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City of Santa Monica 2016 Building Energy Efficiency Reach Code Cost Effectiveness Study

Final Report

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EXECUTIVE SUMMARY

The City of Santa Monica (the City) seeks implementation of a building energy efficiency reach code. The California Energy Commission (CEC) requires that a cost effectiveness study be completed to implement a reach code in the Santa Monica Municipal Code. On behalf of the City and Southern California Edison, TRC investigated reach code options requiring that residential and nonresidential new construction use less energy than a building minimally compliant with 2016 Title 24 Building Energy Efficiency Standards (T24 Standards).

Two methods were used to analyze potential cost effective energy efficiency measures: the CEC Life Cycle Cost (LCC) Methodology using TDV and a life cycle customer cost methodology using customer retail rates for electricity and natural gas. Each analysis method quantifies the energy savings benefits associated with measures as well as the costs of installation and maintenance. The benefit to cost (B/C) ratio is the indicator for cost effectiveness. A B/C ratio greater than 1 indicates that the added cost of the measure is more than offset by the present value life cycle energy cost savings, and the measure is cost effective.

TRC investigated cost effective energy efficiency measures for single family residential, low-rise multifamily residential, and nonresidential buildings. The analysis used CEC prototype buildings simulated in Title 24 compliance software, CBECC-Com and CBECC-Res. Time Dependent Valuation (TDV) energy savings were developed through software simulations and rate payer energy savings were calculated using utility rate structures.

The analysis evaluated the feasibility of:

- Meeting CALGreen Tier 3 Zero Net Energy (ZNE) for residential buildings.[1] This definition requires achieving an Energy Design Rating (EDR) of less than or equal to zero.
- Requiring a percentage improvement above 2016 Title 24 for nonresidential buildings.

Using the CEC LCC methodology, TRC found packages of energy efficiency measures to be cost effective for the single family, low-rise multifamily, and nonresidential prototypes, as shown below in Table 1, Table 2, and Table 3. Additionally, TRC found an Energy Design Rating less than or equal to zero to be cost effective for residential buildings (Table 1 and Table 2). Thus, TRC recommends that Santa Monica implement a Reach Code ordinance to exceed the 2016 Title 24 Standards for these building types.

[1] 2016 CALGreen Voluntary Provisions, 15-Day Language, Express Terms : http://www.energy.ca.gov/title24/2016standards/rulemaking/documents/15-day_calgreen/2015-09-29_Rev_15-Day_Language_Part_11_TN-76193.pdf

Table 1. Summary of Residential Cost Effective Packages

Single Family Residential ZNE Package				
Measure	**2016 T24 Compliance Margin**	**Present Value of Energy Savings (TDV$)**	**Cost**	**Benefit to Cost Ratio**
Quality Insulation Installation	8.5%	$760	$519	1.5
High Performance Walls	7.1%	$635	$641	1.0
Reduced Fan Watt Draw	2.4%	$213	$143	1.5
Piping Insulation, All Hot Water Lines	1.1%	$102	$168	0.6
Improved Glazing	1.1%	$97	$72	1.3
Verified Refrigerant Charge	0.9%	$79	$76	1.0
Energy Efficiency Package	**19.1%**	**$1,709**	**$1,619**	**1.1**
3.7 kW PV to meet EDR = 0	-	$24,696	$10,956	2.3
Zero Net Energy Package	**19.1%***	**$26,405**	**$12,575**	**2.1**

*PV is not awarded compliance credit in simulation software for climate zone 6.

Table 2. Summary of Low-rise Multifamily Cost Effective Packages

Low-rise Multifamily Residential ZNE Package				
Measure	**2016 T24 Compliance Margin**	**Present Value of Energy Savings (TDV$)**	**Cost**	**Benefit to Cost Ratio**
Reduced Fan Watt Draw	3.2%	$1,073	$832	1.3
Compact Domestic Hot Water Distribution	2.6%	$844	$33	25.6
Quality Insulation Installation	2.4%	$784	$1,018	0.8
High Performance Walls	1.9%	$615	$1,237	0.5
Cool Roof	1.8%	$603	$70	8.7
Verified Refrigerant Charge	1.7%	$555	$300	1.8
Verified Low-Leakage Ducts Entirely in Conditioned Space	1.7%	$567	$517	1.1
Improved Glazing	1.6%	$542	$156	3.5
Reduced Infiltration Resulting from Envelope Measures	1.0%	$330	$0	1.0**
Piping Insulation, All Lines	0.9%	$289	$790	0.4
Energy Efficiency Package	**16.4%**	**$5,401**	**$4,952**	**1.1**
16.1 kW PV system to meet EDR = 0	-	$107,456	$47,674	2.3
Zero Net Energy Package	**16.4%***	**$112,857**	**$52,626**	**2.1**

* PV is not awarded compliance credit in simulation software for climate zone 6.
** Measures with no cost are cost effective; B/C ratio is set to 1.0.

Table 3. Summary of Nonresidential Cost-Effective Package

Nonresidential Energy Efficiency Package				
Measure	**2016 T24 Compliance Margin**	**Present Value of Energy Savings (TDV$)**	**Cost**	**Benefit to Cost Ratio**
Institutional Tuning + LEDs	6.4%	$30,322	$4,022	7.5
Open Office Occupancy Sensors	2.9%	$13,718	$6,852	2.0
Daylight Dimming Plus Off	2.1%	$10,028	$0	1.0*
Economizer Control Method	1.0%	$4,541	$0	1.0*
Cool Roof	0.4%	$3,192	$894	3.6
Energy Efficiency Package	**11.0%**	**$51,798**	**$11,768**	**4.4**

*Measures with no cost are cost effective; B/C ratio is set to 1.0.

The CEC LCC methodology also shows that all PV system sizes are be cost effective, as shown in Table 4.

Table 4. Solar Photovoltaics Cost Effectiveness

Size (kW)	Cost	Residential Present Value of Energy Savings (TDV$)	Residential Benefit to Cost Ratio	Nonresidential Present Value of Energy Savings (TDV$)	Nonresidential Benefit to Cost Ratio
1	$2,961	$7,866	2.7	-	-
2	$5,922	$15,732	2.7	-	-
3	$8,883	$23,598	2.7	-	-
50	$148,056	-	-	$202,100	1.4
200	$592,226	-		$808,399	1.4

Based on the findings in this report, TRC recommends the Santa Monica Municipal Code require new construction buildings meet the following requirements:

- Single family and low-rise multifamily residential must meet CALGreen Tier 3 – exceed 2016 Title 24 by at least 15% and achieve an EDR ≤ 0. Note that an efficiency level of 19% was found to be cost effective for single family and 16% for low rise multifamily, which exceeds the minimum Tier 3 requirement.
- Nonresidential buildings must exceed 2016 Title 24 by at least 10%. Note than an efficiency level of 11% was found to be cost effective.
- Must install PV systems to meet residential EDR ≤ 0 and nonresidential to meet the Santa Monica PV Ordinance.

Separately, TRC analyzed life cycle customer cost effectiveness using customer retail rates for electricity and natural gas, as well as the Net Energy Metering (NEM) rates for solar. Using this methodology, only the nonresidential energy efficiency package was found to be cost effective. The residential packages are not cost effective primarily due to two reasons. First, the space heating and cooling loads in CZ6 are very low, and most of the efficiency measures are related to improving envelope and HVAC characteristics. Thus, while the measures achieve a high TDV compliance percentage, the site energy savings and therefore the energy bill savings are minimal. Second, the consumer cost effectiveness uses NEM rates to value exported excess PV electricity generation. Using the current NEM rates and the natural gas costs that are not offset by the PV export, the net benefit to the consumer is lower than the cost of installing the ZNE package.

1. INTRODUCTION

The City of Santa Monica, located in California Climate Zone 6 (CZ6), plans to adopt a Reach Code for the 2016 Title 24 Part 6 Building Energy Efficiency Standards (T24 Standards). The T24 Standards are the minimum energy efficiency requirements for building construction in California. Santa Monica and Southern California Edison (SCE) engaged TRC to provide a cost effectiveness study to support Reach Code requirements above 2016 T24 Standards minimum requirements. The 2016 T24 Standards will be effective beginning January 1, 2017.

TRC researched measures drawn from multiple sources in efforts to develop cost effective packages of measures. Compliance software modeling capability and federal preemption limited the measures that could be considered. Furthermore, the stringency of the 2016 Title 24 coupled with the mild climate of Santa Monica reduced the energy savings impact of many measures in new construction buildings.

Based on the results of TRC's analysis, the City may move forward with a reach code requiring low-rise residential buildings to achieve Zero Net Energy (ZNE) according to CALGreen Tier 3 definition. The City may also adopt a Reach Code requiring that nonresidential buildings improve performance 10% better than the state minimum requirements, and require solar for all buildings.

2. METHODOLOGY

TRC assessed the cost effectiveness of Santa Monica's 2016 Reach Code by analyzing several energy efficiency measures applied to prototype buildings. Analysis consisted of two methods to capture both societal and customer benefits and costs:

1. The Life Cycle Cost (LCC) methodology approved and used by the California Energy Commission (CEC) to establish cost effective building energy standards (Title 24, Part 6), and
2. A life cycle customer cost methodology that values energy savings based on utility rate schedules, which includes the effects of net energy metering (NEM).

2.1 Measure Analysis

TRC investigated measures for single family, low-rise multifamily, and nonresidential buildings, with the goal of establishing cost effective packages of measures above 2016 Title 24, Part 6. With guidance from the City of Santa Monica, TRC used and augmented CEC prototype buildings that represent new construction buildings typically observed in Santa Monica.

TRC used CBECC-Res 2016.2.0 (build 857) to simulate the residential Santa Monica prototypes and CBECC-Com 2016.2.0 (build 861) for the nonresidential Santa Monica prototypes.[2] CBECC is a free public-domain software developed by the CEC for use in complying with the Title 24 Standards. The software is currently used for the 2013 Standards, and preliminary versions approved for compliance with the 2016 Standards have been released. Software algorithms are updated continuously, and new versions of the software are released periodically. CBECC-Com uses EnergyPlus v8.3 as the simulation engine to perform the analysis.

TRC simulated all Santa Monica prototypes in Climate Zone 6, and initialized them to be exactly compliant with the minimum 2016 T24 requirements (0% compliance margin). The TDV of energy savings for energy efficiency measures were derived by implementing the measure in a code compliant Santa Monica prototype, as described in the *Measure Descriptions and Costs*.

2.1.1 Residential Prototypes

The CEC prototypes are fully defined in the Residential Alternative Calculation Method (ACM) reference manual.[3] The prototypes were augmented to have equal geometry facing north, east, south, and west orientations, to ensure that results are applicable regardless of the orientation of a building. Two residential prototypes were simulated:

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[2] More information on CBECC-Res available at: http://www.bwilcox.com/BEES/BEES.html. More information on CBECC-Com available at: http://bees.archenergy.com/software.html

[3] 2016 Residential Alternative Calculation Method, California Energy Commission. Available at: http://www.energy.ca.gov/2015publications/CEC-400-2015-024/CEC-400-2015-024-CMF.pdf

- 2,700 ft^2 single family two-story home
- 6,960 ft^2 low-rise multifamily residential building with two stories and eight dwelling units

Further prototype details are provided in Table 5. Low-rise residential covers all residential construction that is three stories or less, including single and multifamily.

Table 5. Residential Prototypes Summary

Building Type	Two-Story Single Family	Low-Rise Multifamily
Dwelling Units	1	8
Area (ft^2)	2,700	6,960
Ceiling Area (ft^2)	1,450	3,480
Roof Area (ft^2)	1,740	3,771
# of floors	2	2
Window-to-Floor Area Ratio	20%	15%
Attic/Roof Assembly	Tile Roof, Wood Sheathing, 2x4 @ 16” OC, R-30 at the ceiling	
Roof Reflectance	Steep-Sloped: SR = 0.10, TE = 0.85	
Above Grade Wall Assembly	R-15 Cavity Insulation, R4 Synthetic Stucco, 0.065 U-factor	
Cooling System	Split Air Conditioner, 14 SEER	
Heating System	Gas Furnace, 78% AFUE	Gas Furnace, 80% AFUE
HVAC Distribution System	Ducts in Attic	Ducts in Conditioned Space
Thermal Zones	2	2
Domestic Water Heating Prescriptive Baseline 1	Natural Gas Instantaneous Water Heater, 0 Gallon Tank, EF=0.82	8x Natural Gas Instantaneous Water Heater, 0 Gallon Tank, EF=0.82

2.1.2 Nonresidential Prototypes

TRC simulated a 53,600 ft^2 three-story medium office building to represent nonresidential new construction (Table 6). The nonresidential Santa Monica prototype is based on a CEC prototype detailed in the Nonresidential Alternative Calculation Method (ACM) reference manual.[4] Results using this Santa Monica prototype is intended to represent findings for all nonresidential buildings.

