Title 24, Part 11
Local Energy Efficiency Ordinances

2016 Title 24 Residential Reach Code Recommendations: Cost Effectiveness Analysis for All California Climate Zones

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Executive Summary

Southern California Edison (SCE) engaged TRC Energy Services (TRC) to provide a cost effectiveness study to support low-rise residential new construction reach code requirements above 2016 Title 24 Building Energy Efficiency Standards (T24), in all 16 California climate zones (CZs). The T24 Standards are the minimum energy efficiency requirements for building construction in California, and a reach code would require energy performance beyond the minimum. TRC developed high-performance reach code measure packages for each climate zone that represent possible ways to exceed T24, and are not intended to represent a mandatory or prescriptive set of measures.

TRC simulated measures in CBECC-Res 2016 v3.0 to inform energy impacts, and their corresponding costs were attained through expert interviews and online research. TRC tested various measure packages for cost effectiveness to maximize the compliance margin achieved solely through energy efficiency. In alignment with the goals of 2019 Title 24, TRC then sized solar photovoltaic (PV) generation to offset the annual electricity kWh required by the building after maximizing efficiency, referred to as the Efficiency + PV package.

TRC determined cost effectiveness by comparing the incremental cost of each measure package to the net present value (NPV) of energy cost savings over the 30-year period. Energy cost savings were estimated both in time dependent valuation (TDV) as well as on-bill savings determined through utility rates. The PV compliance credit is added to the efficiency-only packages to present the maximum compliance margin TRC found to be cost effective. Based on cost effectiveness results, TRC recommends that jurisdictions adopt ordinances with requirements and 2016 Energy Design Rating targets achieved through both energy efficiency and solar PV, as per Figure 1.

Figure 1. Summary of Cost Effectiveness Results

CZ	Single Family			Low-rise Multifamily		
	Compliance Margin Efficiency-Only	Compliance Margin Efficiency + PV	2016 Energy Design Rating Efficiency + PV	Compliance Margin Efficiency-Only	Compliance Margin Efficiency + PV	2016 Energy Design Rating Efficiency + PV
1	40%	45%	20	20%	25%	15
2	30%	35%	20	20%	25%	20
3	30%	35%	15	10%	15%	15
4	25%	45%	20	20%	30%	15
5	30%	40%	15	10%	10%	15
6	15%	15%	20	15%	15%	15
7	None	15%	15	None	10%	20
8	25%	55%	15	15%	25%	20
9	30%	55%	15	20%	30%	20
10	30%	55%	15	20%	30%	15
11	30%	50%	20	20%	30%	20
12	35%	55%	20	20%	30%	20
13	30%	50%	20	25%	30%	20
14	30%	50%	20	20%	30%	20
15	30%	45%	15	25%	30%	20
16	30%	45%	25	20%	30%	25

1. Introduction

Southern California Edison (SCE) engaged TRC Energy Services (TRC) to provide a cost effectiveness study to support low-rise residential new construction reach code requirements above 2016 Title 24 Building Energy Efficiency Standards (T24), in all 16 California climate zones (CZs). The T24 Standards are the minimum energy efficiency requirements for building construction in California, and a reach code would require energy performance beyond the minimum. The 2016 T24 Standards became effective on January 1, 2017.

The reach code energy efficiency targets for single family and low-rise multifamily are based on the CALGreen Tier 3 definition:

- Single Family: 30% in CZs 1-5 and 8-16; 15% in CZs 6 and 7
- Low-rise Multifamily: 30% in CZs 1, 2, 4, and 8-16; 15% in CZs 3 and 5-7

While TRC targeted these efficiency levels, the CALGreen Tier 3 requirement for an Energy Design Rating (EDR) = 0 was not targeted. Based on coordination with the CEC, TRC sized solar photovoltaic (PV) generation to offset the annual electricity kWh demanded by the buildings after maximizing efficiency, which results in an EDR > 0.

1.1 Scope

TRC researched measures drawn from multiple sources in an effort to develop cost effective packages that achieve the compliance margin targets above. Compliance margin improvement is measured in terms of Time Dependent Valuation (TDV), described further in Section 2.2.1. Measures were simulated in CEC-approved 2016 T24 compliance software to inform energy impacts, and their corresponding costs were attained through expert interviews and online research. Final measure packages represent one possible way to achieve higher compliance margins and are **not intended to represent a mandatory or prescriptive set of measures**.

1.1.1 Prototype

TRC used two single family prototypes and one low-rise multifamily prototype to estimate energy savings and cost effectiveness, further described in *Section 2.1*. These CEC developed prototypes are commonly used in Title 24 Code and Standards Enhancement (CASE) studies and local reach code analysis, and are meant to be representative of the types of buildings constructed in California.[1] Nonetheless, local jurisdictions can choose to analyze other prototypes during the reach code adoption process.

1.1.2 Cost Data

When available, TRC used existing cost data collected through 2019 Draft CASE Reports and other studies. TRC also conducted additional supplier, distributor, and contractor interviews in multiple locations throughout the state. TRC also researched online sources including RSMeans, Grainger, and Home Depot. Measure costs represent the incremental changes beyond the 2016 T24 Standards prescriptive requirements.

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

1.1.3 Cost Effectiveness

TRC determined cost effectiveness by comparing the incremental cost of each measure package to the NPV of energy cost savings over the 30-year period. Results include measure compliance margin, present value of energy savings, costs, and benefit to cost (B/C) ratio.

TRC analyzed cost effectiveness for two scenarios:

- **Energy Efficiency Only:** The efficiency package energy savings benefits are measured in terms of TDV, in accordance with CEC Life Cycle Cost methodology typically used in CASE studies.
- **Energy Efficiency + PV (EE + PV):** The EE + PV package adds enough solar PV to the energy efficiency package to offset annual kWh load. Energy savings benefits are measured in terms of on-bill savings, in accordance with CEC cost effectiveness analysis for solar PV. TRC used life cycle customer cost methodology using residential retail rates for electricity and natural gas for each of the four major investor owned utilities - Pacific Gas & Electric Company (PG&E), Southern California Edison (SCE), Southern California Gas Company (SCG), and San Diego Gas and Electric (SDG&E).

When the B/C ratio is greater than 1.0, the added cost of the measure is offset by the discounted energy cost savings and the measure is cost effective. See Section 2.3 for further detail.

1.2 Limitations

The study has the following scope limitations:

- **Federal Preemption:** The Department of Energy (DOE) regulates the minimum efficiencies required for all appliances, such as space conditioning and water heating equipment. State or city codes that mandate appliance efficiencies higher than the DOE's risk litigation by manufacturer industry organizations. Thus, TRC did not use increased equipment efficiencies as reach code measures, although these measures are often the simplest and most affordable measures to increase energy performance. While this study is limited by federal preemption, developers can use any package of measures to achieve reach code goals, including the use of high-efficiency appliances that are federally regulated.
- **Modeling Capability:** TRC used CEC-approved Title 24-2016 compliance software, CBECC-Res, to ensure that a free and readily available software program could be used by permit applicants to show compliance with the reach code. CEC-approved compliance software does not yet have the capability to model the energy performance of some measures typically associated with energy savings, such as drain water heat recovery, and reduced infiltration in low-rise multifamily. When necessary, TRC used spreadsheet analysis to estimate the energy performance of measures that could not be modeled in compliance software and added the impact to the compliance margin (including interactive effects).
- **Plug and Lighting Loads:** Plug and lighting loads (e.g., kitchen appliances and indoor lighting), have been explicitly excluded from the scope of this study. CEC-approved simulation software does not allow compliance credit for energy efficiency improvements in these end-uses.

2. METHODOLOGY

TRC developed 0% compliant residential prototypes for all 16 climate zones representing buildings that exactly meet the 2016 Title 24 code requirements to create the baseline model. TRC then used CBECC-Res to simulate energy efficiency measures and photovoltaics to evaluate the energy savings and corresponding compliance percentage over the baseline model.

TRC assessed the cost effectiveness of 2016 reach code packages by analyzing several energy efficiency measures applied to the prototype buildings. TRC used the on-bill cost savings to evaluate customer cost effectiveness. This methodology requires estimating and quantifying the value of the energy impact associated with measures as compared to the baseline prototypes using utility rate schedules over a life of 30 years. The methodology also includes quantifying the incremental costs for the construction, maintenance, and replacement of the proposed measure relative to the 2016 Title 24 prescriptive requirements. The methodology to attain incremental costs is described in *Section 2.2.2*.

