020 shipments of halogen and incandescent lamps were estimated to equal 0 for the same reasons indicated in Step 3.
6. The 2026-2017 shipments of halogen and incandescent lamps were linearly interpolated using the data from Step 4 and Step 5.
7. The remaining data is completed by calculation or linear interpolation.

Estimating Stock

In order to estimate the stock of lamps using the shipment data, the Statewide CASE Team followed the DOE methodology in determining mean lamp life with a renovation factor (lamps may not last their entire useful life due to some probability that the consumer renovates the home, changing the lamp in the process, prior to the failure of the lamp.

1. The median life of LED and CFL lamps were obtained from the 2016 DOE GSL.

2. Using common values for the rated hours of halogen and incandescent lamps, median lives were estimated for these lamp types as well.
3. The median lives were converted into integer stock lives in order to simplify the calculations (Table D.3).
4. The 2010 lamp stock was calculated by multiplying the 2010 shipments and the stock life.
5. The stock in future years was estimated by adding the shipments and subtracting the lamp retirements from that year. The lamp retirements of a specified year were determined to be equal to the past shipments from that year minus the stock life.

Table D-1: Forecast of LED, CFL, halogen, and incandescent shipment shares from 2010-2020

	Shipments (thousands)					Market Share (%)			
	LED	**CFL**	**Hal**	**Inc**	**Total**	**LED**	**CFL**	**Hal**	**Inc**
2010	1,294	220,282	11,428	672,844	905,848	0.1	24.3	1.3	74.3
2011	1,682	210,150	17,310	780,499	1,009,641	0.2	20.8	1.7	77.3
2012	4,657	209,520	32,594	644,692	891,463	0.5	23.5	3.7	72.3
2013	12,289	204,490	70,397	557,659	844,836	1.5	24.2	8.3	66.0
2014	30,878	246,904	244,070	282,114	803,965	3.8	30.7	30.4	35.1
2015	79,609	153,276	287,828	107,324	628,037	11.4	25.7	45.8	17.1
2016	127,602	114,993	408,079	71,549	722,224	17.7	15.9	56.5	9.9
2017	173,732	73,481	406,540	35,775	689,527	**25.2**	**10.7**	59.0	5.2
2018	576,321	64,162	0	0	640,483	90.0	10.0	0.0	0.0
2019	526,081	44,486	0	0	570,567	92.2	7.8	0.0	0.0
2020	430,511	31,128	0	0	461,639	93.3	6.7	0.0	0.0

Note: The highlighted cells represent the values used to predict the portion of portable luminaires with LED and CFL lamps. This ratio equates to 70% LED and 30% CFL. The shipments in this table resemble national shipment quantities, but were adjusted to reflect California regulation (see Step 3 above).

Table D-2: Forecast of LED, CFL, halogen, and incandescent stock shares from 2010-2020

	Stock (thousands)					Market Share			
	LED	**CFL**	**Hal**	**Inc**	**Total**	**LED**	**CFL**	**Hal**	**Inc**
2010	24,578	1,321,695	34,285	1,345,688	2,726,246	0.9	48.5	1.3	49.4
2011	24,966	1,311,562	40,166	1,453,344	2,830,038	0.9	46.3	1.4	51.4
2012	28,330	1,300,799	61,332	1,425,192	2,815,652	1.0	46.2	2.2	50.6
2013	39,325	1,285,007	120,301	1,202,352	2,646,984	1.5	48.5	4.5	45.4
2014	68,909	1,311,629	347,060	839,773	2,567,371	2.7	51.1	13.5	32.7
2015	147,225	1,244,622	602,295	389,437	2,383,580	6.2	52.2	25.3	16.3
2016	273,534	1,139,333	939,977	178,873	2,531,717	10.8	45.0	37.1	7.1
2017	445,972	1,002,665	1,102,448	107,324	2,658,408	**16.8**	**37.7**	**41.5**	**4.0**
2018	1,020,999	857,307	814,619	35,775	2,728,700	37.4	31.4	29.9	1.3
2019	1,545,786	697,303	406,540	0	2,649,629	58.3	26.3	15.3	0.0
2020	1,975,003	481,527	0	0	2,456,530	80.4	19.6	0.0	0.0

Note: The highlighted cells represent the values used in the report (as a proxy for the portion of old portable lamps). The shipments in this table resemble national shipment quantities, but were adjusted to reflect California regulation (see above).

