APPENDIX E – PLUG LOADS AND LIGHTING MODELING

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 (Rubin 2016, see Appendix D).

1.1.1 Background

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 2019 *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

Rulesets for all modeled end uses reflect the estimated energy consumption of those devices in new homes built during the 2022 Title 24 Code Cycle. The plug load rulesets estimate annual energy consumption (AEC) as a function of number of bedrooms (BR/Unit) and the lighting rulesets estimate AEC as a function of conditioned floor area (CFA/Unit). The relationship between AEC and BR/Unit 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 BR/Unit 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 CFA/Unit 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 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

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 'BR/Unit' 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, 'CFA/Unit' 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	- BR/Unit - 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 BR/Unit. - 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	- BR/Unit - 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	- BR/Unit - 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.

End Use	User Inputs that Determine Estimated Energy Use	Notes
Clothes Washer	- BR/Unit - 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	- Bedrooms per unit - 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	- Bedrooms per unit - 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	N/A	N/A
Televisions, Set-Top Boxes, Computers and Monitors, Residual MELs	- Bedrooms per unit	N/A
Interior Lighting, Exterior Lighting	- CFA/Unit	N/A

End Use	User Inputs that Determine Estimated Energy Use	Notes
Garage Lighting	- CFA/Unit - 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.

Source: California Energy Commission

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 bedrooms per unit (BR/Unit) for plug loads and CFA/Unit 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 BR/Unit for plug loads or CFA/Unit 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	0.95	BR
Oven	Gas	kWh	41	4.79	BR
Cooktop	Electricity	kWh	84	5.68	BR
Cooktop	Gas	therms	5.0	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	0.0532	CFA
Garage Lighting	Electricity	kWh	20	0.0063	CFA

Source: California Energy Commission

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 water heating is accounted for in the water heating model.

Table 3: Single-Family Residence Algorithms for Dishwasher, Clothes Washer, and Clothes Dryer Annual Energy Use

BRper Unit	Dishwashers (kWh/yr)	Clothes Washers (kWh/yr)	Electric Clothes Dryers (kWh/yr)	Gas Dryer Natural Gas Use (therms/yr)	Gas Dyer 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	227	877	31	44

Source: California Energy Commission

Table 4: Multi-Family Dwelling Unit Algorithms for Dishwasher, Clothes Washer, and Clothes Dryer Annual Energy Use

BRper Unit	Dishwashers (kWh/yr)	Clothes Washers (kWh/yr)	Electric Clothes Dryers (kWh/yr)	Gas Dryer Natural Gas Use (therms/yr)	Gas Dyer Electricity Use (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

Source: California Energy Commission

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 below. The default AEC of the primary refrigerator cannot be adjusted below a certain value, which is dependent on BR/Unit as described in the following equation:

$$MinPrimaryRefrigAEC \frac{kWh}{yr} = \left(8.4 \frac{kWh}{BRperUnit\text{-}yr} \times BRperUnit \right) + 291 \frac{kWh}{yr}$$

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 BR/Unit

BR/Unit	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

Source: California Energy Commission

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

BR/Unit	Single Family Default AEC (kWh/yr)	Single Family High-Efficiency Clothes Washer AEC[1] (kWh/yr)	Multifamily Default AEC (kWh/yr)	Multifamily 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

Source: California Energy Commission

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)

$$RMC\text{-}adjusted\ AEC\ \frac{kWh}{yr}$$
$$= 12.67\ \frac{kWh}{yr} + \left[\left(3.80\ \frac{kWh}{cycle}\left(RMC_{User,Input}\right) + 0.25\ \frac{kWh}{cycle}\right) \times \frac{cycles}{yr}\right]$$

Gas Dryer: RMC-adjusted AEC (therms/yr)

$$RMC\text{-}adjusted\ AEC\ \frac{therms}{yr} = \left[0.136\frac{therms}{cycle}\left(RMC_{User,Input}\right) + 0.00853\ \frac{therms}{cycle}\right] \times \frac{cycles}{yr}$$

Table 7: Annual clothes dryer cycles estimated based on BR/Unit

BR/Unit	Clothes Dryer Cycles Single-Family	Clothes Dryer Cycles Multi-Family
0	290	227
1	290	241
2	291	341
3	342	335
4	346	405
5+	401	368