2.1 Prototypes

TRC used CEC developed residential prototypes to run simulations for all California CZs:

- 2,100 ft^2 single family one-story home
- 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

The CEC prototypes are fully defined in the Residential Alternative Calculation Method (ACM) reference manual.[2] The prototypes have equal geometry facing north, east, south, and west orientations, to ensure that results are applicable regardless of the orientation of a building.

TRC initialized the three prototypes to be exactly compliant with the prescriptive minimum 2016 T24 requirements (0% compliance margin) in each climate zone, summarized in Figure 2. The TDV of energy savings for energy efficiency measures were derived by applying measure packages to the minimally code compliant prototype as described in *Section 2.2*.

[2] 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

Figure 2: Parameters of Residential Prototypes

Parameters	Single Family Building		
	2100 SF	2700 SF	6960 MF
Floor Area (ft2)	2100	2700	6960
# of floors	1	2	2
Window-to-Floor Area Ratio	20%	20%	15%
HVAC Distribution System	Ducts located in ventilated attic		Ducts located entirely in conditioned space
Cooling System	Split AC: SEER 14 & EER 11.7		
Heating System	Gas furnace, 78% AFUE		
Conditioned Thermal Zones	1	1	8
Domestic Water Heating	Natural Gas instantaneous water heater; EF 0.82		
Ceiling Insulation (Option B, Table 150.1-A)	R-30 in CZ3 and 5-7; R-38 in CZ1, 2, 4 and 8-16		
Roof Insulation (Option B, Table 150.1-A)	No Requirement in CZ1-3 and 5-7 R13 in CZ4 and 8-16		
Steep-sloped Roof Solar Reflectance	0.10 in CZs 1-9 and CZ16 0.20 in other CZs		
Wood-framed Wall Insulation (U-factor)	0.065 for CZ6 & CZ7; 0.051 for other CZs		
Fenestration U-factor	0.32		
Fenestration Solar Heat Gain Coefficient (SHGC)	0.50 for CZ1, CZ3 & CZ5; 0.25 for other CZs		
Door U-factor	0.50		

2.2 Measure Analysis

TRC investigated measures for single family and low-rise multifamily prototypes with the goal of establishing cost effective packages of measures above 2016 Title 24, Part 6. TRC used CBECC-Res 2016.3.0 (build 954) to simulate the residential prototypes. CBECC is a free public-domain software developed by the CEC for use in complying with Title 24 Standards. Software algorithms are updated continuously, and new versions of the software are released periodically.

2.2.1 Energy Savings

Compliance software outputs energy performance in terms of TDV, kWh, therms, and EDR totals for both the proposed building and the standard building meeting prescriptive Title 24 requirements. The EDR uses a scale of 1 – 100, where 100 is a prescriptive residential building meeting the prescriptive requirements of the 2006 International Energy Conservation Code.

The compliance margin of the proposed building is determined by comparing the proposed building TDV energy usage for regulated loads to the standard building TDV energy usage. This study targets that the proposed buildings use 15-30% less energy than the standard building's TDV energy usage before PV is added, consistent with CALGreen Tier 3 energy efficiency goals. Note that CBECC-Res allows a compliance credit when a minimum PV system size is installed (see Figure 3). TRC added these compliance credits after determining cost effective, efficiency-only packages.

Figure 3. PV Compliance Credit by Climate Zone

Climate Zone	Maximum PV Credit for Single Family	Maximum PV Credit for Multifamily
1	8.6%	4.5%
2	9.1%	5.1%
3	7.4%	3.3%
4	20.3%	11.1%
5	8.1%	2.7%
6	0.0%	0.0%
7	0.0%	0.0%
8	27.5%	9.2%
9	26.1%	11.1%
10	23.5%	10.1%
11	18.4%	8.8%
12	22.6%	9.4%
13	20.4%	9.2%
14	16.7%	8.2%
15	17.0%	7.7%
16	15.7%	8.4%

TDV assigns values to electricity and natural gas delivered for each hour in the year. TDV accounts for retail rates, greenhouse gas emissions, the demand profile from consumers, and several other factors to value electricity generation. Electricity TDV can vary widely on a given day. However, the TDV of gas has a generally consistent value for several months, with the fall and winter values typically higher than spring and summer. The TDV energy budget and compliance margin is a standard output for building permit applicants completing a performance calculation.

Because TDV combines electric and gas energy impacts, different energy efficiency measures can have different kWh and therms impacts while having the same TDV impact. The measure packages in Section 4.1 represent one possible way to achieve a higher compliance margin – these packages are not intended to represent a mandatory set of reach code measures.

TRC investigated potential energy efficiency measures to apply to the low-rise residential prototype in each climate zone. TRC utilized previous reach code studies, IOU program data, and proposed 2019 Codes and Standards Enhancement (CASE) studies to investigate reach code measures that would have the greatest impact on reducing the largest energy consuming end uses. TRC conducted market research to assess measure feasibility, costs, and potential energy impact. Measures were run as packages to capture interactive effects.

TRC estimated PV energy savings by sizing PV to offset annual electricity demand after applying efficiency packages.

2.2.2 Costs

TRC initially gathered costs for four regions within California to best represent localized costs (Figure 4). TRC anticipated that the main cause of cost variation among the regions would be due to labor rates. However, based on RS Means research and local quotes, the labor rates and material costs vary minimally statewide. Therefore, except where data indicated significant cost fluctuation between regions, average statewide costs were used in the analysis.

Figure 4. Climate Zones Grouped by Geographic Region

Region	Climate Zone
North Coastal	1-5
South Coastal	6-10
Central	11-13
Inland	14-16

TRC reviewed previous studies for relevant cost data, such as CASE studies, when available. TRC conducted cost research by accessing online retailers and interviews with contractors and distributors serving each region. Costs include first costs, maintenance, and replacement if the end of useful life is prior to the end of the measure life for a product. For replacements, an annual two percent (2%) inflation rate was assumed. Taxes and contractor markups were added as appropriate. Detailed costs are provided in *Appendix A – Cost Data*.

Costs for solar PV were estimated in coordination with the CEC and their consultant, Energy and Environmental Economics (E3), as described in Section 3.4.4.

2.3 Cost Effectiveness Methodology

TRC determined cost effectiveness by comparing the incremental costs of a measure including solar PV to the cost savings benefits, in a combined B/C ratio metric. The B/C Ratio is the present value of incremental utility costs savings divided by the present value of total incremental costs. When the B/C ratio is greater than 1.0, the added cost of the measure is offset by the discounted energy cost savings, and the measure is cost effective.

TRC assessed the cost savings benefits of 2016 reach code packages using two methods:

1. **On-Bill:** Customer cost effectiveness using utility rate schedules to value on-bill energy impacts, and
2. **TDV:** The CEC Life Cycle Cost (LCC) methodology using 2016 TDV of energy

Both methodologies require estimating and quantifying the value of the energy impact associated with energy efficiency measures over the life of the measures (30 years) as compared to the prescriptive Title 24 requirements.

TDV values are based on long-term discounted costs over 30 years. The CEC developed the 2016 TDV values for all climate zones used in this study. The TDV values do not account for net-metered PV generation, thus 2016 TDV is only used to analyze efficiency measure packages (excluding PV). TDV energy estimates are presented in terms of "TDV kBtus," which combine electricity and natural gas energy units.[3] The present value of the energy savings is calculated by multiplying the TDV savings of the building by a Net Present Value (NPV) factor of $0.17/TDV kBtu for residential measures with a 30-year life.

The customer cost effectiveness methodology captures the energy cost savings from energy efficiency measures and solar PV resulting from lower energy bills. TRC determined the Net Present Value (NPV) of the on-bill savings over a 30-year lifetime, including a three percent (3%) discount rate and a two percent (2%) energy cost inflation rate. On-Bill savings were estimated by calculating monthly electricity (kWh) and natural gas (therms) savings resulting from energy efficiency measures using current residential utility (IOU) rate schedules as shown in Figure 5. As per net energy metering (NEM) 2.0 program rules, non-bypassable charges (NBCs) are accounted for every billing interval and cannot be offset by PV energy generation credits. As a simplifying assumption, TRC applied an average NBC rate to each billing interval and aggregated them annually. Please see *Appendix B – Utility Rate Schedules* for further schedule details.