Table D-3: Determined median life and stock life based off of rated hours of LED, CFL, halogen, and incandescent lamps

	LED	CFL	Halogen	Incandescent
Rated Hours	25000	10000	2000	1000
Median Life	19.3	6.4	3.4	1.7
Stock Life	19	6	3	2

Figure D-1: Forecast of LED, CFL, halogen, and incandescent market shares from 2010-2020

APPENDIX E: DESKTOP AND NOTEBOOK SATURATION-ADJUSTMENT FACTORS

The Statewide CASE Team calculated saturation adjustment factors for desktops and notebooks to account for changes in saturation between the RASS survey and the 2016 Title 24 code cycle. These saturation adjustment factors were derived in two parts:

- An adjustment from RASS to 2013;
- An adjustment from 2013 to the 2016 Title 24 code cycle.

The use of a two-part conversion was motivated by available data, as was the choice of 2013 as the bridge year.

The saturation adjustment factor to convert from RASS to 2013 is grounded in the 2013 CE Usage Surveys (Urban et al. 2014; see Section 3.1.3). From the CE Usage Surveys, the Statewide CASE Team determined the average number of regularly used desktops and notebooks in an American household in 2013: 1.04 desktops and 1.12 notebooks per American household in 2013, as compared to 0.84 and 0.75 in RASS.

Because Californians tend to have more desktops and notebooks per household than the national average, the Statewide CASE Team adjusted the 2013 national numbers upward, using data from the 2009 Residential Energy Consumption Survey (RECS), to estimate the 2013 California saturation.[82] (The Statewide CASE Team's analysis of the RECS microdata indicated Californians own 9 percent more desktops than the national average and 8 percent more notebooks.) Therefore, the Statewide CASE Team calculated the RASS to 2013 saturation adjustment factor as follows:

$$SAF_{RASS-2013} = \frac{Saturation_{U.S.2013}}{Saturation_{RASS.2009}} \times \frac{Saturation_{CA.RECS}}{Saturation_{US.RECS}}$$

$SAF_{RASS-2013}$ = saturation adjustment factor to convert from RASS to 2013 California households

$Saturation_{US.2013}$ = nationwide saturation in 2013

$Saturation_{RASS.2009}$ = California saturation from RASS 2009

$Saturation_{CA.RECS}$ = California saturation from RECS 2009

[82] RECS is a regularly implemented survey of American households, administered by EIA. RECS 2009 collected data from 12,083 households in housing units statistically selected to represent all housing units that are occupied as a primary residence nationwide. Interviewers collected energy characteristics on the housing unit, appliance saturation, usage patterns, and household demographics.

$Saturation_{US.RECS}$ = nationwide saturation from RECS 2009

For desktops, the RASS to 2013 saturation adjustment factor is 1.35 and is calculated as follows.

$$SAF_{RASS-2013} = \frac{Saturation_{U.S.2013}}{Saturation_{RASS.2009}} \times \frac{Saturation_{CA.RECS}}{Saturation_{US.RECS}}$$

$$Desktop.SAF_{RASS-2013} = \frac{1.04}{0.84} \times 1.09 = 1.35$$

In other words, the Statewide CASE Team estimates that the average number of desktops per household increased 35 percent from the time of the RASS survey to 2013.

For notebooks, the RASS to 2013 saturation adjustment factor is 1.61 and is calculated as follows.

$$SAF_{RASS-2013} = \frac{Saturation_{U.S.2013}}{Saturation_{RASS.2009}} \times \frac{Saturation_{CA.RECS}}{Saturation_{US.RECS}}$$

$$Notebook.SAF_{RASS-2013} = \frac{1.12}{0.75} \times 1.08 = 1.61$$

In other words, the Statewide CASE Team estimates that the average number of notebooks per household increased 61 percent from the time of the RASS survey to 2013.