[4] 2016 Nonresidential Alternative Calculation Method, California Energy Commission. Available at: http://www.energy.ca.gov/2015publications/CEC-400-2015-025/CEC-400-2015-025-CMF.pdf

Table 6. Nonresidential Prototype Summary

Building Type	Medium Office
Total Conditioned Floor Area (ft^2)	53,628
Retail Floor Area (ft^2	0
# of floors	3
Window-to-Floor Area Ratio	13%
Roof Construction	1/16" Metal Standing Seam, R-29 Continuous Insulation Board
Roof Reflectance (Low-sloped)	ASR = 0.63, Thermal Emittance = 0.75
Cooling System	Direct Expansion, 9.8 EER
Heating System	Boiler, 80% Thermal Efficiency
HVAC Distribution System	3 Packaged VAVs (1 per story) with Economizer and Hot Water Reheat
Conditioned Thermal Zones	30
Domestic Water Heating[2]	Gas Storage, 95 Gallons, 78% Thermal Efficiency
Regulated Lighting Power Density	0.75 Watts/ft^2
Daylighting Controls	Continuous, 0.20 Dimming Light/Power Fraction
Occupancy Sensors	Required in Private Offices, Conference Rooms, and Multipurpose Rooms. Not Required in Open Offices

2.1.3 Energy Efficiency and Solar Measures

TRC investigated potential energy efficiency measures to apply to the Santa Monica prototypes. TRC utilized the Title 24 Codes and Standards Enhancement (CASE) reports developed on behalf of the IOUs as the basis of our measure analysis and selection. The CASE reports to support Title 24 proposed updates contain detailed energy savings, market research, and cost estimates for measures, and serve as comprehensive data sources for the Reach Code analysis. TRC conducted market research to assess measure feasibility, costs, and potential energy impact. Additionally, TRC identified measures that are potential topics for the 2019 CASE process and, lastly, measures being investigated for green building codes such as CALGreen (Title 24, Part 11) and ASHRAE Standard 189.1.

TRC investigated the cost effectiveness and feasibility of photovoltaics (PV) for residential and nonresidential new construction. Santa Monica currently has an ordinance that mandates a minimum size of PV for all new construction projects. For the analysis, PV was sized and analyzed to meet ZNE and to meet Santa Monica's PV ordinance.

2.2 Zero Net Energy Policy and Energy Design Rating

The California Public Utilities Commission (CPUC) set goals that California residential new construction will be Zero Net Energy (ZNE) by 2020[5] and nonresidential new construction by 2030[6]. The state will realize these goals partly through more stringent Building Energy Efficiency Standards and partly through renewable energy policy.

The CEC has adopted the CALGreen Tier 3 definition of Zero Net Energy (ZNE) low-rise residential buildings. The definition requires that a building produce enough on-site generation to offset its TDV electricity and natural gas consumption annually, after achieving a certain energy efficiency performance threshold. (TDV is further explained in the Cost Effectiveness analysis section). For CZ6 the energy efficiency threshold is 15% above minimum T24 requirements.[7]

The Energy Design Rating (EDR) is a metric added to the 2016 residential compliance software to indicate how close building projects are to achieving ZNE.[8] EDR is a scoring system that rates residential building energy performance on a scale that closely resembles the HERS index and references the 2006 IECC code. The net EDR of a residential building accounts for all energy efficiency and PV generation, and includes all energy end uses, not just those regulated under Title 24. An EDR ≤ 0 represents a ZNE project that meets CEC's ZNE-TDV definition.

To achieve ZNE, TRC estimated the necessary PV needed in addition to the minimum required by the Santa Monica PV ordinance. TRC first established the cost-effective packages of energy efficiency measures for the single family and low-rise multifamily prototypes, then evaluated whether the PV mandate alone is capable of achieving an EDR of zero, or if additional PV panels are required.

2.3 Cost Effectiveness

TRC used two methods to analyze cost effectiveness of the proposed Reach code:

[5] CA Energy Efficiency Strategic Plan: New Residential Zero Net Energy Action Plan 2015 – 2020, CPUC and CEC. June 2015. Available online at: http://www.cpuc.ca.gov/General.aspx?id=4125

[6] CA Energy Efficiency Strategic Plan: Zero Net Energy Commercial Building Sector 2010-2012. Engage 360. June 2011. Available online at: http://www.cpuc.ca.gov/General.aspx?id=4125

[7] In all other climate zones, the minimum threshold is 30%.

[8] Details of the calculation can be found in the Residential Alternative Calculation Method Reference Manual, Section 3: http://www.energy.ca.gov/2015publications/CEC-400-2015-024/CEC-400-2015-024-CMF-REV.pdf

1) CEC LCC Methodology[9]
2) Life cycle customer cost methodology

Both methodologies require estimating and quantifying the energy savings associated with energy efficiency measures, as well as quantifying the costs associated with the measures. The main difference between the methodologies is the manner in which they value energy and thus the cost savings of reduced or avoided energy use. The CEC LCC Methodology uses a Time Dependent Valuation (TDV) of energy savings,[10] intended to capture the societal impact of energy savings, while the life cycle customer cost methodology uses utility rate schedules to estimate the cost savings of energy efficiency solely to the customer, including NEM resulting from excess PV electricity generation (if any).

Using both of the LCC methodologies (CEC method and customer cost method), TRC determined cost effectiveness by assessing the incremental costs of a measure and comparing them to the energy cost savings. Incremental costs represent the construction and maintenance costs of the proposed measure relative to the 2016 Title 24 Standards prescriptive requirements. The Benefit to Cost (B/C) Ratio is the incremental energy costs savings divided by the total incremental costs. When the B/C ratio is greater than 1.0, the added cost of the measure is more than offset by the discounted energy cost savings and the measure is cost effective.

2.3.1 Energy Savings

TRC used CEC approved simulation software to estimate energy savings and excess PV generation, if applicable. Both TDV energy savings and customer life cycle energy savings were estimated from the simulation software, as described below.

Measures that are not capable of being modeled in the current CBECC software were instead analyzed through spreadsheet analysis. Details of the analyses are provided in *Appendix A – Spreadsheet Analysis Savings*. These include:

- Improved building infiltration in low-rise multifamily residential
- Open office occupancy sensors

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[9] Architectural Energy Corporation (January 2011) Life-Cycle Cost Methodology. California Energy Commission. Available at: http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/general_cec_documents/2011-01-14_LCC_Methodology_2013.pdf

[10] E3 (July 2014) Time Dependent Valuation of Energy for Developing Building Efficiency Standards: 2016 Time Dependent Valuation (TDV) Data Sources and Inputs. California Energy Commission. Available at: http://www.energy.ca.gov/title24/2016standards/prerulemaking/documents/2014-07-09_workshop/2017_TDV_Documents/

Time Dependent Valuation of Energy Savings

The CEC LCC Methodology uses TDV as the primary metric for energy savings, which reflects not only the cost to the end user but also the value of reduced energy demand to society, such as reduced greenhouse gas emissions and reduced strain to the electric grid. TDV assigns costs to electricity and natural gas consumed for each hour throughout the year. During peak usage times, when electricity is costlier to generate and typically is generated at dirtier plants, the TDV is higher than during off peak times. (The TDV of gas is generally constant throughout the year).

TDV values are based on long term discounted costs (30 years for all residential measures and nonresidential envelope measures, and 15 years for all other nonresidential measures). TDV energy estimates are based on the present value of cost savings, but are presented in terms of "TDV kBtus." TDV kBtus allows savings to be evaluated in terms of energy units, and measures with different periods of analysis can be combined into a single value.[11] The CEC developed the TDV values that were used in the analyses for this report, and are representative of Santa Monica's climate zone.

TDV energy savings are calculated in terms of per-square-foot of the building, similar to the output of CBECC software. The present value of the energy savings is calculated by multiplying the TDV savings/ft^2 by the building area, and then by the Net Present Value (NPV) factor. The NPV factor is \$0.173/TDV kBtu for residential measures, \$0.154/TDV kBtu for nonresidential envelope measures, and \$0.089/TDV kBtu for all other nonresidential measures.

The minimally compliant energy consumption of the residential and nonresidential Santa Monica prototypes are summarized by end-use in Table 7 and Table 8. Note that indoor lighting and plug loads are not regulated end uses for residential spaces in T24, and thus cannot count toward compliance credit even with efficiency measures. The largest residential energy consumer is domestic hot water. Similarly, process and plug loads are not regulated in nonresidential spaces, though lighting is regulated. The total compliance TDV values in Table 7 and Table 8 represent only the regulated energy end uses.

[11] kBtus = thousands of British Thermal Units.

Table 7. Residential Prototype TDV Energy Consumption

Regulated End Use	Single Family 2-story (kBtu/ft^2-yr)	Low-Rise Multifamily (kBtu/ft^2-yr)
Space Heating	7.22	1.71
Space Cooling	2.58	6.87
IAQ Ventilation	1.11	2.39
Water Heating	8.40	16.42
Total Standard Design Compliance TDV	**19.31**	**27.39**

Table 8. Nonresidential Prototype TDV Energy Consumption

Regulated End Use	Medium Office (kBtu/ft^2-yr)
Space Heating	4.28
Space Cooling	42.54
Indoor Fans	16.70
Pumps & Miscellaneous	0.41
Domestic Hot Water	1.82
Indoor Lighting	33.36
Total Standard Design Compliance TDV	**99.11**

CBECC software does not capture the full TDV impact of solar PV. Thus, the TDV output of solar PV was calculated using the CECPV calculator.[12] The CECPV Calculator was developed for use in the New Solar Homes Partnership program. The calculator estimates monthly kWh and annual TDV production based on climate zone and system specifications.

Life Cycle Customer Energy Cost Savings

Customers who save energy through energy efficiency measures and produce electricity from on-site generation have lower energy bills and may benefit from NEM income. In particular, solar PV that is sized to achieve an EDR of zero must, by definition, generate enough electricity on a TDV basis to account for a building's natural gas consumption. Thus, the PV system is oversized compared to the building's electricity consumption, and excess generation must be

[12] The tool is available online at: http://www.gosolarcalifornia.org/tools/nshpcalculator/index.php

fed back to the grid under SCE net energy metering policy. Societal benefits are not included, in contrast with TDV.

To estimate the customer cost savings, TRC used the monthly electricity and natural gas savings from energy efficiency and PV, if applicable, for each prototype using compliance simulation software. Then, current utility rates were applied to estimate the on-bill cost savings resulting from the efficiency measures and PV excess generation. TRC used the following SCE and Southern California Gas (SCG) residential and commercial rate schedules were used to estimate cost savings from energy efficiency and net energy metering:

- Residential rates:
  - Electricity: TOU-D-T
  - Natural Gas: GR
  - NEM: $0.0298/kWh
- Nonresidential rates:
  - Electricity: TOU-GS-2-A
  - Natural Gas: G-10, GN-10

The residential packages were analyzed over a 30-year lifetime and the nonresidential package was analyzed over a 15-year lifetime. The analysis includes a 3% discount rate and a 3% energy cost inflation rate.

2.3.2 Measure Costs

TRC reviewed CASE reports for relevant cost data. To better align the accuracy of costs for Santa Monica, TRC conducted further cost research through interviews and online retailers serving the City to supplement CASE data. Building material and labor costs were localized, and taxes and contractor markups were added as appropriate, as described in Section 3. Detailed costs are provided in *Appendix C – Cost Details*.

3. Measure Descriptions and Costs

This section provides a description, general modeling parameters, market overview, and summarized costs for energy efficiency measures and solar PV.

After initial investigation and analysis of several energy efficiency measures, the measure packages described below were selected based on cost effectiveness and technical feasibility in the Santa Monica new construction market.

3.1 Residential Energy Efficiency Measures

CEC Climate Zone 6 is a coastal climate that does not experience extreme weather conditions. TRC investigated and included the following measures into the single family and low-rise multifamily residential packages, some of which require Home Energy Rating System (HERS) verification. Measures are grouped by categories: Envelope (ENV), heating and cooling (HVAC), and domestic hot water (DHW).