Figure 5. Investor-Owned Utility (IOU) Rate Schedules

CLIMATE ZONES	Utility	Commodity	Rate Schedule
1, 2, 3, 4, 5, 11, 12, 13, 16	Pacific Gas and Electric Company	Electric	E-TOU Option A
		Gas	G1
6, 8, 9, 14, 15	Southern California Edison	Electric	TOU-D-T
	Southern California Gas Company	Gas	GR
7, 10	San Diego Gas and Electric Company	Electric	DR-SES
		Gas	GR

[3] kBtus = thousands of British Thermal Units.

3. Measure Descriptions and Costs

This section provides a description, general modeling parameters, market overview, and summarized costs for energy efficiency measures. After initial investigation and analysis of several energy efficiency measures, TRC selected the measures listed below and the subsequent packages described in *Section 4.1* based on cost effectiveness and technical feasibility in the California low-rise residential new construction market. Single family costs presented here represent the average installation cost for the two prototypes: the 2,100 and 2,700 square foot.

- Home Energy Rating System (HERS) verification measures, as indicated for the applicable measures
- Envelope measures
  - Quality Insulation Installation (QII) (HERS)
  - Cool Roof
  - Improved Fenestration
  - Insulated Door
  - High-Performance Walls (HPW)
  - High-Performance Attics (HPA)
  - Reduced Infiltration (HERS)
- Domestic Hot Water (DHW) measures
  - Hot Water Piping Insulation of All Lines (HERS)
  - Compact Hot Water Distribution (HERS)
  - Drain Water Heat Recovery (DWHR)
- Heating, Ventilation, and Air Conditioning (HVAC) measures
  - Air Handling Unit (AHU) Reduced Fan Watt Draw (0.3 W/CFM) (HERS)
  - Verified Refrigerant Charge (HERS)
  - Verified Low-leakage Ducts entirely in Conditioned Space (HERS)
  - Heat or Energy Recovery Ventilation
- Solar Photovoltaics

3.1 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 total project verification price 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. The costs below reflect HERS verification costs when all of the indicated HERS measures are employed; therefore, a different combination of HERS measures may result in different individual measure costs.

3.1.1 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 Figure 6.

Figure 6. Single Family HERS Verification Costs Summary

Component	Single Family
On-site visit ($/visit) – mandatory measure	$100
Additional Measure verification ($/measure)	$84
On-site visit ($/visit) – individual measure trip	$202
Registry documentation ($/measure/visit)	$25

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, TRC identified that 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 to perform mandatory verifications, and additional verification costs for each non-mandatory measure. If a measure, such as QII, needs an additional trip where no other measure will be verified, a $202 fee is applied per trip. An additional trip is included for each measure to account for an initial model field verification, as required by the HERS testing procedures.[4] From discussions with HERS raters, common practice is to conduct a site visit to test one sample home in order for a builder to make any necessary adjustments before the rest of the homes are tested. Figure 7 provides a summary of the total costs per HERS Measure per single family home. The costs assume that one in five homes (two for QII) are tested, which reduces the cost per home.

Figure 7. Single Family Total HERS Measure Costs Summary

Single Family HERS Measure	Cost/Home
Duct Leakage (Mandatory; sampling 1-in-5)	$90
Verified Airflow/Fan Efficiency (Mandatory; sampling 1-in-5)	$90
Whole Building Mechanical Ventilation (Mandatory; sampling 1-in-5)	$90
Quality Insulation Installation (Sampling 1-in-2)	$444
Compact Hot Water Distribution (Sampling 1-in-5)	$83
Piping Insulation, All Hot Water Lines (Sampling 1-in-5)	$83
Verified Refrigerant Charge (Sampling 1-in-5)	$83
Total cost per single family home	**$964**

[4] CEC. (2015). 2016 Reference Appendices for the 2016 Building Energy Efficiency Standards.

3.1.2 Low-rise Multifamily

For multifamily buildings, HERS Rating companies either price by the number of site visits required or by the number of dwelling units. HERS raters use built in assumptions about the number of dwelling units to be verified (1-in-5 or 1-in-7) when estimating the cost per visit or per unit.

The values in Figure 8 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 a 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.

Figure 8. Low-rise Multifamily HERS Verification Costs Summary

Component		Multifamily
Method 1	On-site visit ($/visit)	$213
	Registry documentation ($/measure/visit)	$25
Method 2	Per unit verification, no QII ($/unit)	$175
	Per unit cost of QII ($/unit)	$50
	Registry documentation ($/unit)	$25

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, TRC developed three scenarios to estimate the costs for the low, middle, and highest case scenarios for the number of site visits required for each HERS measure. For Method 2, TRC priced the HERS verifications using the prototype building, including the cost for QII. To be conservative, TRC assumed that measures that require more than one site visit would be scheduled separately as additional visits. In practice, it is common and more economical for builders to schedule multiple verifications during a single visit. The final per measure costs in Figure 9 represent the average Method 1 and Method 2.

Figure 9. Low-rise Multifamily Total HERS Measure Costs Summary

Multifamily HERS Measure	Total Cost/Building
Duct Leakage (Mandatory)	$198
Verified Airflow/ Fan Efficiency (Mandatory)	$159
Whole Building Mechanical Ventilation (Mandatory)	$159
Quality Insulation Installation	$625
Compact Hot Water Distribution	$255
Piping Insulation, All Hot Water Lines	$255
Verified Refrigerant Charge	$223
Verified Low Leakage Ducts in Conditioned Space	$263
Total cost per multifamily building	**$2,138**

3.2 Envelope Measures

3.2.1 Quality Insulation Installation (QII) (HERS)

In 2016 Title 24, QII is a compliance credit for the performance path.[5] 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 Figure 10 are drawn from the findings of the 2016 Residential High-Performance Walls and QII CASE Report.[6,7] 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.

Figure 10. Residential QII Incremental Costs Summary

Component/Material	Base Case	Proposed Update	Additional Labor (hour)	Average Installation Labor[1]	HERS Verification	Total Cost
Single Family	Standard	Improved	2.1	$103	$427	**$530**
Low-rise Multifamily	Standard	Improved	9.7	$466	$764	**$1,230**

[1] Installation labor varies by climate region. Values in Figure represents average labor cost.

3.2.2 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 high-rise 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 this analysis, only steep-sloped roofs were included based on the prototypes.

To develop cost estimates, TRC conducted interviews with roofers and roof supply distributors throughout California. In addition to interviews, TRC reviewed product material costs from online retailers. 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 for steep-sloped roofs. Several interviewees mentioned 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.

Although the residential prototypes specify tile roofing, TRC included cost estimates for asphalt shingles to represent the mix of roofing products employed in the market; therefore, the costs are greater than zero

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

[6] California Utilities Statewide Codes and Standards Team. (September 2014) Residential High Performance Walls and QII Codes and Standards Enhancement Initiative. 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

[7] California Utilities Statewide Codes and Standards Team. (April 2017) Quality Insulation Installation Codes and Standards Enhancement Initiative.

because asphalt shingles can carry a cost premium for cool roof products. Cool roof ASR values up to 0.29 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 an increased cost over their non-cool roof equivalents (i.e. consistent in other qualities such as durability), depending on the product. The incremental cost of non-white asphalt shingles meeting an ASR = 0.20 is minimal to zero, as compared to shingles meeting an ASR = 0.10. 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. However, achieving an ASR of 0.32 is significantly more expensive for asphalt shingles because white shingles cannot achieve this performance, and product selection meeting this value is currently limited. The incremental cost of each proposed ASR value is an average of asphalt shingles, both white and non-white, and tile roofing.

Figure 11 provides the incremental cost to go from the base case (ASR=0.10 or ASR=0.20) to a cool roof requirement (ASR = 0.28 or ASR = 0.32) for steep-sloped roofs. TRC only applied the cool roof measure to the prototypes in climate zones where they achieve energy savings; therefore, not all climate zones are included, some are proposed to 0.28, and others are proposed to 0.32.

Figure 11. Low-Rise Residential Steep-Sloped Cool Roof Incremental Costs Summary

Building Type	Base Case	Proposed Update	Average Incremental Costs/Building[1]
Single Family	ASR=0.10 or 0.20, TE=0.75	ASR=0.20, TE=0.85	$0
	ASR=0.10 or 0.20, TE=0.75	ASR=0.28, TE=0.85	$215
	ASR=0.10 or 0.20, TE=0.75	ASR=0.32, TE=0.85	$1,308
Low-rise Multifamily	ASR=0.10 or 0.20, TE=0.75	ASR=0.20, TE=0.85	$0
	ASR=0.10 or 0.20, TE=0.75	ASR=0.28, TE=0.85	$421
	ASR=0.10 or 0.20, TE=0.75	ASR=0.32, TE=0.85	$2,564

[1] Costs vary by climate region. Values in Figure represents average cost. The analysis found no cost difference between ASR 0.10 and 0.20; therefore, costs are the same for both base case scenarios.