Source: California Energy Commission

1.1.4.3   *Load Profiles*

Dishwashers and clothes washers 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	0.005	0.035	0.040	0.036	0.037	0.023	0.046
2	0.004	0.026	0.040	0.033	0.035	0.019	0.046
3	0.004	0.023	0.040	0.032	0.034	0.015	0.046
4	0.004	0.022	0.040	0.032	0.034	0.017	0.046
5	0.004	0.021	0.040	0.031	0.032	0.021	0.046
6	0.014	0.021	0.040	0.032	0.036	0.031	0.037
7	0.019	0.025	0.040	0.034	0.042	0.042	0.035
8	0.025	0.032	0.041	0.036	0.044	0.041	0.034
9	0.026	0.038	0.040	0.039	0.037	0.034	0.033
10	0.022	0.040	0.040	0.043	0.032	0.029	0.028
11	0.021	0.038	0.040	0.045	0.033	0.027	0.022
12	0.029	0.038	0.040	0.045	0.033	0.025	0.015
13	0.035	0.041	0.040	0.046	0.032	0.021	0.012
14	0.032	0.042	0.040	0.046	0.033	0.021	0.011
15	0.034	0.042	0.041	0.046	0.035	0.021	0.011
16	0.052	0.041	0.041	0.047	0.037	0.026	0.012
17	0.115	0.044	0.042	0.048	0.044	0.031	0.019
18	0.193	0.049	0.043	0.049	0.053	0.044	0.037
19	0.180	0.056	0.044	0.049	0.058	0.084	0.049
20	0.098	0.064	0.045	0.049	0.060	0.117	0.065
21	0.042	0.070	0.046	0.049	0.062	0.113	0.091
22	0.020	0.074	0.047	0.048	0.060	0.096	0.105
23	0.012	0.067	0.045	0.044	0.052	0.063	0.091
24	0.010	0.051	0.045	0.041	0.045	0.039	0.063

Source: California Energy Commission

Table 8: Hourly Multiplier – Weekends

Hour	Oven and Cooktop	Televisions	Set-Top Boxes	Computers and Monitors	Residual MELs	Interior and Garage Lighting	Exterior Lighting
1	0.005	.035	0.041	0.036	0.037	0.023	0.046
2	0.004	0.027	0.041	0.034	0.035	0.019	0.046
3	0.003	0.022	0.040	0.033	0.034	0.015	0.045
4	0.003	0.021	0.041	0.033	0.034	0.017	0.045
5	0.003	0.020	0.040	0.032	0.032	0.021	0.046
6	0.005	0.020	0.040	0.033	0.036	0.031	0.045

Hour	Oven and Cooktop	Televisions	Set-Top Boxes	Computers and Monitors	Residual MELs	Interior and Garage Lighting	Exterior Lighting
7	0.010	0.022	0.040	0.033	0.042	0.042	0.044
8	0.027	0.029	0.040	0.035	0.044	0.041	0.041
9	0.048	0.037	0.041	0.038	0.037	0.034	0.036
10	0.048	0.043	0.042	0.042	0.032	0.029	0.030
11	0.046	0.042	0.042	0.044	0.033	0.027	0.024
12	0.055	0.039	0.041	0.045	0.033	0.025	0.016
13	0.063	0.040	0.041	0.046	0.032	0.021	0.012
14	0.059	0.042	0.041	0.047	0.033	0.021	0.011
15	0.062	0.045	0.041	0.047	0.035	0.021	0.011
16	0.068	0.048	0.042	0.048	0.037	0.026	0.012
17	0.091	0.051	0.042	0.049	0.044	0.031	0.019
18	0.139	0.052	0.043	0.049	0.053	0.044	0.038
19	0.129	0.056	0.044	0.048	0.058	0.084	0.048
20	0.072	0.061	0.044	0.048	0.060	0.117	0.060
21	0.032	0.065	0.045	0.048	0.062	0.113	0.083
22	0.014	0.069	0.045	0.047	0.060	0.096	0.098
23	0.009	0.064	0.044	0.044	0.052	0.063	0.085
24	0.005	0.050	0.039	0.041	0.045	0.039	0.059

Source: California Energy Commission

Table 9: 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	0.991	0.84	0.87	1.11
Mar	1.074	0.986	0.92	0.89	1.02
Apr	0.889	0.990	0.98	1.11	0.93
May	0.891	0.971	0.91	1.14	0.84
Jun	0.935	0.971	0.94	0.99	0.80
Jul	0.993	1.002	1.05	1.05	0.82
Aug	0.920	1.013	1.06	1.01	0.88
Sep	0.923	1.008	1.06	0.96	0.98
Oct	0.920	1.008	1.14	0.97	1.07
Nov	1.128	1.020	1.03	0.99	1.16
Dec	1.168	1.008	1.05	1.04	1.20

Source: California Energy Commission