- ENV - Quality Insulation Installation (QII) (HERS)
- ENV/HVAC – Low Leakage Ducts in Conditioned Space (HERS)
  - Reduced Infiltration Resulting from Envelope Measures
- ENV - High Performance Walls
- ENV - Improved Glazing
- ENV - Cool Roof
- HVAC - Reduced Fan Watt Draw (HERS)
- HVAC - Verified Refrigerant Charge (HERS)
- DHW - Compact Distribution (HERS)
- DHW - Piping Insulation, All Lines (HERS)

3.1.1 HERS Verification Measures

Several of the residential measures require HERS verification in order to show compliance. HERS verification can range from a visual inspection and confirmation to a test requiring specialized equipment. HERS Raters typically provide a lump sum amount based on the location of a project, the number of site visits required, and the number of units and measures to be verified. It is not market practice to identify the cost for an individual HERS verification, as several factors affect the cost.

TRC estimated HERS verification costs including the cost for site visits and tests by a certified HERS Rater. 2016 Title 24 has mandatory HERS measures, effectively requiring that a HERS Rater arrive on-site for almost every new construction project.

Single Family

Typical single family HERS verification pricing includes a set fee for each site visit and additional fees for each HERS measure to be verified during that visit. To estimate costs for each single family HERS measure, TRC used the per-site and per-measure costs shown in Table 9.

Table 9. Single Family HERS Verification Costs Summary

Component	Single Family
On-site visit ($/visit)	$220
Standard Measure verification ($/measure)	$45
Additional Measure verification ($/measure)	$100

To estimate the cost for each HERS verification in the single family building, TRC developed a scenario to estimate the number of site visits necessary for all of the HERS measures and which measures could be verified in the same trip. Based on discussion with multiple HERS Raters in California, builders typically minimize HERS fees by scheduling HERS Raters to test and verify multiple measures and units during one visit. For single family, TRC assumed costs for HERS verifications include a cost for site visits and additional verification costs for each measure

Low-rise Multifamily

For multifamily buildings, HERS verification pricing differs by HERS company; HERS Raters either price by the number of site visits required or by the number of dwelling units.

The values in Table 10 depict the two multifamily HERS pricing methods:

- Method 1 is to price per site visit required. Measures that require multiple visits and large projects that cannot be verified in one visit due to construction schedules will be more costly.
- Method 2 is to price per unit. This method makes general assumptions on standard number of visits per measure and averages costs amongst the number of units in a project.

The cost for multiple site visits is captured in Method 1 simply by requiring a flat fee for each visit. In Method 2, QII adds an additional $50 to each unit cost due to multiple site visits required.

Table 10. Multifamily HERS Verification Costs Summary

Component	Multifamily
Method 1: On-site visit ($/visit)	$245
Method 2: Per unit verification, no QII ($/unit)	$198
Method 2: Per unit cost of QII ($/unit)	$50

To estimate costs for each HERS verification in the low-rise multifamily building, TRC developed cost estimates using both methods. For Method 1 which has a fee per site visit, three scenarios were developed to estimate the costs for the best, mid, and worst case scenarios for the number of site visits required for all HERS measures, plus the cost for QII. The final per measure costs used for the analysis is the average of the Method 1's worst case scenario and Method 2. Therefore, each measure is priced based on the number of worst case number of site visits required to complete verification.

3.1.2 ENV – Quality Insulation Installation (QII) (HERS)

In 2016 Title 24, QII is a compliance credit for the performance path.[13] QII ensures that insulation is installed properly in floors, walls, and roofs/ceilings to maximize the thermal benefit of insulation. Depending on the type of insulation used, QII can be simple to implement for only the additional cost of HERS verification. Batt insulation may require an increase in installation time because the insulation needs to be cut to fit around penetrations and special joists. Although this should be standard practice, feedback from the field is that installers do not typically take the time to do it properly.

Measure costs shown in Table 11 are drawn from the findings of the 2016 Residential High Performance Walls and QII CASE Report.[14,15] Additionally, TRC spoke with over 14 HERS Raters to gather more recent cost estimates. TRC assumed an increase in labor time to account for a learning curve for insulation installers. The HERS verification costs reflect those described in Table 9 and Table 10 at the beginning of this section.

Table 11. Residential QII Incremental Costs Summary

Component/Material	Base Case	Proposed Update	Single Family	Multifamily
Installation (labor)	Standard	Improved	$89	$310
HERS Verification	None	Verified	$430	$708
Total Incremental Cost			**$519**	**$1,018**

3.1.3 ENV – Verified Low Leakage Ducts in Conditioned Space (HERS)

This measure verifies that ducts and air handling equipment is located in conditioned space and meets CEC's definition that leakage to the outside cannot exceed 25 cubic feet per minute (cfm). This is achieved through three verifications:

- Duct leakage test
- Envelope leakage test (i.e., blower door test)

[13] QII is also included in a prescriptive package to trade instantaneous water heaters for storage water heaters

[14] TRC Energy Services (September 2014) Residential High Performance Walls and QII Codes and Standards Enhancement Initiative. California Utilities Statewide Codes and Standards Team. Available at: http://www.energy.ca.gov/title24/2016standards/prerulemaking/documents/2014-07-21_workshop/final_case_reports/2016_T24_CASE_Report-High_Perf_Walls-Sep2014.pdf

[15] Quality Insulation Installation, or QII, was found to be cost-effective as a standalone measure in the referenced CASE report. Table 31, Cost-effectiveness Summary for QII, shows a B/C Ratio of 1.5 for Climate Zone 4. This measure is not proposed for the Palo Alto Reach Code as it was not pursued for the 2016 Title 24.

- Verify low leakage air handling unit

This measure is only implemented in the low-rise multifamily prototype. Prescriptive requirements are for ducts located ducts in conditioned space; therefore, the only additional cost is for the HERS verification to confirm that the system meets the specified leakage values.

CEC has established a testing protocol for this verification in the Title 24 Reference Appendices, along with all other HERS verification tests. To test the building leakage in multifamily buildings, some HERS Raters use a blower door test method by compartmentalizing individual dwelling units. HERs Raters estimate cost for this verification would be equal to duct leakage testing. To be conservative, the analysis assumed additional trips and time required beyond the duct leakage testing to estimate the cost for this measure. Thus, there is a $517 cost for low leakage ducts in conditioned space for low-rise multifamily buildings, about double that of only duct leakage testing.

Reduced Infiltration Resulting from Envelope Measures

Based on discussions with HERS Raters and HVAC contractors, TRC assumes that the low-rise multifamily building would reduce infiltration down to 5ACH50, 30% lower than the 7ACH50 software default, as a result of implementing QII and HERS verified low leakage ducts in conditioned space. The software does not allow infiltration rates to be modified for multifamily buildings because there is no CEC-defined verification test method. As described above, verified low leakage ducts in conditioned space requires that a HERS Rater test envelope leakage (i.e. a blower door test) on individual units, and that the total duct leakage to outside does not exceed 25 cfm.[16]

QII will have the effect of reducing building infiltration through proper sealing and help a project meet the 25 cfm requirement for duct leakage to the outside. Thus, for the analysis, it is recommended that both QII and verified low leakage ducts in conditioned space be implemented in order to claim building infiltration reduction down to 5ACH50.[17] There are no costs associated with this measure because the benefit of reduced infiltration is a result of the additional effort and HERS testing for QII and verified low leakage ducts in conditioned space, which costs are already included in the analysis.

No infiltration improvements resulting from QII were assumed for single family buildings, as the software default for infiltration is already at 5ACH50.

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[16] Additionally, although not covered under Title 24, LEED for Homes requires that low-rise residential projects verify leakage to the outside. TRC spoke with HERS Raters who have worked on projects pursuing LEED certification and have experience with this procedure.

[17] HERS Raters and building professionals indicated that these two measures combined could likely achieve 3 ACH50. Thus, 5 ACH50 is a conservative assumption.

3.1.4 ENV – High Performance Walls

High performance walls (HPW) increase the performance of the residential envelope, reducing the amount of heat transfer through exterior walls and reducing HVAC loads. This measure requires lower wall U-factor via improved insulation and increased stud thickness. The proposed measure reduces the exterior above-grade wall U-factor from 0.065 to 0.051. This is the prescriptive requirement in many California climate zones in 2016 Title 24 Standards. There are several ways to achieve this U-factor, and TRC assumed the CEC prescriptive assembly of R-19 cavity insulation in 2x6 walls at 16" on center with R-5 continuous exterior insulation (Table 12). Costs were derived from the 2016 High Performance Walls CASE Report.[18]

Table 12. High Performance Walls Incremental Costs Summary

Component	Base Case	Proposed Update	Single Family	Low-Rise Multifamily
Wall Framing	2x4 @ 16"	2x6 @ 16"	$752	$1,427
Cavity Insulation	R-15	R-19	($424)	($719)
Continuous Exterior Insulation	R-4	R-5	$312	$529
Total Incremental Cost			**$641**	**$1,237**

3.1.5 ENV – Improved Glazing

The National Fenestration Rating Council rates glazing performance by U-factor and Solar Heat Gain Coefficient (SHGC). U-factor rating describes the overall ability of the window (including framing) to resist heat transfer. SHGC describes how solar radiation is admitted through a window from sunlight exposure. The lower the value for each rating, the more resistive a window is to heat transfer and better at insulating. This measure reduces the U-factor from the prescriptive value of 0.32 to 0.30 and reduces the (SHGC) from the prescriptive value of 0.25 to 0.23. The costs in Table 13 are based on PG&E's CALGreen Cost Effectiveness Study.[19]

Table 13. Improved Glazing Incremental Costs Summary

Component	Base Case	Proposed Update	Incremental Cost/ft^2	Single Family	Low-Rise Multifamily
Window	U-0.32/SHGC-0.25	U-0.30/SHGC-0.23	$0.15	$72	$156

[18] 2016 Residential High Performance Walls CASE Report: http://www.energy.ca.gov/title24/2016standards/rulemaking/documents/dru_title24_parts_01_06/2016%20T24%20CASE%20Report%20-%20High_Perfornace_Walls_2015-02-06_TN-74502.pdf

[19] Davis Energy Group (September 2016) CALGreen Cost Effectiveness Study. CA Statewide Codes and Standards Program.

3.1.6 ENV – Cool Roof

Cool roof requirements in Title 24 are specific to roof slope and building type. Title 24 defines low-sloped roofs as having a roof pitch of ≤2:12. Low-sloped roofs are generally found on multifamily and commercial construction, and can be built with a variety of roofing products. Steep-sloped roofs are more typical of low-rise residential construction in California, and are built with asphalt shingles or concrete or clay tile. For the residential analysis, only steep-sloped roofs were included based on the prototypes. There are currently no cool roof requirements for low-sloped or steep-sloped roofs in CZ6.

To develop cost estimates, TRC conducted interviews with roofers and roof supply distributors throughout California and in the Santa Monica region. In addition to interviews, TRC reviewed product material costs from online retailers serving the Santa Monica area. Multiple roofers and product distributors stated that there is little or no additional labor to install cool roof products for either low- or steep-sloped roofs.

TRC gathered costs for asphalt shingles and concrete and clay tile that meet the current and proposed aged solar reflectance (ASR) values (ASR = 0.10 to ASR = 0.20) for steep-sloped roofs. Several interviewees mention that the cool roof properties of tile do not impact costs, and that costs are associated with color and other performance characteristics. Therefore, there is no incremental cost for tile meeting the proposed ASR value.

Asphalt shingles, however, can carry a cost premium for cool roof products. The proposed cool roof requirements can be met with white shingles, which have no incremental cost over current market standard shingles. Shingles in a variety of non-white colors that meet the cool roof values can have a slight increased cost over their non-cool roof equivalents, depending on the product. The incremental cost of non-white asphalt shingles meeting the proposed ASR is minimal. The most likely reason for this is that ASR = 0.20 is the prescriptive requirement in the majority of California climate zones and product availability and costs have adjusted since this requirement was adopted under 2013 Title 24.

Table 14 provides the incremental cost to go from the base case (no requirement) to a cool roof requirement (ASR = 0.20) for steep-sloped roofs. This cost assumption is a straight average of the asphalt shingle and tile incremental cost estimates.

Table 14. Low-Rise Residential Steep-Sloped Cool Roof Incremental Costs Summary

Base Case	Proposed Update	Incremental $/ ft^2 roof	Single Family		Low-Rise Multifamily	
			Roof Area	$/Bldg	Roof Area	$/Bldg
No Requirement[1]	ASR=0.20, TE=0.85	$0.02	1,740	$32	3,771	$70

[1] Although there is no prescriptive requirement in CZ6 for residential roofs, the model default is ASR=0.10 and TE=0.75 to represent standard roofing materials.