3.2.3 Improved Fenestration

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.

This measure reduces the U-factor from the prescriptive value of 0.32 to 0.30 and, in climate zones with SHGC requirements, reduces the SHGC from the prescriptive value of 0.25 to 0.23. In climate zones without an SHGC requirement, the default SHGC is assumed to be 0.50. The cost of $0.20/ft^2$ of window is based on the 2019 High Performance Windows and Doors CASE report (see Figure 12).[8]

[8] California Utilities Statewide Codes and Standards Team. (April 2017) Residential High Performance Windows and Doors Codes and Standards Enhancement Initiative.

Figure 12. Improved Glazing Incremental Costs Summary

Component	Climate Zones	Base Case	Proposed Update	Incremental Costs/Building	
				Single Family	Low-Rise Multifamily
Window	2, 4, 6-16	U-0.32/SHGC-0.25	U-0.30/SHGC-0.23	$94	$204
	1, 3 & 5	U-0.32/SHGC-0.50	U-0.30/SHGC-0.50	$94[1]	$204[1]

[1] TRC did not find product prices for 0.50 SHGC windows, and conservatively used the cost for an SHGC = 0.23, assuming these would be more expensive.

3.2.4 Insulated Door

This measure reduces the U-factor of the door from 0.50 to 0.20 in all climate zones except CZ6.[9] This proposed update is the same for both single family and low-rise multifamily building types. The 2019 High Performance Windows and Doors CASE Study suggests an incremental cost of $1.30 per unit resulting from material cost of $1.00/ft^2 of door with a 30% markup for overhead and profit (Figure 13). [10]

Figure 13. Improved Doors Incremental Costs Summary

Component	Base Case	Proposed Update	Incremental Costs/Building	
			Single Family	Low-rise Multifamily
Door	U-0.50	U-0.20	$26	$208

3.2.5 High Performance Walls (HPW)

High performance walls (HPW) increase the performance of the exterior above-grade walls, reducing the amount of heat transfer and reducing HVAC loads. This measure requires a lower wall U-factor, which can be achieved through various assemblies; this analysis uses improved insulation within 2x6 studs. This measure reduces the required U-factor in each climate zone beyond the 2016 T24 prescriptive requirements, except in climate zones CZ6 and CZ7 where a reduced U-factor was not found to cost effective at this time. U-0.051 is proposed in CZ6 for the LRMF prototype. Climate zones with prescriptive U-factor wall requirements of 0.051 are upgraded to 0.043, consistent with the 2019 High Performance Walls CASE Report value. [11]

Costs for this upgrade were derived from the 2019 CASE Report, which assumes U-0.051 is achieved using R-21 cavity insulation and R-4 exterior insulation, and U-0.043 is achieved using R-21 cavity insulation and an R-7.5 exterior insulation. The 2016 Title 24 CASE Report used R-19 and R-5 exterior insulation to estimate costs, but the 2019 Title 24 draft CASE Report suggests that installing R-21 and R-4 exterior insulation is a more common practice. The incremental cost includes upgrading to R-7.5 insulation, increasing weep screed and window flashing depth, and installing the continuous exterior insulation by hand rather than the traditional nail gun.

[9] This was done to keep consistent with TRC's previously developed study for Santa Monica's reach code.

[10] California Utilities Statewide Codes and Standards Team. (April 2017) Residential High Performance Windows and Doors Codes and Standards Enhancement Initiative.

[11] California Utilities Statewide Codes and Standards Team. (March 2017) Residential High Performance Walls Codes and Standards Enhancement Initiative.

These additional components are required when exterior insulation exceeds 1”. Costs to upgrade from 0.065 to 0.051 in CZ6 are derived from the 2016 Title 24 CASE Report and the 2019 Title 24 CASE Report (Figure 14).

Figure 14. High Performance Walls Incremental Costs Summary

Climate Zone	Base Case	Proposed Update	Incremental Costs/Building	
			Single Family	Low-rise Multifamily
1-5 & 9-16	U-0.051	U-0.043	$913	$2,299
6	U-0.065	U-0.051	-	$1,615

3.2.6 High Performance Attics (HPA)

The high performance attics (HPA) measure assumes insulation is installed at the ceiling and at the roof deck, either above or below the deck. In most climate zones, the prescriptive standard assembly for 2016 Title 24 is an HPA consisting of R-38 insulation at the ceiling and R-13 insulation below the roof deck. TRC evaluated combinations of ceiling and roof deck insulation to achieve a HPA based on current 2016 Title 24 prescriptive requirements for each climate zone. This measure requires adding below roof deck insulation of R19. There are several other options for above or below deck insulation that meet the prescriptive requirement, as noted in the 2016 Title 24 High Performance Attics CASE Report.[12]

Measure costs include installing R-13 below deck insulation in CZ 1 and upgrading from R-13 to R-19 below deck insulation in CZs 8-16. TRC used cost data from the 2016 CASE Report, the 2019 Draft CASE Report, and online retailers.[13] Deck insulation costs are based on batt insulation with cabling to hold the insulation in place, as referenced in the 2019 Draft CASE Report. Figure 15 provides total incremental costs for each of the proposed measures.

Figure 15. High Performance Attics Measure Costs Summary

Climate Zone	Base Case	Proposed Update	Incremental Costs/Building	
			Single Family	Low-rise Multifamily
1	R-38	R-38 + R-13	$1,387	$2,784
8-16[1]	R-38 + R-13	R-38 + R-19	$460	$1,462

[1] R-19 is proposed only for single family in climate zone 8.

3.2.7 Reduced Infiltration ACH50 (HERS)

As described in Section 3.4.3, verified low leakage ducts in conditioned space requires that a HERS rater test envelope leakage (i.e. a blower door test) on low-rise multifamily dwelling units, and that the total duct leakage

[12] California Utilities Statewide Codes and Standards Team. (July 2014) Residential High Performance Walls Codes and Standards Enhancement Initiative. Available at: http://www.energy.ca.gov/title24/2016standards/prerulemaking/documents/2014-07-21_workshop/case_reports/2016_Title_24_Draft_CASE_Report-Residential_Ducts_in_Conditioned_Space-High_Performance_Attics.pdf

[13] California Utilities Statewide Codes and Standards Team. (April 2017) Residential High Performance Attics Codes and Standards Enhancement Initiative.

to the outside does not exceed 25 cfm.[14] QII, described in Section 3.2.1, reduces building infiltration through proper sealing and helps a project meet the 25 cfm requirement for duct leakage to the outside. Thus, for the analysis, TRC assumed QII and verified low leakage ducts in conditioned space can be implemented in order to achieve building infiltration reduction in low-rise multifamily buildings.

Based on discussions with HERS raters and HVAC contractors, TRC assumes that the low-rise multifamily building would reduce infiltration down to five air changes per hour at 50 Pascals (5 ACH50), 30% lower than the 7 ACH50 software default, as a result of implementing QII and HERS verified low leakage ducts in conditioned space.[15] CBECC-Res simulation software does not allow this measure to be implemented in low-rise multifamily buildings (because there is no CEC-defined verification test method), hence the associated savings are evaluated by extrapolating the savings from single family simulations.

For single family homes, TRC assumes that only QII is applied to help reduce infiltration rates (verified low-leakage ducts in conditioned space does not apply to single family homes because the ducts are assumed to be in a vented attic). The baseline infiltration of single family homes is 5 ACH50, which is proposed to be reduced to 3 ACH50. As per the PG&E CALGreen Cost Effectiveness Study, the incremental cost for reducing infiltration by 2 ACH50 (i.e., from 5 ACH50 to 3 ACH50) is $0.115 per square foot of conditioned floor area for single family homes.[16]

For low-rise multifamily buildings, TRC also estimates an additional cost of $0.115/ft^2 based on data available from the National Renewable Energy Laboratory (NREL) residential cost database.[17] See Figure 16 for full costs per building. Verification costs associated with QII and verified low leakage ducts are added separately.

Figure 16. Infiltration Incremental Costs Summary

Base Case	Proposed Update	Incremental Costs/Building	
		Single Family	Low-rise Multifamily
5 ACH50	3 ACH50	$276	-
7 ACH50	5 ACH50	-	$800

3.3 DHW Measures

3.3.1 Hot Water Piping Insulation of All Lines (HERS)

Part 6 of the 2016 Title 24 Standards include mandatory pipe insulation requirements that cover all hot water pipes ¾" and larger, as well as the hot water lines running to the kitchen use point. To receive compliance 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. This measure is applied to all climate zones in single family and multifamily building types.