The second part of the Statewide CASE Team's overall saturation adjustment factor was a conversion from 2013 to 2017, the first year of the 2016 Title 24 code cycle. The Statewide CASE Team used estimated US shipments from the leading market research firm International Data Corporation (IDC) (also used in the Title 20 CASE Reports and addendums) to predict the change in saturation over this time period (IDC 2016). The Statewide CASE Team estimated the nationwide stock of desktops and notebooks for each year from 2013 to 2017 using shipment data from 2009 to 2017. To do so, the Statewide CASE Team had to first determine the design life of desktops and notebooks. Once a device is shipped, it is counted toward the nationwide stock for the duration of its design life. The Statewide CASE Team assumed the design life of desktops to be 5 years and the design life of notebooks to be 4 years, based on a 2015 CEC Staff Report on Computers, Computer Monitors, and Electronic Displays (CEC 2015b). Therefore, annual desktop stock was calculated as the sum of annual desktop shipments in the previous 5 years and annual notebooks stock was calculated as the sum of annual notebook shipments in the previous 4 years, as presented in Table E-1.

Table E-1: Estimated shipments and stock of desktops and notebooks

Year	Desktop Shipments (million/yr)	Desktop Stock (million)	Notebook Shipments (million/yr)	Notebook Stock (million)
2009	28	-	43	-
2010	28	-	46	-
2011	26	-	46	-
2012	25	-	42	176
2013	25	131	42	176
2014	23	126	45	174
2015	22	120	45	174
2016	22	117	45	177
2017	22	114	46	181

Source: (IDC 2012, 2013, 2014)

The Statewide CASE Team calculated the 2013 to 2017 saturation adjustment factors for desktops and notebooks by dividing the 2017 stock by the 2013 stock. The resultant saturation adjustment factors are 0.87 for desktops (114/131) and 1.03 for notebooks (181/176). In other words, the Statewide CASE Team estimates that the average number of desktops per household will decrease 23 percent from 2013 to 2017 and the average number of notebooks per household will increase by a modest 3 percent.

The overall saturation adjustment factors, calculated as the product of the two constituent saturation adjustment factors, are 1.17 (+17 percent) for desktops and 1.66 (+66 percent) for notebooks. The Statewide CASE Team applied these factors to the survey-reported saturation from each home in RASS, resulting in a saturation-adjusted average of 0.98 desktops and 1.24 notebooks for new homes built during the 2016 Title 24 Code Cycle. Table E-2 summarizes the resulting shift in assumed saturation.

Table E-2: Desktops and notebooks per household, before and after the application of the saturation adjustment factor.

Number of Devices	Desktops	Notebooks
RASS 2009	0.84	0.75
2016 Title 24 code cycle	0.98	1.24

The Statewide CASE Team recommends that future updates to the model draw on data from California-specific field studies to determine a more empirical set of saturation adjustment factors.

APPENDIX F: LIST OF KEY TERMS AND ACRONYMS

0-bedroom home	a studio apartment; only a small number of single-family homes report 0 bedrooms.
Adjusted volume	a representation, in cubic feet, of the volume useful volume of a refrigerator, as defined by 10 C.F.R. 430 Subpart B Appendix A
AEC	Annual Energy Consumption
AEO	Annual Energy Outlook developed by the EIA
Algorithm or ruleset	a set of conditional equations or look-up tables used to model energy use
BA HSP	Building America House Simulation Protocols (Wilson et al. 2014)
BTU	British Thermal Unit
CBECC-Res	California Building Energy Code Compliance (for residential buildings) software; a public domain software program developed by the California Energy Commission for use in complying with the Residential Building Energy Efficiency Standards
CE Usage Survey	Consumer Expenditure Survey by the U.S. Department of Labor Bureau of Labor Statistics.
CEC WH Model	California Energy Commissions water heating models
CEF	Combined Energy Factor, pertaining to the efficiency of clothes dryers, and measured in pounds per kilowatt-hour
CFA	Conditioned floor area (CFA) is the total floor area (in square feet) of enclosed conditioned space on all floors of a building, as measured at the floor level of the exterior surfaces of exterior walls enclosing the conditioned space. CFA means per dwelling unit
CFL	Compact Fluorescent Lamp, as defined in 42 U.S.C §6291(30)
CLASS	California Lighting Appliance Saturation Survey
CPUC	California Public Utilities Commission
DEER	Database for Energy Efficient Resources, sponsored by the CEC and CPUC
DOE	U.S. Department of Energy
Duty cycle	generally refers to average annual time spent in each of the main operational modes
EDR	Energy Design Rating