3.1.7 HVAC – Reduced Fan Watt Draw (HERS)

This measure upgrades the fan in the furnace or air handler from one using permanent split capacitor (PSC) motor to one with an electronically commutated motor (ECM) that meets an efficacy of 0.3 watts/cfm or lower operating at full speed. New federal regulations that go into effect July 3, 2019 are expected to result in equivalent performance for all newly manufactured furnaces provided that the ducts are sized properly. Fan watt draw is a mandatory HERS measure; therefore the cost does not include HERS verification fees.

Table 15. Reduced Fan Watt Draw Incremental Costs Summary

Component/Material	Base Case	Proposed Update	Single Family	Low-Rise Multifamily
ECM Motor	0.58 watts/cfm	0.30 watts/cfm	**$143**	**$832**

3.1.8 HVAC – Verified Refrigerant Charge (HERS)

This measure requires that a HERS Rater verify the amount of refrigerant in an air-cooled conditioner or air-source heat pump system is at an appropriate level. Having too much (overcharge) or too little (undercharge) can reduce the efficiency of a system and result in early failure. The correct refrigerant charge can improve the performance of a system and reduce energy wasted from an inefficient system. The costs, as shown in Table 16, assume HERS sampling of HVAC units for multifamily buildings.[20]

Table 16. Refrigerant Charge Verification Incremental Costs Summary

Component	Base Case	Proposed Update	Single Family	Low-Rise Multifamily
HERS Verification	None	Verified	$76	$272

3.1.9 DHW – Compact DHW Distribution (HERS)

Compact DHW distribution is a design strategy that reduces the length of pipe runs from the water heater to appliances and fixtures. Designing a project to meet Compact DHW Distribution requires forethought in floor plan and fixture placement, and/or moving a water heater to a location closer to fixtures (e.g. the attic, an exterior or interior closet). Generally, compact distribution limits the hot water pipe length between the water heater and the fixtures, thus reducing distribution heat losses, as well as water waste and time waiting for hot water to arrive to the fixture. The maximum allowed pipe lengths to qualify as a compact distribution system are outlined in Residential Reference Appendices RA3.6.5.

Feedback from HERS Raters indicates that compact distribution vaguely defined and not yet widely adopted in single family new construction. TRC only applied this measure to the low-rise multifamily prototype, which has individual water heaters and dwelling units that are typically smaller than a single family home. Thus, compact distribution is more feasible for this

[20] Sampling is typically done by performing testing on one out of every five or seven dwelling units, as determined by the HERS Rater and project team.

prototype, without requiring significant changes to water heater location, floorplan, or piping design. TRC assumed that this measure would result in a reduction of 20 linear feet of 1/2" diameter insulated pipe per dwelling unit.

Table 17. Compact Distribution Incremental Costs Summary

Component/ Material	Base Case	Proposed Update	Low-Rise Multifamily
Gas + Vent Piping	Standard design	None	$0
Length of ½" diameter pipe (ft)	Standard design	Reduced by 20 ft/unit	($117)
HERS Verification	None	Verified	$150
Total Incremental Cost			**$33**

3.1.10 DHW – Piping Insulation, All Lines (HERS)

The 2016 Title 24 Standards include mandatory pipe insulation requirements that cover the majority of hot water pipes. To receive the credit for pipe insulation, all pipes between the water heater and fixtures that are not covered under the mandatory requirement must be insulated and verified by a HERS Rater.

Beginning in January 1, 2017 the 2016 California Plumbing Code will require pipe insulation levels that are similar to that required if taking the non-HERS pipe insulation credit. Thus, the non-HERS credit will be obsolete under the 2016 energy code. However, the HERS-Verified Pipe Insulation Credit will remain. While CBECC-Res algorithms have not yet been updated to reflect this, for this analysis we assumed that the revised HERS verified credit would be equivalent to the current credit for pipe insulation without HERS verification. TRC ran simulations that demonstrated the HERS credit is roughly twice that for pipe insulation without verification, in terms of TDV energy.[21]

Pipe insulation requirements vary depending on the pipe diameter and the expected temperature of water being transported through the pipe. The majority of pipes that would be triggered under this requirement are 1/2" and are transporting water from a main branch to an end-use fixture at lower temperatures. According to Table 120.3-A in 2016 Title 24, these pipes will need 1" of insulation. TRC gathered costs from several sources, including the 2013 Single Family Domestic Hot Water and Residential Solar Water Heating Ready CASE Reports, RS Means, and online retailers. 1" of insulation for pipes less than ¾" in diameter is estimated to cost $3.87 per linear foot of pipe.

TRC estimated pipe lengths based on typical design practice. The costs and pipe length estimates are shown in Table 18. The cost of pipe insulation depends on the length of pipes.

[21] Analysis performed in accordance with: Davis Energy Group (September 2016) CALGreen Cost Effectiveness Study. CA Statewide Codes and Standards Program.

Table 18. Residential Pipe Insulation Incremental Costs Summary

Component/ Material	Base Case	Proposed Update	Single Family	Low-Rise Multifamily
Insulation (pipes <3/4" diameter)	None	1 in	$91	$640
HERS Verification	None	Verified	$76	$150
Total Incremental Cost			**$167**	**$790**

3.2 Nonresidential Energy Efficiency Measures

3.2.1 ENV – Cool Roof

The cool roof requirements for nonresidential building are shown in Table 19. Low-sloped roofs are more typical of high-rise multifamily and nonresidential construction. For the purposes of this analysis, only low-sloped roofs were included based on the prototypes.

Table 19. Prescriptive Nonresidential Cool Roof Requirements in CZ6

Slope	3-Year Aged Solar Reflectance	Thermal Emittance
Low-Sloped	0.63	0.75
Steep-Sloped	0.20	0.75

This measure would require that nonresidential buildings go from an ASR of 0.63 to an ASR of 0.70. For low-sloped roofs, most products that meet the proposed cool roof requirements do not introduce a cost increase over non-cool roof or baseline products, and based on feedback from roofers and distributors, there are even cost savings for some products.

The 2013 Nonresidential Cool Roofs CASE Report supports how cool roofs can be less expensive than their darker, non-cool roof counterparts:[22]

> "Within the cool roof market, many of the products with [ASR] values close to 0.55 are actually tinted versions of the more conventional white versions of the same product. The products with the darker reflectance can, therefore, actually have a higher initial cost while also driving higher energy costs."

Overall, the results also show that there is potential for no cost increase for ASR of 0.70 on low-sloped roofs. Additionally, according to Cool Roof Rating Council[23] certified product directory,

[22] California Utilities Statewide Codes and Standards Team (October 2011) Nonresidential Cool Roofs Codes and Standards Enhancement Initiative. Available at: http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Nonresidential/Envelope/2013_CASE_NR_Cool_Roofs_Oct_2011.pdf

[23] Available at: http://coolroofs.org/products/results

there are about three times as many cool roof products available at the proposed ASR of 0.70 value than at the current required ASR of 0.63. To be conservative, TRC estimated a small incremental cost for products that meet the proposed low-sloped cool roof requirements. This incremental cost represent product types that may have higher costs to meet the proposed values, even though cost analysis suggests there is no incremental cost on average. To estimate this cost, TRC looked at the cost difference between two products of the same type from the same manufacturer that meet the current ASR value and the proposed ASR value.

The incremental costs of going from the base case to a cool roof are summarized in Table 20. Additional details for the cost analysis are provided in *Appendix C – Cost Details*.

Table 20. Low-Sloped Cool Roof Incremental Costs Summary

Base Case	Proposed Update	Incremental $/ ft^2 roof	Units/ Bldg	$/Bldg
ASR=0.63, TE=0.85	ASR=0.70, TE=0.85	$0.05	17,876	**$894**

3.2.2 LTG – Indoor Lighting

There are four proposed lighting measures as described below. All of these measures, except the lighting power density reduction measure, are Power Adjustment Factors (PAFs). PAFs allow a building to install wattages that are higher than prescriptively allowed, due to improvements in controls. Please note, when TRC analyzed measures that allow a PAF, we did not assume that higher wattages are installed.

Daylight Dimming-Plus-Off

This measure revises the control settings for daylight sensors to be able to shut-off completely when adequate daylight levels are provided to the space. There is no associated CASE report for this measure, but there is a related report by the Pacific Northwest National Laboratory.[24] The measure is modeled by revising the daylight control type from Continuous (with a minimum dimming light and power fractions of 0.20), to Continuous Plus Off (which effectively reduces the dimming light and power fractions to 0).

There is no associated cost with this measure, as the 2013 T24 Standards already require multilevel lighting and daylight sensors in primary and secondary daylit spaces. This measure does not increase the number of sensors required, or labor to install and program a sensor, but requires a revised control strategy.

[24] Pacifica Northwest National Laboratory (August 2013) Analysis of Daylighting Requirements within ASHRAE 90.1. Available at: http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22698.pdf

Lighting Power Density Reduction

This measure reduces the lighting power density (LPD) from the 2016 Title 24 prescriptive requirement of 0.75 W/ft^2 for open office areas to 0.70 W/ft^2 assuming LED fixtures as the primary fixture. Cost research shows that some T8 fluorescent basket fixtures may be more costly than LED basket fixtures, because fluorescent fixtures require dimming ballasts to comply with Title 24, while LED fixtures do not. In many cases, the cost may be equivalent or only a small difference once the dimming ballast cost is considered. Three sources of data show cost equivalency for basket fixtures. Research shows that it is technologically feasible to achieve 0.70 W/ft^2 design at no incremental cost, and further, that LED luminaires are not required to achieve 0.70 W/ft^2, as some fluorescent luminaires are able to achieve this power density as well.

Institutional Tuning

Institutional tuning was introduced as a Power Adjustment Factor (PAF) in the 2013 T24 Standards through the 2013 CASE Report for Requirements for Controllable Lighting.[25] To show compliance with this measure, a designer should meet the requirements of 2016 Title 24 Section 140.6(d). This measure works in conjunction with dimmable ballasts, which were adopted as a requirement in the 2013 T24 Standards. Tuning addresses the frequent practice of designing light levels in a space to exceed that needed for the tasks of the space. Based on space factors and normal lighting design practices, a lighting designer typically overdesigns the light levels specified for a space to ensure adequate lighting is provided. The higher light levels are often a result of designing a space to meet the required light levels while satisfying the luminaire spacing or ceiling layout. The resulting design provides more light (e.g. 65 footcandles) than necessary or recommended in the space (e.g. 50 footcandles). [26]

Institutional tuning sets the maximum light levels in a space at a lower level than the fully installed light levels, but still at an acceptable level for occupants. The maximum power use is thus lower and energy is continuously saved. Tuning requires that lighting designers commission the lighting after installation and tune down the lighting to meet the design criteria. In the example above, the lighting designer may tune down the lighting to 60 or 55 foot candles. The designer still wants to maintain initial light levels above the minimum requirement to account for depreciation in lamp efficacy over time.

Institutional tuning has been shown to reduce lighting energy consumption in a space by 10 to 15 percent of the original design. The analysis conservatively assumes a 10 percent reduction in

[25] California Utilities Statewide Codes and Standards Team (March 2011) Requirements for Controllable Lighting. Codes and Standards Enhancement Initiative. Available at: http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/2011-04-04_workshop/review/Nonres_Controllable_Lighting.pdf

[26] A footcandle is the illuminance on a one square foot surface from a uniform source of light. It is a commonly used metric for lighting design.

LPD for an office from 0.70 W/ft^2 to 0.63 W/ft^2 (assuming this measure is in conjunction with the LPD reduction measure above).

The additional cost for this measure is the labor required to tune the lighting in each space, as shown in Table 21. This cost is dependent on the particular design of an office and the number of unique areas that a lighting designer must address. The 2013 CASE Report estimates that the cost is about $0.10 per watt for an office space. TRC determined the total cost by calculating the total number of watts in each prototype based on the allowed LPD.