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

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

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

[17] National Renewable Energy Laboratory (NREL) National Residential Efficiency Measure Database v3.0.0.

Beginning on January 1, 2017 the 2016 California Plumbing Code requires pipe insulation levels that are similar to that required if taking the non-HERS pipe insulation credit. Thus, the non-HERS credit is obsolete under the 2016 energy code and all pipes must be insulated. However, the HERS-Verified Pipe Insulation Credit will remain. While CBECC-Res algorithms have not yet been updated to reflect this change, 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.[18]

Due to the 2016 California Plumbing Code requiring that all DHW pipes be insulated, the measure cost only consists of the additional HERS verification required to receive performance credit under Title 24. The HERS verification cost in Figure 17 is derived using the HERS verification methods described above.

Figure 17. Residential Pipe Insulation Incremental Costs Summary

Component/ Material	Base Case	Proposed Update	Single Family	Low-rise Multifamily
HERS Verification	None	Verified	$175	$131

3.3.2 Compact Hot Water 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 under the 2016 as a compact distribution compliance option are outlined in Residential Reference Appendices RA3.6.5.

Feedback from HERS raters indicates that code vaguely defines compact distribution and that it is not yet widely adopted in single family new construction. Compact distribution in single family homes can be done in a variety of ways, but this study assumes that the water heater must be moved to an interior wall of the garage, in accordance with the 2019 Draft Compact Hot Water Distribution CASE Study.[19] The low-rise multifamily prototype, which has individual water heaters and dwelling units that are typically smaller than a single family home, does not require significant changes to water heater location, floorplan, or piping design to achieve compact distribution.

TRC derived material and labor impacts from the 2019 CASE Study, and related costs from RS Means and online retailers.

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

[19] California Utilities Statewide Codes and Standards Team. (April 2017) Residential Compact Hot Water Distribution Codes and Standards Enhancement Initiative.

Figure 18. Compact Distribution Incremental Costs Summary

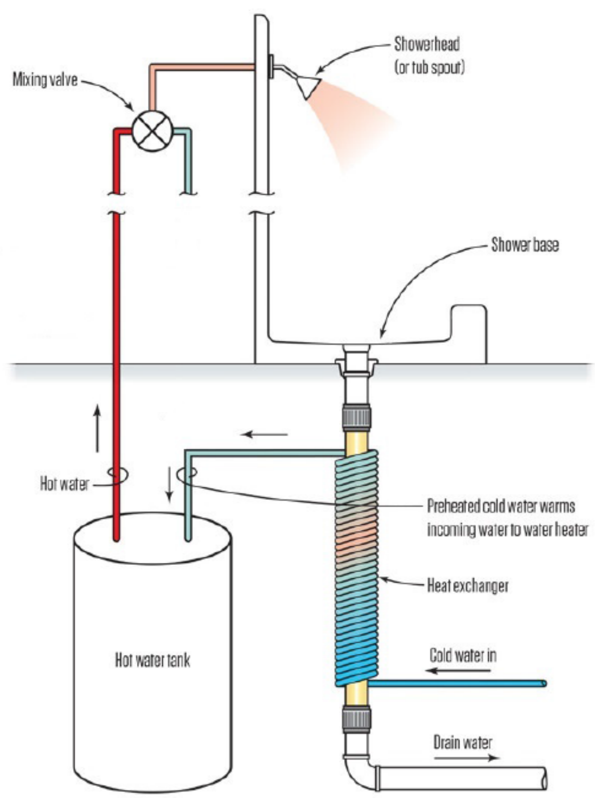
Base Case	Proposed Update	Single Family	Low-rise Multifamily
Standard design	None	$498	$0
No Verification	HERS Verified	$175	$131
Total Costs		**$673**	**$131**

3.3.3 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 shower drain line to pre-heat cold water supplied to the cold water side of a water heater or fixtures. There are multiple configurations possible, and Figure 19 shows DWHR in an equal flow configuration where all makeup flow is directed to the water heater. In an equal flow configuration, makeup flow is piped to both the water heater and the shower.

To avoid overlapping interactive effects with other DHW measures, TRC assumed an unequal flow configuration where preheated water is directed only to the water heater. This configuration reduces the energy necessary to heat cold water entering the water heater, and should not overlap with the pipe insulation and compact DHW measures, which reduce pipe distribution losses.

Figure 19. Drain Water Heat Recovery in Unequal Flow Configuration (Journal of Light Construction, September 2016)



DWHR is currently most commonly installed in a vertical configuration, so only the two-story single-family prototype will have the vertical space necessary to locate the system below showers. CBECC-Res cannot currently model the benefits of Drain Water Heat Recovery, so TRC used energy performance data and cost data from the 2019 Title 24 Draft CASE Study to estimate the maximum potential energy savings in the two-story 2,700 ft^2 single family prototype assuming an unequal flow to the water heater configuration.[20] Energy savings were translated from 2019 TDV to 2016 TDV, resulting in savings between 15-17% of the total DHW TDV energy (1%-10% of the total building TDV energy) depending on the climate zone.

The additional cost to implement DWHR, as estimated by the 2019 CASE study, is $731 for a two-story single family building, assuming a single device can be connected to all second floor showers. This measure was not applied to the low-rise multifamily prototype because each dwelling unit has an individual water heater without adequate vertical piping to apply the DWHR device; DWHR are more cost effective in multifamily buildings with a central water heater.

3.4 HVAC Measures

3.4.1 AHU Reduced Fan Watt Draw (0.3 W/CFM)

This measure upgrades the fan in the furnace or air handler from one using a 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. Costs are based on the PG&E CALGreen Cost Effectiveness Study (Figure 20).[21] Fan watt draw is a mandatory HERS measure; therefore the cost does not include HERS verification fees.

Figure 20. 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

3.4.2 Verified Refrigerant Charge

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 Figure 21, assume HERS sampling of HVAC units for multifamily buildings.[22]

[20] California Utilities Statewide Codes and Standards Team. (April 2017) Residential Drain Water Heat Recovery Codes and Standards Enhancement Initiative.

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

[22] 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.

Figure 21. Refrigerant Charge Verification Incremental Costs Summary

Component	Base Case	Proposed Update	Single Family	Low-rise Multifamily
HERS Verification	None	Verified	$175	$131

3.4.3 Verified Low-leakage Ducts Entirely in Conditioned Space

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

- Duct leakage test
- Envelope leakage test (i.e., blower door test)
- Verify low leakage air handling unit

This measure is only implemented in the low-rise multifamily prototype. Prescriptive requirements are for ducts located 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 verification of low leakage ducts entirely in conditioned space 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. Based on discussions with HERS raters, the estimated HERS verification cost for this measure would be equal to that of duct leakage testing. To be conservative, TRC assumes additional trips and time required beyond the duct leakage testing to estimate the cost for this measure. Thus, there is a $527 cost for low leakage ducts in conditioned space for low-rise multifamily buildings, about double that of only duct leakage testing (Figure 22).

Figure 22. Low Leakage Ducts in Condition Space Incremental Costs Summary

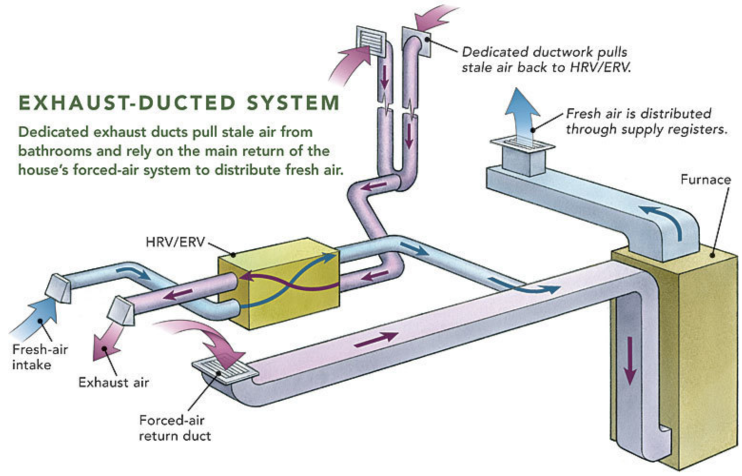
Component	Base Case	Proposed Update	Single Family	Low-rise Multifamily
HERS Verification	None	Verified	n/a	$527

3.4.4 Heat or Energy Recovery Ventilation

This measure includes installing heat or energy recovery ventilation (HRV/ERV) in single family homes to improve their energy efficiency and indoor air quality. It introduces a 'balanced' mechanical ventilation system, which exhausts air from bathrooms and supplies outdoor air in equal quantities using the existing ductwork (see Figure 23). TRC used the Home Ventilating Institute (HVI) database to identify HRV systems with airflow rates that comply with ASHRAE 62.2 ventilation standards.[23] The average Sensible Recovery Efficiency (SRE) of the selected products is 67%.