EIA	U.S. Energy Information Administration
Home	a residential unit, including units in multi-family housing, single-family houses, and mobile homes
Home	a single-family or multi-family residential dwelling unit
Hourly schedule	hourly energy use of a particular load; for this analysis the hourly schedule is expressed in the percentage of daily energy use that occurs in a specified hour.
Household	the regular occupants of a residential dwelling unit
IMEF	Integrated Modified Energy Factor, metric of evaluating energy performance of clothes washers, and measured in cubic feet per kilowatt-hour per cycle
kWh	kilowatt-hour
LED	Light Emitting Diode, as defined in 42 U.S.C §6291(30)
Luminous Efficacy	a lamp characteristic defined by amount of the luminous flux generated per watt of power.
Luminous Flux	a quantification of the energy of light emitted per second in all directions, often referred to as "brightness," and measured in lumens
MEL	an appliance or electronic device that can be plugged in to a receptacle or receptacle outlet or hard-wired (connected permanently to a building electrical system) and that is not related to hardwired lighting, HVAC that is fixed in place (non-portable), water heating, domestic and service water pumps and related systems that are fixed in place (non-portable), renewable power, process loads, swimming pools, spas, saunas, elevators, escalators, moving walkways, transit systems, or electric vehicle charging. In this CASE Report, portable lighting is considered in the same end use group as hardwired lighting; therefore, portable lighting is excluded from the scope of MELs
NBr	Number of bedrooms per dwelling unit
NEEA RBSA	Northwest Energy Efficiency Alliance Residential Building Stock Assessment
NOPR	Notice of Proposed Rulemaking, an official notice by DOE to solicit comments regarding amendments to energy efficiency standards
NRDC	National Resources Defense Council
Per-household AEC	annual energy consumption per household of all devices in a product category

Pilot Light	a continuously burning flame used to light a larger burner when needed
Plug loads	white good appliances, major consumer electronics (e.g. televisions, computers), and miscellaneous electric loads (MELs), excluding portable lighting
Power by mode	the power draw of different operational modes, such as active mode or sleep mode
Range	a cooking appliance that consists of both an oven and a cooktop
RASS	Residential Appliance Saturation Survey
RECS	Residential Energy Consumption Survey
RESNET	Residential Energy Services Network
RMC	Remaining Moisture Content, as measured for the evaluation of clothes dryers, a percentage defined in 10 C.F.R. 430.23
Saturation	the number of devices of a product category per dwelling unit
SCE	Southern California Edison Company, a California investor-owned utility
Seasonal multipliers	factors used to adjust energy use on a monthly basis; average daily load is determined by dividing AEC by 365 days per year, where for each month, daily load is then multiplied by the monthly multiplier to calculate the seasonally-adjusted average daily load
Standby Power	the power consumed by electronics when they are switched off or not performing their primary functions
Submetering	the act of measuring the individual end uses within a home, rather than the total home energy consumption.
TEC	Total Energy Consumption, used for certain consumer electronics
Therms	a unit of energy equal to 100,000 BTU, commonly used for gas appliances, and is approximately the energy equivalent of burning 100 cubic feet of natural gas
TSD	Technical Support Documents provided by DOE for supporting the amendments proposed in the NOPR
ZNE	Zero Net Energy