Table 21. Nonresidential Institutional Tuning Incremental Costs Summary

Component	Base Case	Proposed Update	Commissioning cost	Medium Office
Institutional Tuning	0.75 W/ft^2 (no tuning)	0.68 W/ft^2 (tuning)	$0.10/Watt	**$330**

Open Office Occupancy Sensors

This measure draws from the findings of the 2013 Indoor Lighting Controls CASE Report.[27] This CASE report investigates the use of occupancy controls in open office spaces at various control group sizes and proposes one occupancy sensor for every four workstations (approximately 500 ft^2). The energy savings associated with occupancy sensors cannot be modeled effectively in CBECC-Com, and is instead calculated in spreadsheet analysis and added to the results of the modeling analysis, as detailed in *Appendix A – Spreadsheet Analysis Savings*.

Occupancy controls have been commercially available for several decades, and the technology for this measure is readily available from a wide variety of manufacturers. Both passive infrared and ultrasonic occupancy sensors are widely accepted in office buildings, have been acknowledged to save energy successfully, and are frequently required by codes.

The incremental costs for this measure include only the costs of the sensors, according to the CASE report, which is $116.13 per sensor. Costs summarized in Table 22 assume seven (7) sensors for the small office, and 59 sensors for the medium office. Though the cost estimates are from 2011, current costs for the equipment are likely to be similar or have decreased since then due to increased market adoption.

[27] California Utilities Statewide Codes and Standards Team (October 2011) Nonresidential Indoor Lighting Controls Codes and Standards Enhancement Initiative. Available at: http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Nonresidential/Lighting_Controls_Bldg_Power/2013_CASE_NR_Indoor_Lighting_Controls_Oct_2011.pdf

Table 22. Nonresidential Open Office Occupancy Sensors Incremental Costs Summary

Component	Base Case	Proposed Update	Medium Office
Infrared Occupancy Sensor, Equipment and Labor to Install, in an Open Office	No Sensor	One Sensor for Every Four Workstations	**$6,852**

3.2.3 HVAC – Economizer Control

Economizers use a high limit control in order to know when to turn off. The high limit control can be based either on fixed dry bulb setup, or differential dry bulb (which is the software default). Differential dry bulb control uses one more temperature sensor (on the return air side) to calculate appropriate economizing conditions. Feedback from manufacturers and an engineering firm suggest that there is no additional cost to using a fixed dry bulb control versus a differential dry bulb, and there may actually be material and labor cost savings. TRC found that using a fixed dry bulb high limit of 71°F produced energy savings.

3.3 Photovoltaics

As described earlier, Santa Monica and SCE engaged TRC to investigate the feasibility of meeting CALGreen Tier 3 ZNE for residential new construction. To meet this definition of ZNE, PV is required in addition to energy efficiency measures.

Santa Monica Solar Mandate

Santa Monica has adopted a PV mandate (*Appendix E – Santa Monica PV Mandate*) requiring a minimum size system to be installed on all new construction buildings. TRC first established the cost-effective packages of energy efficiency measures for the single family and low-rise multifamily prototypes, then determined the PV size necessary to achieve ZNE using two scenarios:

1) The energy efficiency packages with the full PV size necessary to achieve ZNE. The analysis includes the full PV size necessary to achieve ZNE for each residential building, not accounting for PV that would already be required on each building to meet the City's ordinance.

2) The energy efficiency packages with only the additional PV necessary to achieve ZNE beyond the ordinance minimum requirements. The results of this analysis is in *Appendix B – High Rise Multifamily Modeling*.

Solar Costs

PV systems installed in Santa Monica are eligible for both the NSHP rebate and the federal solar Investment Tax Credit (ITC), which rebates 30% of the cost of the system.[28]

Costs for solar PV were estimated using statewide data from the New Solar Homes Partnership (NSHP) program.[29] TRC retrieved costs for both small systems (less than 10 kW) and larger systems (between 10 kW and 100 kW). Average and median costs (in $/watt installed) were extracted from the NSHP database, and median costs were found to be higher and more conservative. Although array costs ($/watt installed) for large systems are less than costs for small systems, TRC used only the cost of small systems in cost effectiveness analysis, to remain conservative. The costs reflect the upfront costs to the building owner when purchasing a PV system – TRC did not investigate other financing mechanisms such as loans and leases.

2016 NSHP program data showed that the median cost for small PV systems was $4.63/Watt. Several studies have tracked the installation costs of PV to provide market trends. Lawrence Berkeley National Laboratory, for example, found that national median installed prices in 2014 declined year-over-year by 9% for both residential and nonresidential systems, as did a recent CEC report. [30,31] From the NSHP database, TRC observes a recent decline in costs closer to 6% per year. By applying this cost reduction through to 2017, the median installed cost of PV is expected to be $4.35/watt, as shown in Table 23.

Note that TRC observed the NSHP incentive to decline year-over-year by 45%, and projected the decline to continue through to 2017. (Note that NSHP median incentives dropped significantly in 2016, while average incentives actually increased). The median incentive in 2016 was $0.22/watt, while in 2015 it was $1.41/watt. To be conservative TRC assumed trends and $/watt associated with median NSHP incentives. When accounting for the NSHP rebate and ITC, the estimated net cost for installed solar PV in 2017 is $2.96/watt.

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[28] More information available at: http://www.seia.org/policy/finance-tax/solar-investment-tax-credit

[29] Available at: https://www.newsolarhomes.org/WebPages/Public/Reports.aspx

[30] Barbose, G., et al. (August 2015) Tracking the Sun VIII: The Installed Price of Residential and Non-Residential Photovoltaic Systems in the United States. Available at: https://emp.lbl.gov/sites/all/files/lbnl-188238_1.pdf

[31] E3 (May 2013) Cost-Effectiveness of Rooftop Photovoltaic Systems for Consideration in California's Building Energy Efficiency Standards. Prepared for the California Energy Commission. Available at: http://www.energy.ca.gov/2013publications/CEC-400-2013-005/CEC-400-2013-005-D.pdf

Table 23. Costs for Solar PV

Installed Cost ($/Watt)	**2016**	**2017**
Median Cost	$4.63	$4.35
Federal ITC	-	-$1.27
NSHP Incentive	-	-$0.12
Net Cost	-	**$2.96**

4. Energy Savings and Cost Effectiveness Results

The results for the energy efficiency packages are presented below for the single family, multifamily, and nonresidential prototypes. Results include measure compliance margin, present value of energy savings, costs, and benefit to cost (B/C) ratio. When the B/C ratio is greater than 1.0, the added cost of the measure is more than offset by the discounted energy cost savings and the measure is cost effective.

As shown below, all packages are cost effective under the CEC LCC methodology, but the residential packages are not cost effective under the life cycle customer cost methodology. This is primarily due to two reasons. First, the space heating and cooling loads in CZ6 are very low, and most of the efficiency measures are related to improving envelope and HVAC characteristics. Thus, while the measures achieve a high TDV compliance percentage, the site energy savings and therefore the energy bill savings are minimal. Second, the consumer cost effectiveness uses NEM rates to value exported excess PV electricity generation. Using the current NEM rates and the natural gas costs that are not offset by the PV export, the net benefit to the consumer is lower than the cost of installing the ZNE package.

4.1 Residential Packages

4.1.1 Single Family

The single family package achieves 19% savings and ZNE based on TDV with the combination of measures and PV system shown in Table 24. A 3.7 kW PV system would achieve an EDR of zero to meet ZNE. The simulation software does not award compliance credit to PV in climate zone 6; therefore, the Title 24 compliance percentage is 19.1%. Based on the CALGreen definition of ZNE which requires PV to meet the entire energy load of a building on a TDV basis, the package would theoretically be 100% above Title 24.

Table 24. Single Family ZNE Package TDV Cost Effectiveness

Single Family Residential ZNE Package				
Measure	**2016 T24 Compliance Margin**	**Present Value of Energy Savings**	**Cost**	**Benefit to Cost Ratio**
Quality Insulation Installation	8.5%	$760	$519	1.5
High Performance Walls	7.1%	$635	$641	1.0
Reduced Fan Watt Draw	2.4%	$213	$143	1.5
Piping Insulation, All Hot Water Lines	1.1%	$102	$168	0.6
Improved Glazing	1.1%	$97	$72	1.3
Verified Refrigerant Charge	0.9%	$79	$76	1.0
Energy Efficiency Package	**19.1%**	**$1,709**	**$1,619**	**1.1**
3.7 kW PV to meet EDR of zero	-	$24,696	$10,956	2.3
Zero Net Energy Package	**19.1%***	**$26,405**	**$12,575**	**2.1**

*PV is not awarded compliance credit in simulation software for climate zone 6.

Although cost effective based on TDV energy savings, neither the energy efficiency nor the ZNE package is cost effective based on the life cycle customer cost analysis, as shown in Table 25. The ZNE package includes the cost for the full PV size needed to meet ZNE. The savings reflect energy bill savings a customer would observe from energy savings and PV export over a 30 year period.

Table 25. Single Family ZNE Package Customer Cost Effectiveness

	Single Family Residential ZNE Package				
Measure	**Annual kWh Savings**	**Annual Therm Savings**	**Present Value of On-bill Savings**	**Cost**	**Benefit to Cost Ratio**
Energy Efficiency Package	80	31	$939	$1,619	0.6
Zero Net Energy Package, 3.7 kW PV	5,922	31	$11,570	$12,575	0.9

TRC estimates that a PV cost of $2.69/watt would make this single family ZNE package cost effective.

4.1.2 Low-rise Multifamily

The low-rise multifamily package achieves 16% and ZNE based on TDV with the combination of measures and PV system shown in Table 26. A 16.1 kW PV system would achieve an EDR of zero to meet ZNE. Similar to single family, although the Title 24 compliance percentage is 16%, theoretically the ZNE package is 100% better than Title 24.

Table 26. Low-rise Multifamily ZNE Package TDV Cost Effectiveness

Low-rise Multifamily Residential ZNE Package				
Measure	**2016 T24 Compliance Margin**	**Present Value of Energy Savings**	**Cost**	**Benefit to Cost Ratio**
Reduced Fan Watt Draw	3.2%	$1,073	$832	1.3
Compact Domestic Hot Water Distribution	2.6%	$844	$33	25.6
Quality Insulation Installation	2.4%	$784	$1,018	0.8
High Performance Walls	1.9%	$615	$1,237	0.5
Cool Roof	1.8%	$603	$70	8.7
Verified Refrigerant Charge	1.7%	$555	$300	1.8
Verified Low-Leakage Ducts Entirely in Conditioned Space	1.7%	$567	$517	1.1
Improved Glazing	1.6%	$542	$156	3.5
Reduced Infiltration Resulting from Envelope Measures	1.0%	$330	$0	1.0**
Piping Insulation, All Lines	0.9%	$289	$790	0.4
Energy Efficiency Package	**16.4%**	**$5,401**	**$4,952**	**1.1**
16.1 kW PV system to meet EDR = 0	-	$107,456	$47,674	2.3
Zero Net Energy Package	**16.4%***	**$112,857**	**$52,626**	**2.1**

* PV is not awarded compliance credit in simulation software for climate zone 6.
** Measures with no cost are cost effective; B/C ratio is set to 1.0.

Although cost effective based on TDV energy savings, neither the energy efficiency nor the ZNE package is cost effective based on the life cycle customer cost analysis, as shown in Table 27. The ZNE package includes the cost for the full PV size needed to meet ZNE. The savings reflect energy bill savings a customer would observe from energy savings and PV export over a 30 year period.

Table 27. Low-rise Multifamily ZNE Package Customer Cost Effectiveness

	Low-rise Multifamily ZNE Package				
Measure	**Annual kWh Savings**	**Annual Therm Savings**	**Present Value of On-bill Savings**	**Cost**	**Benefit to Cost Ratio**
Energy Efficiency Package	267	59	$2,662	$4,953	0.5
Zero Net Energy Package, 16.1 kW PV	25,687	59	$50,717	$52,627	0.96

TRC estimates that a PV cost of $2.80/watt would make this single family ZNE package cost effective.

4.2 Nonresidential Package

The nonresidential energy efficiency package is achieved largely through low or no incremental cost lighting measures, as shown in Table 28. TRC did not analyze a nonresidential ZNE package with PV because there is currently no CEC ZNE definition for nonresidential buildings.

Table 28. Nonresidential Energy Efficiency Package Cost Effectiveness

Nonresidential Energy Efficiency Package				
Measure	**2016 T24 Compliance Margin**	**Present Value of Energy Savings**	**Cost**	**Benefit to Cost Ratio**
Institutional Tuning + LEDs	6.4%	$30,322	$4,022	7.5
Open Office Occupancy Sensors	2.9%	$13,718	$6,852	2.0
Daylight Dimming Plus Off	2.1%	$10,028	$0	1.0*
Economizer Control Method	1.0%	$4,541	$0	1.0*
Cool Roof	0.4%	$3,192	$894	3.6
Package	**11.0%**	**$51,798**	**$11,768**	**4.4**

*Measures with no cost are cost effective; B/C ratio is set to 1.0.