[23] https://www.hvi.org/proddirectory/CPD_Reports/section_3/index.cfm

Figure 23. Balanced HRV/ERV System Connected via Existing HVAC System



Source: http://www.finehomebuilding.com/2014/11/05/ducting-hrvs-and-ervs

Costs for this measure include the ventilator, installation of the ventilator, ducting, and wiring, and MERV6 filter replacements once per year. Costs in Figure 24 were derived from online retailers and RSMeans.

Figure 24. Heat/Energy Recovery Ventilator Incremental Cost Summary

Cost Component	Cost per Single Family Home
HRV/ERV fan	$700
Installation, including ducting	$415
Filter replacements	$186
Total Cost	**$1,301**

3.5 Solar Photovoltaics

To meet the CEC's current proposed goal for 2019 Title 24 at the time of this analysis, the PV system must be sized to offset the building's annual electricity consumption (after accounting for energy efficiency measures).[24] TRC estimated solar PV costs in coordination with the CEC and their consultant, Energy and Environmental Economics (E3). E3's PV cost estimates in 2017 dollars include two inverter replacements over a 30 year lifetime, costing $0.45/W. PV systems installed in California are eligible for both the NSHP rebate and the federal solar Investment Tax Credit (ITC), which rebates 30% of the initial cost of the system. TRC determined the median NSHP incentive of $0.17/W by reviewing recent program data for systems smaller than 10 kW. Total costs in

[24] Based on coordination with the CEC, TRC sized solar photovoltaic (PV) generation to offset the annual electricity kWh demanded by the buildings after maximizing efficiency, which results in an EDR > 0. This is in alignment with CEC's 2019 Title 24 goal.

Figure 25 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.

Figure 25. Solar Photovoltaics Incremental Costs Summary

Cost Component	2017 $/Watt
PV Median Cost, including inverter replacements	$3.32
NSHP Incentive	-$0.17
30% Federal ITC, excluding inverter replacements	-$0.81
Net Cost	**$2.34**

4. RESULTS

The cost effectiveness and greenhouse gas savings results are presented in this section for the energy efficiency and Efficiency + PV packages in each climate zone. Figure 26 and Figure 27 list the efficiency measures implemented for the single family and low-rise multifamily prototypes, respectively. These measures have been selected because they are market feasible and optimize cost effectiveness while achieving high compliance margin targets. Single family 2100 ft^2 and 2700 ft^2 prototypes are comprised of the exact same measure package, with the exception of drain water heat recovery, which is only applied to the 2700 ft^2 two-story prototype.

Figure 26: Efficiency Measure Summary for Single Family Prototype (2100 & 2700 ft²)

Measure			Climate Zone															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Envelope	*Quality Insulation Installation (HERS)*		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Cool Roof	*(ASR-0.28 / TE-0.85)*								x	x	x						
		(ASR-0.32 / TE-0.85)											x	x	x	x	x	
	Improved Fenestration	*(U-0.30 / SHGC-0.23)*		x		x		x		x	x	x	x	x	x	x	x	x
		(U-0.30 / SHGC-0.50)	x		x		x											
	Insulated Door (U-0.20)		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	High Performance Walls (U-0.043)		x	x							x	x	x	x	x	x	x	x
	High Performance Attics (R13 below deck)		x															
	High Performance Attics (R19 below deck)									x	x	x	x	x	x	x	x	x
	Reduced Infiltration (3 ACH50)		x	x		x				x	x	x	x	x	x	x	x	x
DHW	*Hot Water Piping Insulation, All Lines (HERS)*		x	x	x	x	x			x	x	x	x	x	x	x	x	x
	Compact Hot Water Distribution (HERS)		x								x	x	x	x	x	x	x	x
	Drain Water Heat Recovery (2700 ft² only)		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
HVAC	*AHU Reduced Fan Watt Draw (0.3 W/CFM)*		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Verified Refrigerant Charge (HERS)		x		x	x	x		x									x
	Heat / Energy Recovery Ventilation		x	x	x	x	x					x	x	x	x	x	x	x

Figure 27: Efficiency Measure Summary for Low-rise Multifamily Prototype

Measure			Climate Zone															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Envelope	*Quality Insulation Installation (HERS)*		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Cool Roof	*(ASR-0.20 / TE-0.85)*					x											
		(ASR-0.28 / TE-0.85)						x	x									
		(ASR-0.32 / TE-0.85)		x		x				x	x	x	x	x	x	x	x	x
	Improved Fenestration	*(U-0.30 / SHGC-0.23)*		x		x		x		x	x	x	x	x	x	x	x	x
		(U-0.30 / SHGC-0.50)	x		x		x											
	Insulated Door (U-0.20)		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	High Performance Walls (HPW)	*(U-0.051)*						x										
		(U-0.043)	x	x		x				x	x	x	x	x	x	x	x	x
	High Performance Attics (HPA)	*R13 below deck*	x															
		R19 below deck									x	x	x	x	x	x	x	x
	Reduced Infiltration (5 ACH50)		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
DHW	*Hot Water Piping Insulation, All Lines (HERS)*		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Compact Hot Water Distribution (HERS)		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
HVAC	*AHU Reduced Fan Watt Draw (0.3 W/CFM)*		x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
	Verified Refrigerant Charge (HERS)		x		x	x	x	x	x									x
	Verified Low-Leakage Ducts Entirely in Conditioned Space (HERS)		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

4.1 Cost Effectiveness

TRC determined cost effectiveness by comparing the incremental cost of each measure package (Figure 26 and Figure 27) to the NPV of energy cost savings over the 30-year period. Results include measure compliance margin, present value of energy savings, costs, and B/C ratio.

TRC developed cost effectiveness for two scenarios:

- **Energy Efficiency Only:** The efficiency package energy savings benefits are measured in terms of TDV, in accordance with CEC Life Cycle Cost methodology typically used in CASE studies. The compliance margin achieved in these packages reflects only energy efficiency packages, and no solar PV or PV compliance credit.
- **Energy Efficiency + PV (EE + PV) Package:** The EE + PV package adds enough solar PV to the energy efficiency package to offset annual kWh load. Energy savings benefits are measured in terms of on-bill savings in accordance with CEC cost effectiveness analysis for solar PV.[25]

When the B/C ratio is greater than 1.0, the added cost of the measure is offset by the discounted energy cost savings and the measure is cost effective. See Section 2.3 for further detail.

Cost-effectiveness results for the single family and multifamily prototypes are shown in Figure 28 and Figure 29, respectively:

- Column A shows the California climate zone (CZ)
- Column B shows the CALGreen Tier 3 definition targets
- Column C shows the compliance margin achieved through only the Efficiency-Only packages
- Columns D and E show the energy savings estimated with the Efficiency-Only packages
- Column F shows the TDV savings of the Efficiency-Only packages
- Column G shows the cost of the Efficiency-Only packages
- Column H is the B/C Ratio of each package (Column F divided by Column G).
- Column I shows the PV size necessary to offset annual kWh loads.
- Column J shows the 2016 EDR found to be cost effective with the efficiency package and PV array
- Column K shows the compliance margin achievable when including the PV compliance credit (refer to Figure 3 for more detail)
- Columns L and M show the energy savings estimated with the EE + PV packages.
- Column N shows the on-bill savings of the EE + PV packages
- Column O shows the cost of the EE + PV packages
- Column P is the B/C Ratio of each package (Column N divided by Column O).

[25] During the development of this study, CEC was in the process of developing TDV values for excess PV generation; TDV for the EE + PV packages are not currently included.

Single family results are as follows:

- Cost effective reach code packages were found in all climate zones except efficiency-only in CZ7. All EE + PV packages are cost effective using the on-bill cost effectiveness methodology.
- CALGreen Tier 3 compliance targets are achieved in all CZs when including the PV compliance credit (column K). When excluding the PV compliance credit, CZs 4 and 8 do not achieve the CALGreen Tier 3 compliance targets.

Low-rise multifamily results are as follows:

- Cost effective packages were found in all climate zones except efficiency-only in CZ7. All EE + PV packages are cost effective using the on-bill cost effectiveness methodology.
- CALGreen Tier 3 compliance targets are achieved in all CZs except CZs 1, 2, 5, 7, and 8 when including the PV compliance credit (column K). When excluding the PV compliance credit, only CZs 6 achieves the CALGreen Tier 3 compliance target.

Figure 28. Cost Effectiveness Results for Single Family Prototype (Average of 2100 & 2700 ft^2)

CZ		ENERGY EFFICIENCY ONLY PACKAGE (TDV)						EE + PV PACKAGE (ON-BILL)							
	CALGreen Tier 3 Target	Comp-liance Margin	Annual kWh savings	Annual Therm savings	Present Value of Savings (TDV)	Present Value of Costs	B/C Ratio	PV Size (kW)	2016 Energy Design Rating	Compliance Margin with PV Compliance Credit	Annual kWh savings	Annual Therm savings	Present Value of Savings (On-Bill)	Present Value of Costs	B/C Ratio
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	**30%**	40%	341	278	$9,882	$5,807	1.7	3.6	18	49%	4,683	278	$45,481	$14,326	3.2
2	**30%**	31%	234	148	$6,066	$3,755	1.6	3.1	18	40%	4,661	148	$37,896	$11,093	3.4
3	**30%**	31%	147	120	$4,714	$2,705	1.7	3.0	13	39%	4,573	118	$35,181	$9,915	3.5
4	**30%**	28%	180	109	$4,673	$2,925	1.6	3.0	16	48%	4,650	109	$35,729	$10,053	3.6
5	**30%**	35%	140	127	$4,983	$3,169	1.6	2.8	11	43%	4,592	127	$35,226	$9,910	3.6
6	**15%**	16%	63	15	$1,279	$1,171	1.1	2.6	16	16%	3,461	15	$16,192	$7,305	2.2
7	**15%**	16%	21	11	$777	$1,680	0.5	2.5	13	16%	3,434	11	$20,600	$7,567	2.7
8	**30%**	28%	137	13	$2,344	$2,065	1.1	2.7	13	56%	3,668	13	$17,289	$8,374	2.1
9	**30%**	31%	259	24	$4,230	$3,560	1.2	2.7	15	57%	3,958	24	$18,850	$9,939	1.9
10	**30%**	34%	353	80	$6,492	$4,860	1.3	3.2	13	57%	4,842	80	$33,373	$12,470	2.7
11	**30%**	34%	799	139	$11,694	$5,789	2.0	3.7	18	53%	6,425	139	$51,718	$14,624	3.5
12	**30%**	36%	389	135	$8,728	$5,789	1.5	3.2	17	59%	5,086	135	$40,260	$13,443	3.0
13	**30%**	34%	837	124	$11,598	$5,789	2.0	3.9	18	54%	6,642	124	$52,376	$15,080	3.5
14	**30%**	34%	759	138	$11,106	$6,552	1.7	3.3	19	51%	5,689	138	$32,751	$14,312	2.3
15	**30%**	31%	1,872	28	$14,252	$6,552	2.2	5.1	15	48%	9,586	28	$51,947	$18,534	2.8
16	**30%**	31%	420	236	$9,517	$5,231	1.8	2.5	23	47%	4,904	236	$45,321	$11,142	4.1

Figure 29. Cost Effectiveness Results for Low-rise Multifamily Prototype

CZ		ENERGY EFFICIENCY ONLY PACKAGE (TDV)						EE + PV PACKAGE (ON-BILL)							
	CALGreen Tier 3 Target	Comp-liance Margin	Annual kWh savings	Annual Therm savings	Present Value of Savings (TDV)	Present Value of Costs	B/C Ratio	PV Size (kW)	2016 Energy Design Rating	Compliance Margin with PV Compliance Credit	Annual kWh savings	Annual Therm savings	Present Value of Savings (On-Bill)	Present Value of Costs	B/C Ratio
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	30%	21.3%	262	234	$9,068	$8,449	1.1	15.3	15	26%	20,676	234	$128,705	$44,267	2.9
2	30%	21.0%	483	119	$9,311	$8,406	1.1	13.2	16	26%	21,192	119	$127,503	$39,498	3.2
3	15%	12.6%	54	86	$3,875	$3,366	1.2	13.0	13	16%	20,580	86	$120,910	$33,921	3.6
4	30%	21.2%	479	95	$8,618	$8,406	1.0	12.9	11	32%	21,323	95	$127,460	$38,820	3.3
5	15%	11.0%	-24	79	$3,224	$2,534	1.3	12.3	12	14%	20,587	79	$120,484	$31,334	3.8
6	15%	16.9%	306	45	$5,319	$5,076	1.0	13.2	14	17%	21,169	45	$110,604	$36,028	3.1
7	15%	11.1%	127	16	$3,109	$3,257	0.95	12.6	16	11%	20,822	16	$101,450	$32,934	3.1
8	30%	19.1%	659	28	$7,816	$7,069	1.1	13.9	15	28%	22,626	28	$118,344	$39,612	3.0
9	30%	23.4%	1007	43	$12,528	$8,531	1.5	13.8	16	35%	23,604	43	$123,512	$40,957	3.0
10	30%	21.9%	1076	52	$11,848	$8,531	1.4	14.2	15	32%	24,231	52	$126,000	$41,748	3.0
11	30%	24.9%	1889	131	$21,033	$8,827	2.4	15.6	18	34%	26,705	131	$173,607	$45,417	3.8
12	30%	24.2%	1031	129	$15,751	$8,827	1.8	14.2	19	34%	23,244	129	$144,832	$42,071	3.4
13	30%	25.2%	2053	114	$21,629	$8,827	2.5	16.3	18	34%	27,298	114	$177,170	$47,171	3.8
14	30%	24.5%	1763	131	$19,650	$8,827	2.2	13.7	20	33%	26,385	131	$142,912	$40,949	3.5
15	30%	25.8%	4613	12	$31,532	$8,827	3.6	19.7	18	33%	37,580	12	$203,040	$54,984	3.7
16	30%	23.1%	912	270	$15,742	$8,827	1.8	12.5	23	31%	22,067	270	$141,531	$38,095	3.7

4.2 Greenhouse Gas Savings

New construction low-rise residential buildings complying with the reach code will reduce energy consumption and thereby reduce greenhouse gas (GHG) emissions. GHG reduction estimates are based on the proposed Efficiency + PV packages, however, compliance with the reach code may be achieved through a variety of measure packages. Each measure package will have varying electric and natural gas usages, and therefore varying GHG savings.

TRC multiplied saved energy by a factor of 0.65 lbs of CO_2 equivalent (CO_2e) per kWh, and 11.7 lbs of CO_2e per therm to estimate GHG savings.[26] Percent GHG savings are calculated by comparing GHG emission savings to the emissions a prescriptive building. Jurisdictions adopting a reach code can use Figure 30 and Figure 31 below to approximate reductions of GHG emissions in typical single family and low-rise multifamily residential buildings, respectively.

Figure 30. Estimated GHG Savings per Single Family Building

CZ	kWh Savings / Bldg	Therms Savings / Bldg	Lbs CO_2e Avoided / Bldg from Electricity	Lbs CO_2e Avoided/ from Natural Gas	GHG Savings %
1	4,683	278	3,044	3,252	54%
2	4,661	148	3,029	1,726	50%
3	4,573	118	2,973	1,375	55%
4	4,650	109	3,023	1,281	52%
5	4,592	127	2,985	1,488	58%
6	3,461	15	2,249	171	44%
7	3,434	11	2,232	134	49%
8	3,668	13	2,384	158	49%
9	3,958	24	2,573	281	51%
10	4,842	80	3,147	932	58%
11	6,425	139	4,176	1,624	59%
12	5,086	135	3,306	1,582	53%
13	6,642	124	4,317	1,455	60%
14	5,689	138	3,698	1,613	54%
15	9,586	28	6,231	327	74%
16	4,904	236	3,187	2,764	45%

[26] 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.