The nonresidential energy efficiency package, contrary to the residential packages, is cost effective based on the life cycle customer cost analysis, as shown in Table 29. The nonresidential package is cost effective because the energy efficiency measures achieve larger savings at lower cost than the residential measures. The present value of on-bill savings represents annual savings for a 15-year period.

Table 29. Nonresidential Energy Efficiency Package Customer Cost Effectiveness

Nonresidential Energy Efficiency Package					
Measure	**Annual kWh Savings**	**Annual Therm Savings**	**Present Value of On-bill Savings**	**Cost**	**Benefit to Cost Ratio**
Energy Efficiency Package	18,700	102	$40,624	$11,768	3.5

4.3 Photovoltaics

PV is included in the cost effectiveness analysis for the residential ZNE packages described above. When analyzed separately, PV is cost effective at all sizes using the CEC LCC methodology, as shown in Table 30. Nonresidential B/C ratios are lower than residential because the NPV factor for nonresidential is lower than residential, as described in Section 2.3.1.

Table 30. Solar PV Cost Effectiveness

Size (kW)	Cost	Residential Present Value of Energy Savings	Residential Benefit to Cost Ratio	Nonresidential Present Value of Energy Savings	Nonresidential Benefit to Cost Ratio
1	$2,961	$7,866	2.7	-	-
2	$5,922	$15,732	2.7	-	-
3	$8,883	$23,598	2.7	-	-
50	$148,056	-	-	$202,100	1.4
200	$592,226	-		$808,399	1.4

4.4 Greenhouse Gas Savings

New construction complying with the proposed Reach Code will result in greenhouse gas (GHG) savings through saving electricity and natural gas. Electricity and natural gas usage are estimated in CBECC simulations for each prototype building. Saved energy is multiplied by a factor of 0.65 lbs of CO_2 equivalent (CO_2e) per kWh, and 11.7 lbs of CO_2e per therm, as per Environmental Protection Agency research.[32]

As shown in Table 31:

- 69% GHG savings are achieved for each newly constructed single family building
- 70% GHG savings are achieved for each newly constructed low-rise multifamily building
- 4% GHG savings are achieved for each newly constructed nonresidential building

These GHG reduction estimates are based on complying with the residential ZNE packages and the nonresidential energy efficiency package using the measures analyzed in this study. Compliance with the Reach Code may be achieved through a variety of measures, each of which will have varying electric and natural gas usages, and therefore varying GHG savings. Note also that these are percentage savings of the total greenhouse gas emissions from the buildings, including unregulated loads.

[32] United States Environmental Protection Agency. 2015. "Emission Factors for Greenhouse Gas Inventories." Available at: https://www.epa.gov/sites/production/files/2015-12/documents/emission-factors_nov_2015.pdf.

Table 31. Greenhouse Gas Savings Summary

Single Family Packages					
Measure	**Gas Therms / Home**	**Electric kWh / Home**	**lbs CO2e**	**lbs CO2e Avoided / Home**	**GHG Savings***
Code Compliant Building	276	4,468	6,138	-	-
Energy Efficiency Package	245	4,388	5,721	417	**7%**
ZNE Package	245	-1,454	2,868	3270	**69%**
Low-rise Multifamily Packages					
Measure	**Gas Therms / Building**	**Electric kWh / Building**	**lbs CO2e**	**lbs CO2e Avoided / Building**	**GHG Savings***
Code Compliant Building	946	21,182	24,841	-	-
Energy Efficiency Package	887	20,915	23,979	861	**3%**
ZNE Package	887	-4,505	10,378	14,463	**70%**
Nonresidential Package					
Measure	**Gas Therms / Building**	**Electric kWh / Building**	**lbs CO2e**	**lbs CO2e Avoided / Building**	**GHG Savings***
Code Compliant Building	2,104	439,500	310,417	-	-
Energy Efficiency Package	2,206	420,800	299,449	10,968	**4%**

*GHG percentage savings include unregulated loads, such as residential lighting, plug loads, and federally pre-emptive appliances. Percentages would be higher if including only regulated loads.

4.5 Reach Code Recommendations

Energy efficiency packages and solar PV are cost effective in the City of Santa Monica based on the CEC LCC methodology. TRC recommends the Santa Monica Municipal Code require that new construction buildings meet the following requirements:

- Single family and low-rise multifamily residential must meet CALGreen Tier 3 – exceed 2016 Title 24 by at least 15% and achieve an EDR ≤ 0.
- Nonresidential buildings must exceed 2016 Title 24 by at least 10%.
- Must install PV systems to meet residential EDR ≤ 0 and nonresidential to meet the Santa Monica PV Ordinance.

4.5.1 Compliance

The majority of new construction T24 compliance submittals use building simulation software. CBECC-Res and CBECC-Com are CEC approved software tools which have released versions to be used with the 2016 Title 24 Standards. The compliance software outputs the TDV energy usage of a proposed building, and the percent compliance margin compared with a standard prescriptively-compliant building. EDR values are also standard outputs of the software. For nearly all the measures described in this report, Santa Monica building officials can confirm that building designs meet the Reach Code by reviewing the compliance margin and residential EDR value presented in the simulation software output reports.

For design strategies that cannot currently be modeled in CEC approved software the applicant must show compliance through ancillary documentation:

- **DHW Compliance Credits -** Currently, CBECC only allows one DHW distribution credit in a simulation. Therefore, for example, a project that incorporates compact distribution as well as insulating all pipes can only receive credit for one of the measures through the software. DHW distribution measures will have overlapping benefits, so it is not justified to provide the full credit of each standalone measure. To comply with multiple DHW distribution measures in one prototype, TRC suggests that the permit applicant simulate the DHW distribution measure with the lowest distribution multiplier as per in Table B-1 of Appendix B in the Residential ACM Reference Manual. Then, the applicant would simulate the other DHW distribution measures individually and reduce savings proportionally by the total number of DHW distribution measures.[33,34]
- **Infiltration -** To comply with low-rise multifamily reduced building infiltration, a project will need to implement and pass HERS verified QII and low leakage ducts in conditioned space. The Title 24 documentation will state that a project is implementing both of these measures and the HERS verification documents will confirm that they pass. TRC recommends that such projects be awarded an extra 1% compliance margin credit to account for reduced HVAC loads.
- **PAF Lighting Measures -** To comply with the PAF lighting measures, building designers will need to apply for the Power Adjustment Factor (PAF) in T24 Standards Table 140.6-A, using the appropriate compliance form(s). Lighting designers should not use this credit to increase installed wattage elsewhere in the building. Plan checkers can confirm the installed wattage design when reviewing the building model. The indoor lighting energy should not exceed the prescriptive T24 requirements *without* the PAF credit applied.
- **High-rise Multifamily Buildings** - High rise multifamily buildings may need exceptional compliance calculations to achieve 10%, as described in *Appendix B – High Rise Multifamily Modeling*.

[33] 2016 Residential ACM Reference Manual, California Energy Commission. Available online at: http://www.energy.ca.gov/2015publications/CEC-400-2015-024/CEC-400-2015-024-CMF-REV2.pdf

[34] For two measures, the savings of each measure simulated individually would be halved, for three measures, the savings would be 1/3, and so on.

5. Appendix A – Spreadsheet Analysis Savings

The energy impact of the Improved Infiltration and Open Office Occupancy Sensors measures described in Section 3 could not be calculated using CBECC. TRC estimated the energy impact using spreadsheet analysis.

5.1 Improved Building Infiltration in LRMF

Building leakage for LRMF is set at 7ACH50 in the compliance software, based on the Residential ACM. If a multifamily building were constructed with proper sealing and QII, it is feasible for each unit and the building to have a leakage level lower than 7ACH50. However, there has not been sufficient field testing for the CEC to award compliance credit for lower leakage in multifamily buildings. Complications may arise when considering leakage between individual units, corridors, and other space outside an individual dwelling unit.

Based on feedback and data from HERS raters, TRC assumed that multifamily buildings successfully implementing QII and low leakage ducts in conditioned space are able to achieve 5ACH50 or less. TRC ran simulations of a single family building with infiltration rates equal to 7ACH50 and 5ACH50 and found the TDV energy savings were almost entirely from reduce heating. TRC translated the proportional savings from the single family home to the low-rise multifamily building based on envelope area, and reduced it by half to account for leakage to corridors and neighboring units.

5.2 Open Office Occupancy Sensors

To determine the potential energy savings associated with this measure, TRC estimated the number of occupancy sensors using the floor plan provided in Figure 5 of the 2013 CASE report was used.[35] This floor plan shows that open office workstations occupies approximately 53% of the floor plan area, and each work station occupied about 120 ft^2. Using the CASE savings for 4 workstations per occupancy sensor (or, one occupancy sensor per 480 ft^2), TRC determined the total number of occupancy sensors for each prototype, as well as the associated costs and TDV savings. (The costs and TDV savings per sensor are provided in tables in the executive summary of the CASE report, on page 9 and 14, respectively).

Since daylight sensors are required by the 2013 T24 Standards, overlapping savings were estimated to be 20% of non-daylit spaces when in primary daylight zones. Thus, the portion of the open office spaces in the floor plan that were in primary daylight zones (approximately 21% of the workstation floor area) had savings reduced by 80%. Savings were also reduced by the

[35] California Utilities Statewide Codes and Standards Team (October 2011) Nonresidential Indoor Lighting Controls Codes and Standards Enhancement Initiative. Available at: http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Nonresidential/Lighting_Controls_Bldg_Power/2013_CASE_NR_Indoor_Lighting_Controls_Oct_2011.pdf

proportion that lighting power density would be reduced from the Reduced LPD and Tuning measures. The summary of findings is provided in Table 32.

Table 32. Nonresidential Proximity Sensors TDV Energy Savings

	Medium Office
Workstation Proportion	53%
Workstation Area (ft^2)	28,201
# Sensors	59
Building Cost	$6,852
TDV $ Savings*	$13,553*
TDV kBtu Savings*	152,289*
Percent Savings	2.9%

* Accounting for overlap with potential daylight sensor savings.

6. Appendix B – High Rise Multifamily Modeling

At the request of the City of Santa Monica, TRC performed simulations to show that mixed use high-rise multifamily (HRMF) new construction projects can achieve a 10% compliance margin cost effectively, as per the nonresidential reach code recommendation for all nonresidential buildings. The methodology aligns with the rest of this report, except that TRC performed the HRMF simulations in CBECC-Com v2.1 (build 868).

The HRMF prototype is outlined in Table 33.

Table 33. High-Rise Multifamily Prototypes Summary

Building Type	High-Rise Multifamily
Total Conditioned Floor Area (ft^2)	84,360
Dwelling Units	60
Retail Floor Area (ft^2)	19,000
# of floors	4
Window-to-Floor Area Ratio	40%
Roof Construction	1/16" Metal Standing Seam, R-29 Continuous Insulation Board
Roof Reflectance (Low-sloped)	No Requirement[1]
Cooling System	Chiller and Cooling Tower
Heating System	Boiler, 80% Thermal Efficiency
HVAC Distribution System	Four Pipe Fan Coil (residential), Packaged VAV System (retail and corridors)
Domestic Water Heating	Central Gas Storage, 122 Gallons, 80% Thermal Efficiency, 1.2% Standby Loss, R-12 tank insulation
Regulated Lighting Power Density	(Retail Only) 1.20 W/ft^2
Daylighting Controls	(Retail Only) Continuous, 0.20 Dimming Light/Power Fraction

[1] Although there is no prescriptive requirement in CZ6 for high-rise residential, the model default is ASR=0.08 and TE=0.75 as per section 110.8(i)1 of the Title 24 Standards.

6.1 Efficiency Measures

TRC conducted TDV cost effectiveness analysis using the following energy efficiency measures:

- DHW – 2" pipe Insulation
- DHW -- Drain water heat recovery
- ENV – Cool roof
- LTG - Interior lighting LPD reduction

- LTG - Daylight dimming plus off (as described in 3.2.2)

Measures not described in the body of the report are described below.

6.1.1 DHW – 2" Recirculation Loop Pipe Insulation

The domestic hot water line is served by a recirculation loop with 1.5 inches of insulation. Increasing this insulation to 2" results in slight increases in materials and labor costs (Table 34). TRC estimated the recirculation pipe length in the HRMF prototype, and attained costs through RS Means for three types of commercial pipe insulation.

Table 34. High-rise Multifamily Recirculation Pipe Insulation Incremental Costs Summary

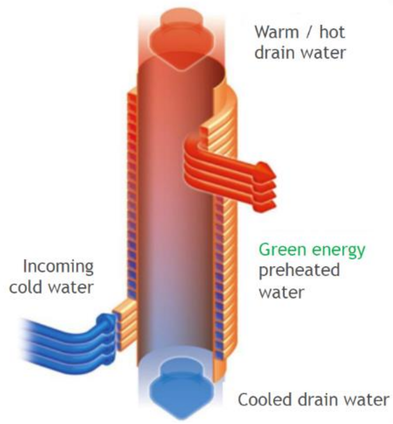
Component/ Material	Base Case	Proposed Update	Incremental Cost / Linear Foot	Linear Feet	Total Incremental Cost
Insulation on Recirculation Loop	1.5 in	2 in	$3.01	2,668	$8,021

6.1.2 DHW – Drain Water Heat Recovery

Drain water heat recovery (DWHR) is a technology used to reduce the amount of energy needed by a water heater or fixture to heat incoming water to the required temperature. The technology utilizes a heat exchanger in the drain line to pre-heat cold water supplied to the cold water side of fixtures. Figure 1 shows a common drain water heat recovery configuration.

A number of organizations have studied heat exchanger performance including: Southern California Gas Company, PG&E Food Service Technology Center, Lawrence Berkeley National Laboratory, Federal Energy Management Program, Oak Ridge National Laboratory, University of Wisconsin, Florida Solar Energy Center, and Natural Resources Canada. IECC 2015 added a performance option for DWHR and DWHR has been adopted into local codes in Canada.

Figure 1. Drain Water Heat Recovery Diagram (courtesy of PowerPipe)



Neither CBECC-Res nor CBECC-Com can currently model the benefits of Drain Water Heat Recovery. TRC used energy performance data from technology studies to estimate energy savings in the HRMF prototype. Additionally, ANSI/RESNET includes a procedure for calculating savings from DWHR.

The additional cost to implement DWHR, as shown in Table 35 is about $774 in material and labor for every 4 dwelling units. Costs were derived from online retailers, RS Means, and Craftsman Cost Book.

Table 35. Drain Water Heat Recovery Costs

Cost Component	Base Case	Proposed Update	HRMF Multifamily
Drain Water Heat Recovery Equipment	None	1 for every 4 units	$8,700
Installation Labor	None	2 hrs each	$2,904
Total Incremental Cost			**$11,604**

6.1.3 LTG – Lighting Power Density Reduction

This measure reduces the lighting power density (LPD) from the 2016 Title 24 prescriptive requirement of 1.2 W/ft^2 for retail areas (using the Area Category Method) to 0.90 W/ft^2 using light emitting diode (LED) fixtures and a lighting control system. As described above in Section 3.2.2, cost research shows that some T8 fluorescent basket fixtures may be more costly than LED basket fixtures. However, when implementing high output fixtures, such as those that might be installed to achieve the LPD for a retail space, LEDs fixtures may have a cost increase over T8 fixtures, even when including the cost for dimmable ballasts.

The incremental costs shown in Table 36 includes the increased cost for LED fixtures and the control system. These costs are conservative because, as trend data has shown, the costs for LEDs is reducing, meaning that the cost difference between high output T8 and LED fixtures will likely decrease over time. Costs were derived from the Santa Monica High Performance Building Cost Effectiveness Study, and online retailers.[36]

Table 36. Retail Lighting Power Density Reduction Costs

Measure	Base Case	Proposed Update	Incremental $/ fixture	Units/ Bldg	$/Bldg
Lighting Power Density	1.2 W/ft^2 (fluorescent)	0.9 W/ft^2 (LEDs)	$135	238	$32,063

6.1.4 ENV – Cool Roof

The cool roof requirements for high-rise multifamily buildings in CZ6 are shown in Table 37. Low-sloped roofs are more typical of high-rise multifamily and nonresidential construction. For the purposes of this analysis, only low-sloped roofs were included based on the prototypes.

Table 37. Prescriptive Cool Roof Requirements in CZ6

Building Sector	Slope	3-Year Aged Solar Reflectance	Thermal Emittance
High-Rise Residential	Low-Sloped	No Requirement[1]	
	Steep-Sloped	0.20	0.75

[1] Title 24 compliance software defaults ASR=0.08 and TE=0.75 as per section 110.8(i)1 of Title 24 Standards.

This measure requires that high-rise residential buildings go from no requirement (default assumption of ASR = 0.08) to an ASR = 0.70, the same ASR value included in the nonresidential package above. As described above in Section 3.2.1, research found that most low-sloped cool roof products do not introduce a cost increase over their non-cool roof counterparts. However, to be conservative, TRC included the incremental costs for products that do incur a cost increase for cool roof performance. The cost analysis used data from the 2013 Nonresidential Cool Roofs CASE Report and additional cost data collection. TRC used the average incremental cost for roofing types including single-ply TPO, membranes, and field applied coatings.

The incremental costs of going from the base case to a cool roof are summarized in Table 38. Additional details for the cost analysis are provided in *Appendix C – Cost Details*.

[36] Integral Group and Skanska (2015). City of Santa Monica High Performance Building Cost Effectiveness Study Available at: https://www.smgov.net/uploadedFiles/Departments/OSE/Categories/Green_Building/SantaMonica_HighPerformanceStudy_Final.pdf

Table 38. HRMF Low-Sloped Cool Roof Incremental Costs Summary

Prototype	Base Case	Proposed Update	Incremental $/ ft² roof	Units/ Bldg	$/Bldg
High-Rise Multifamily	No Requirement[1]	ASR=0.70, TE=0.85	$0.10	21,090	$2,039

[1] Title 24 compliance software defaults ASR=0.08 and TE=0.75 as per section 110.8(i)1 of Title 24 Standards.

6.2 Cost Effectiveness Results

Using the TDV methodology described in Section 2.3.1, the HRMF energy efficiency package is estimated to be cost effective, as shown in Table 39. TRC did not analyze a HRMF ZNE package with PV because there is currently no CEC ZNE definition for HRMF buildings.

To attain the present value of savings, TRC applied the 30-year residential NPV factor to all measures except the nonresidential lighting measure, which uses the 15-year nonresidential NPV factor.

Table 39. High-rise Multifamily Energy Efficiency Package TDV Cost Effectiveness

High-rise Multifamily Energy Efficiency Package				
Measure	**2016 T24 Compliance Margin**	**Present Value of Energy Savings**	**Cost**	**Benefit to Cost Ratio**
2" Recirculation Loop Pipe Insulation	0.3%	$3,507	$8,021	0.4
Drain Water Heat Recovery	1.3%	$20,977	$11,604	1.8
Cool Roof[1]	1.9%	$26,154	$2,039	12.8
Lighting Power Density Reduction + Dimming Plus Off	6.9%	$49,403	$32,063	1.5
Package	**10.3%**	**$97,551**	**$53,727**	**1.8**

[1] TRC found an error in CBECC-Com that resulted in reduced TDV values for the standard model following the modeling of a cool roof. To avoid this error, TRC 1) Modeled all measures except for cool roof and noted the standard model TDV numbers, 2) Modeled the all measures with the cool roof and noted the proposed model TDV numbers, and 3) Calculated the compliance margin when comparing the value in Step 1 and Step 2. TRC anticipates this bug to be fixed in the next version of the software, in which case permit applicants will not need to perform this procedure.

6.2.1 Compliance

To achieve the cost effectiveness results shown in Table 39, TRC removed the residential internal lighting load from the compliance total. In a mild climate like Santa Monica's, the lighting usage represents about 40% of the total compliance TDV budget of the HRMF building. However, in low-rise multifamily buildings, lighting is 0% of the compliance TDV budget, because all residential lighting requirements are mandatory and the CEC does not award performance credit for residential lighting improvements. Since there are no credits allowed for better than code lighting in residential spaces, this 40% of TDV use cannot typically be lowered in HRMF. Furthermore, the software algorithms used to calculate the lighting energy use are an order of magnitude different for low-rise multifamily than they are for HRMF. For LRMF, the lighting energy use is calculated using equations in Appendix C of the residential ACM whereas for HRMF, the lighting energy use is calculated using equations in Appendix 5.4A of the nonresidential ACM. As a result, a HRMF building has a lighting energy intensity that is 5 times that of a low-rise multifamily building.

Similar to the methods used by the California Multifamily New Housing program and GreenPoint Rated efforts, TRC recommends that Santa Monica allow HRMF permit applicants to remove the residential lighting energy from the compliance total. One of the ways that a permit applicant can choose to remove the residential lighting is the following:

1. Simulate the mixed-use HRMF building as designed.
2. Simulate the building with 0 W/ft^2 of lighting installed in the nonresidential and corridor spaces, as applicable.
3. Subtract the lighting TDV/ft^2 in Step 2 from the lighting TDV/ft^2 in Step 1. This isolates the lighting TDV/ft^2 value for the nonresidential and corridor spaces.
4. Replace the lighting TDV/ft^2 value in Step 3 instead of the lighting TDV/ft^2 in Step 1, and calculate the new compliance total.

7. Appendix C – Cost Details

Table 40. Single Family HERS Verification Base Costs

	Single Family
On-site visit ($/visit)	$220
Standard Measure verification ($/measure)	$45
Additional Measure verification ($/measure)	$100

Table 41. Single Family HERS Verification Detailed Costs

Single Family HERS Measure	Site Visit 1	Site Visit 2	Site Visit 3	Total # Visits	Total Cost
Duct Leakage (Mandatory)		X		1	$76
Verified Airflow/ Fan Efficiency (Mandatory)		X		1	$76
Whole Building Mechanical Ventilation (Mandatory)		X		1	$76
Quality Insulation Installation (Additional)	X	X	(X)	2-3	$430
Piping Insulation, All Hot Water Lines (Standard)		X		1	$76
Verified Refrigerant Charge (Standard)		X		1	$76

*Assuming measures that require 2 or more on-site visits can be verified on the same visit.

Table 42. Multifamily HERS Verification Base Costs

	Multifamily
Method 1: On-site visit ($/visit)	$245
Method 2: Per unit verification, no QII ($/unit)	$198
Method 2: Per unit verification, with QII ($/unit)	$248

Table 43. Multifamily HERS Verification Detailed Costs

Multifamily HERS Measure	Best Case # Site Visits	Mid Case # Site Visits	Worst Case # Site Visits	Total Average Cost
Duct Leakage (Mandatory)	1	1	2	$272
Verified Airflow/ Fan Efficiency (Mandatory)	1	1	1	$150
Whole Building Mechanical Ventilation (Mandatory)	1	1	1	$150
Quality Insulation Installation	3	4	5	$708
Compact DHW Distribution	1	1	1	$150
Piping Insulation, All Hot Water Lines	1	1	1	$150
Verified Refrigerant Charge	1	1	2	$272
Verified Low Leakage Ducts in Conditioned Space	2	3	4	$517

*Assuming measures that require 2 or more on-site visits can be verified on the same visit.

Table 44. Residential Quality Insulation Installation Detailed Costs

Component	Base Case	Proposed Update	Incremental $/Unit	Unit	Single Family		Multifamily	
					Units/ Home	$/Home	Units/ Building	$/Building
Installation Labor	Standard	+2 hrs	$44.29	hour	2	$89	8	$354
HERS Verification	None	Verified	$430 or $708	-	1	$430	1	$708
				Totals	**$519**		**$1,062**	

Cost source: Local HERS Raters

Table 45. High Performance Walls Detailed Costs

Component	Base Case	Proposed Update	Cost ($/unit)	Unit	2-Story		Low-rise Multifamily	
					Units	$/home	Units	$/building
Wall Framing	2x4 @ 16”	2x6 @ 16”	$0.29	linear ft	2594	$752	4919	$1,427
Cavity Insulation	R-15	R-19	-$0.19	square ft	2231	-$424	3782	-$719
Continuous Exterior Insulation	R-4	R-5	$0.14	square ft	2231	$312	3782	$529
Additional Sill Flashing	1"	1"	$0.00	square ft	2231	$0	3782	$0
				Total Cost	**$641**		**$1,237**	

Costs source: 2016 Residential High Performance Walls CASE Report:
http://www.energy.ca.gov/title24/2016standards/rulemaking/documents/dru_title24_parts_01_06/2016%20T24%20CASE%20Report%20-%20High_Perfornace_Walls_2015-02-06_TN-74502.pdf

Table 46. Improved Glazing Detailed Costs[1]

Component	Base Case	Proposed Update	Cost ($/unit)	Unit	2-Story		Low-rise Multifamily	
					Units	$/home	Units	$/building
Fenestration	U-0.32/ SHGC-0.25	U-0.30/ SHGC-0.23	$0.15	square ft fenestration	481	$72	1,042	$156

[1]Costs sourced from Davis Energy Group, Inc., Enercomp, Inc., Misti Bruceri & Associates, LLC. (2016). *CALGreen Cost Effectiveness Study*.

Table 47. Steep-Sloped Cool Roof Detailed Costs

Component/ Material	Base Case	Proposed Update	Incremental $/ ft² roof	Low-Rise Multifamily	
				Units/ Bldg	$/Bldg
Asphalt Shingles	No Requirement[1]	ASR=0.20, TE=0.85	$0.04	3,771	$151
Tile	No Requirement[1]	ASR=0.20, TE=0.85	$0.00	3,771	$0
			Average[2]	**$70**	

[1] Although there is no prescriptive requirement in CZ6 for residential roofs, the model assumes ASR=0.10 and TE=0.75 for low-rise residential to represent standard roofing materials.
[2]Values in table reflect rounding.

Table 48. Reduced Fan Watt Draw Detailed Costs[1]

Component	Baseline Efficiency	Proposed Efficiency	Incremental SF Cost ($/unit)	Incremental MF Cost ($/unit)	2-Story		Low-rise Multifamily	
					Units	$/home	Units	$/building
ECM Motor	0.58 watts/cfm	0.30 watts/cfm	$143	$104	1	$143	8	$832

[1]Costs sourced from Davis Energy Group, Inc., Enercomp, Inc., Misti Bruceri & Associates, LLC. (2016). *CALGreen Cost Effectiveness Study*.

Table 49. Compact DHW Distribution Detailed Costs

Component	Base Case	Proposed Update	Cost ($/unit)	Unit	Low-rise Multifamily	
					Units	$/building
PEX Pipe Length	standard	reduced	$1.39	linear ft	84	-$117
HERS Verification	standard	verified	$150	-	1	$150
					Incremental Cost	**$33**

Cost source: 2013 Residential Single Family Water Heating Distribution System Improvements CASE Report:
http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Residential/Water_Heating/2013_CASE_R_SEMPRA_Single_Family_DHW_%20Sept_2011.pdf

Table 50. Residential Piping Insulation for All Hot Water Lines Detailed Costs

Component	Base Case	Proposed Update	Incremental $/Unit	Unit	2-story		Multifamily	
					Units/ Home	$/Home	Units/ Building	$/Building
1/2” Pipes Insulation + Labor	None	1”	$3.87	Linear ft	24	$91	165	$640
HERS Verification	None	Verified	$76 or $150	Dwelling Unit	-	$76	-	$150
				Totals	**$167**		**$790**	

Costs source: 2013 Single Family Water Heating Distribution System Improvements CASE Report:
http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Residential/Water_Heating/2013_CASE_R_SEMPRA_Single_Family_DHW_%20Sept_2011.pdf

Table 51. Low-Sloped Cool Roof Costs Summary

Product Type	Average Cost ($/ft^2)			Incremental Cost ($/ft^2)	
	ASR=0.08	ASR=0.63	ASR=0.70	ASR=0.08 to ASR=0.70	ASR=0.63 to ASR=0.70
TPO	$0.49	$0.49	$0.49	$0	$0
Membrane	$0.44	$1.01	$0.88	$0.43	($0.13)
Field Applied Coating	$0.56	$0.53	$0.42	($0.14)	($0.10)
			Average	**$0.10**	**($0.08)**

In addition to the cool roof cost data, distributors and roofers provided the following feedback regarding low-sloped cool roofs:

> "For TPO, if the reflectance you want is a product they sell, there is no cost increase."
>
> "For BUR, at the manufacturing level, products typically come out as standard white, then they color it for aesthetic reasons. Colored products are more expensive because it is non-standard."
>
> "For [field applied] coatings, what makes the cost difference is the solid content. This is a quality characteristic that has nothing to do with reflectance properties."
>
> “…more expensive to use cool roof cap sheet product than standard.”

Table 52. Low-Sloped Cool Roof Representative Detailed Costs

Product Type	Product Line	ASR	Cost ($/ft^2)
Field Applied Coating	Black Jack Roof Gard 700	0.65	$0.51
Field Applied Coating	Black Jack Ultra Roof 1000	0.70	$0.56
		Incremental Cost	**$0.05**

Cost source: Phone interviews with distributors and online retail.

Table 53. Nonresidential Institutional Tuning for Lighting Detailed Costs

Material/ Component	Base Case	Proposed Update	Incremental $/Unit	Unit	Units/ Building	$/ Building
Installation Labor	None	Additional labor time	$0.10	watt	37,540	$3,218

Cost source: 2013 Nonresidential Controllable Lighting CASE Report: http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/2011-04-04_workshop/review/Nonres_Controllable_Lighting.pdf

Table 54. Nonresidential Open Office Lighting Occupancy Sensors Detailed Costs

Material/ Component	Base Case	Proposed Update	Incremental $/Unit	Unit	Units/ Building	$/ Building
Occupancy Sensors	None	1 sensor per 4 workstations	$116.13	Sensor	59	$6,852

Cost source: 2013 Nonresidential Lighting Controls CASE Report: http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Nonresidential/Lighting_Controls_Bldg_Power/2013_CASE_NR_Indoor_Lighting_Controls_Oct_2011.pdf

Table 55. Nonresidential Lighting Power Density (LPD) Reduction Detailed Costs

Source	0.75 W/ft² Product	0.70 W/ft² Product	$/ft² Cost for 0.75 W/ft²	$/ft² Cost for 0.70 W/ft²	$/ft² Incremental Cost
The Lighting Agency, Chris Davis	T8 Basket Fixture - e.g. Lithonia 2VT8	LED Basket Fixture - e.g. Lithonia 2BLT	$1.68	$1.38	($0.30)
Associated Lighting Representatives			Stated that prices are the same for some options, did not provide product pricing		
Online			$2.18	$2.25	$0.06
		Average	**$1.93**	**$1.82**	**($0.11)**

8. Appendix D – Alternative PV Package Cost Effectiveness

In the cost effectiveness analyses shown in Section 4 (using both the CEC LCC methodology and life cycle customer cost methodology), the full PV array necessary to meet an EDR of zero was included for the residential packages. However, Santa Monica previously adopted a PV ordinance (*Appendix E – Santa Monica PV Mandate*) that requires new construction residential and nonresidential projects to install a minimum PV size based on the simulated energy use or size of the building. Assuming that minimum PV sizes according to Santa Monica's PV ordinance will already be installed for each new construction project, a separate cost effectiveness analysis was done including only the additional PV size that would be needed to meet an EDR of zero for the single family and low-rise multifamily projects.

For the analysis, the following methods were used to size the PV system to meet Santa Monica's PV ordinance:

- **Single Family Residential:** Method ii which requires, at minimum, a PV system that will offset 75% of the proposed TDV energy budget. By definition, this requirement does not meet CALGreen Tier 3 ZNE definition.
- **Low-rise Multifamily Residential:** 2.0 watts per square foot.

For the single family building, an additional 1 kW of PV would need to be installed beyond the 2.7 kW required from the PV mandate. As shown in Table 56, the ZNE package with only the additional savings and costs from the 1 kW PV is cost effective.

Table 56. Single Family ZNE with Santa Monica PV Ordinance TDV Cost Effectiveness

Single Family ZNE Package with Santa Monica PV Ordinance				
Measure	% Above Title 24	Present Value of Energy Savings (TDV$)	Cost	Benefit to Cost Ratio
EE Package	19.1%	$1,709	$1,619	1.1
Zero Net Energy Package (Additional 1kW PV)	19.1%	$8,382	$4,580	1.8

The life cycle customer cost analysis does not show the ZNE package with the additional 1 kW PV to be cost effective, as shown in Table 57. The analysis reflects the savings that a 1 kW PV would have beyond those of the 2.7 kW system. The majority of the 1 kW PV savings result in net exported electricity, which are valued lower than the price of electricity and natural gas used in a home. Therefore, the energy cost savings do not outweigh the additional cost of the PV.

Table 57. Single Family ZNE with Santa Monica PV Ordinance Customer Cost Effectiveness

Single Family ZNE Package with Santa Monica PV Ordinance				
Measure	**% Above Title 24**	**Present Value of Energy Savings**	**Cost**	**Benefit to Cost Ratio**
EE Package	19.1%	$939	$1,619	0.6
Zero Net Energy Package (1 kW PV)	19.1%	$1,984	$4,580	0.4

For the low-rise multifamily building, an additional 2.2 kW of PV would need to be installed beyond the 13.9 kW required from the PV mandate. As shown in Table 58, the ZNE package with only the additional savings and costs from the 2.2 kW PV is cost effective.

Table 58. Low-rise Multifamily ZNE with Santa Monica PV Ordinance TDV Cost Effectiveness

Low-rise Multifamily Residential ZNE Package				
Measure	**% Above Title 24**	**Present Value of Energy Savings (TDV$)**	**Cost**	**Benefit to Cost Ratio**
EE Package	16.4%	$5,401	$4,953	1.1
Zero Net Energy Package (2.2 kW PV)	16.4%	$20,083	$11,408	1.8

The life cycle customer cost analysis does not show the ZNE package with the additional 2.2 kW PV to be cost effective, as shown in Table 59, due to the same reasons as the single family ZNE package.

Table 59. Low-rise Multifamily ZNE with Santa Monica PV Ordinance Customer Cost Effectiveness

Low-rise Multifamily Residential ZNE Package				
Measure	**% Above Title 24**	**Present Value of Energy Savings (TDV$)**	**Cost**	**Benefit to Cost Ratio**
EE Package	16.4%	$2,662	$4,953	0.5
Zero Net Energy Package (2.2 kW PV)	16.4%	$3,302	$11,408	0.3

9. APPENDIX E – SANTA MONICA PV MANDATE

Below is the abridged language of the Santa Monica solar photovoltaics mandated, which amends Section 4.201 of the 2013 California Green Building Standards Code.

4.201.4. One-and-Two Family Dwelling Solar Photovoltaic Installations

(a) All new one-and-two family dwellings are required to install a solar electric photovoltaic (PV) system. The required installation of the PV system shall be implemented using one of the following methods:

> i. Install a solar PV system with a minimum total wattage 1.5 times the square footage of the dwelling (1.5 watts per square foot); or
>
> ii. Install a solar PV system or other renewable energy system that will offset 75%-100% of the Time Dependent Valuation (TDV) energy budget.
>
> iii. Demonstrate that the Time Dependent Valuation (TDV) energy budget is reduced by the same wattage required by (a)(i).

(b) The requirements of this Section shall be waived or reduced by the minimum extent necessary. Where production of electric energy from solar panels is technically infeasible due to lack of available and feasible unshaded areas.

(c) The requirements of this Section shall take priority if there is a conflict between compliance with Section 4.201.3 and this section.

4.201.5 Low-Rise Residential Solar Photovoltaic Installations.

(a) All new Low-Rise Residential dwellings are required to install a solar electric photovoltaic (PV) system. The required installation of the PV system shall be implemented by installing a solar PV system with a minimum total wattage 2.0 times the square footage of the building footprint (2.0 watts per square foot).

(b) The requirements of this Section shall be waived or reduced, by the minimum extent necessary where production of electric energy from solar panels is technically infeasible due to lack of available and feasible unshaded areas.

(c) The requirements of this Section shall take priority if there is a conflict between compliance with Section 4.201.3 and this section.

5.201.4 Non-Residential, High-Rise Residential, Hotels and Motels Solar Photovoltaic Installation.

(a) All now non-residential, high-rise residential, hotel, motel buildings are required to install a solar electric photovoltaic (PV) system. The required installation of the PV system shall be implemented by installing a solar PV system with a minimum total wattage 2.0 times the square footage of the building footprint (2.0 watts per square foot).

(b) The requirements of this Section shall be waived or reduced by the minimum extent necessary, where production of electric energy from solar panels is technically infeasible due to lack of available and feasible unshaded areas.

(c) The requirements of this Section shall take priority if there is a conflict between compliance with Section 5.201.3 and this section.