Figure 31. Estimated GHG Savings for Low-rise Multifamily building

CZ	kWh Savings / Bldg	Therms Savings / Bldg	Lbs CO_2e Avoided / Bldg from Electricity	Lbs CO_2e Avoided/ from Natural Gas	GHG Savings %
1	20,676	234	13,439	2,737	53%
2	21,192	119	13,775	1,387	53%
3	20,580	86	13,377	1,004	56%
4	21,323	95	13,860	1,115	56%
5	20,587	79	13,382	919	56%
6	21,169	45	13,760	530	59%
7	20,822	16	13,534	192	59%
8	22,626	28	14,707	332	61%
9	23,604	43	15,342	499	62%
10	24,231	52	15,750	609	63%
11	26,705	131	17,358	1,536	61%
12	23,244	129	15,108	1,505	57%
13	27,298	114	17,744	1,334	62%
14	26,385	131	17,150	1,532	61%
15	37,580	12	24,427	140	76%
16	22,067	270	14,344	3,155	47%

4.3 Reach Code Recommendations

TRC recommends that California jurisdictions adopt reach codes meeting the compliance margin and EDR requirements in Figure 32:

- If a jurisdiction desires an efficiency-only reach code, the efficiency-only compliance margin may be used in the ordinance.
- If a jurisdiction desires an Efficiency + PV reach code, the Efficiency + PV compliance margin and 2016 EDR may be used in the ordinance. New construction residential buildings would need to achieve the recommended compliance margins and install solar PV to achieve the 2016 EDR target.[27]

Recommended reach code values are more lenient than the levels found to be cost effective – compliance margins are rounded down, and EDR values are rounded up. To create more lenient reach codes, jurisdictions can draft ordinances further reducing compliance margins or increasing EDR requirements beyond those recommended for more lenient reach codes. There is no energy efficiency target compliance margin target for low rise residential buildings in CZ7 because TRC did not find a cost effective package of efficiency-only measures. However, because the EE + PV packages are cost effective using the on-bill methodology, TRC has provided the recommendations for reach code compliance margins and EDR ratings.

[27] EDR Targets are highly dependent on TDV. 2016 TDVs are significantly different than 2019 TDVs, which will result in different 2019 EDR Targets. Nonetheless, the solar PV size required to achieve comparable EDR targets is not expected to vary by more than 0.5 kW array size.

Figure 32. New Construction Residential Reach Code Recommendations for 2016 Title 24

CZ	Single Family			Low-rise Multifamily		
	Compliance Margin Efficiency-Only	Compliance Margin Efficiency + PV	2016 Energy Design Rating Efficiency + PV	Compliance Margin Efficiency-Only	Compliance Margin Efficiency + PV	2016 Energy Design Rating Efficiency + PV
1	40%	45%	20	20%	25%	15
2	30%	35%	20	20%	25%	20
3	30%	35%	15	10%	15%	15
4	25%	45%	20	20%	30%	15
5	30%	40%	15	10%	10%	15
6	15%	15%	20	15%	15%	15
7	None	15%	15	None	10%	20
8	25%	55%	15	15%	25%	20
9	30%	55%	15	20%	30%	20
10	30%	55%	15	20%	30%	15
11	30%	50%	20	20%	30%	20
12	35%	55%	20	20%	30%	20
13	30%	50%	20	25%	30%	20
14	30%	50%	20	20%	30%	20
15	30%	45%	15	25%	30%	20
16	30%	45%	25	20%	30%	25

TRC recommends that individual projects consider battery storage technology alongside PV installations to achieve reach code requirements while reducing hourly exports to the electric grid.

4.4 Compliance

The majority of new construction T24 compliance submittals use building simulation software. CBECC-Res is a CEC approved software tool used for 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. EDRs are also standard outputs of the 2016 compliant software. For nearly all the measures described in this report, local 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, and thus not captured adequately in the compliance margin and EDR, 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.[28,29]

- **Drain Water Heat Recovery (DWHR):** The currently available version of CBECC-Res (v3.0) cannot model the benefits of a DWHR device. A DWHR compliance credit has been submitted as a 2019 Title 24 CASE measure and is expected to be incorporated into the 2019 version of the compliance software. To use DWHR to comply with 2016 Title 24 and a Reach Code, an applicant must indicate on the plans how many water heaters are installed. TRC recommends that the building department estimate that the DWHR system reduces the DHW kTDV load by 10% if 100% of dwelling units are connected to a DWHR system and use the same ratio if less than 100% of dwelling units are connected to DWHR. The overall building compliance margin should then be adjusted with the reduced DHW load.
- **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.

[28] 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

[29] 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 – Cost Data

The following figures provide detailed cost when necessary for the measures presented in Section 3.

Figure 33. Single Family HERS Verification Base Cost

	Single Family
On-site visit ($/visit)	$220
Standard measure verification ($/measure)	$45
Additional measure verification ($/measure)	$100
Registry documentation ($/measure/visit)	$25

Figure 34. Single Family HERS Verification Detailed Costs

Single Family HERS Measure	"Test" Visit	Site Visit 1	Site Visit 2	Site Visit 3	Total # Visits	Total Cost[2]
Duct Leakage (Mandatory)	X			X	2	$250
Verified Airflow/ Fan Efficiency (Mandatory)	X			X	2	$250
Whole Building Mechanical Ventilation (Mandatory)	X			X	2	$250
Quality Insulation Installation[1]	X	X	X	X	4	$427
Compact Hot Water Distribution[1]	X		X		2	$175
Piping Insulation, All Hot Water Lines[1]	X		X		2	$175
Verified Refrigerant Charge[1]	X			X	2	$175

[1] Denotes projects that can be verified using sampling; the cost analysis assumed 1-in-2 sampling

[2] Assumes measures that require 2 or more on-site visits will be optimally scheduled

Figure 35. Multifamily HERS Verification Base Costs

	Single Family
On-site visit ($/visit)	$213
Non-mandatory additional measure verification ($/visit)	$50
Registry documentation ($/measure/visit)	$25

Figure 36. Multifamily HERS Verification Detailed Costs

Single Family HERS Measure	Best Case # Site Visits	Mid Case # site visits	Worst Case # site visits	Avg. Measure Cost[1]
Duct Leakage (Mandatory)	1	1	2	$122
Verified Airflow/ Fan Efficiency (Mandatory)	1	1	1	$52
Whole Building Mechanical Ventilation (Mandatory)	1	1	1	$52
Quality Insulation Installation	3	4	5	$764
Compact Hot Water Distribution	1	1	2	$131
Piping Insulation, All Hot Water Lines	1	1	2	$131
Verified Refrigerant Charge	1	1	2	$131
Verified Low Leakage Ducts in Conditioned Space	2	3	4	$527

[1] Assumes that measures that require 2 or more on-site visits will be scheduled individually without consideration of other measures.

Figure 37. Residential Quality Insulation Installation Detailed Costs

Component/ Material	Climate Zones	Base Case	Proposed Update	Installation Labor	HERS Verification	Total Cost
Single Family	1-5	Standard	+2.1 hrs of labor	$111	$427	**$537**
	6-10			$99		**$526**
	11-13			$101		**$528**
	14-16			$101		**$528**
Low-rise Multifamily	1-5	Standard	+9.7 hrs of labor	$501	$764	**$1,265**
	6-10			$449		**$1,213**
	11-13			$457		**$1,221**
	14-16			$457		**$1,221**

Cost Source: RS Means 2017 and local HERS raters
[1] Additional labor hours is based on envelope surface area for each prototype

Figure 38. Cool Roof Detailed Costs

Component	Base Case	Proposed Update (ASR/TE)	Unit	IMC ($/unit)			
				North Coast	South Coast	North Central	Inland
Asphalt Shingles	NR	0.20/0.85	roof ft2	$1.16	$2.19	$1.35	$1.48
Concrete/Clay Tile				$1.59	$1.75	$1.59	$1.59
			Average	**$1.38**	**$1.97**	**$1.47**	**$1.53**
Asphalt Shingles	NR	0.28/0.85	roof ft2	$1.61	$1.15	$1.42	$1.52
Concrete/Clay Tile				$1.59	$1.75	$1.59	$1.59
			Average	**$1.60**	**$1.45**	**$1.51**	**$1.56**
Asphalt Shingles	NR	0.32/0.85	roof ft2	$2.47	$1.89	$2.29	$2.80
Concrete/Clay Tile				$1.59	$1.75	$1.59	$1.59
			Average	**$2.03**	**$1.82**	**$1.94**	**$2.19**
Asphalt Shingles	0.20/0.85	0.32/0.85	roof ft2	$1.31	($0.31)	$0.94	$1.32
Concrete/Clay Tile				$1.59	$1.75	$1.59	$1.59
			Average	**$0.66**	**($0.15)**	**$0.47**	**$0.66**

Source: Online retailers and roofing product distributors

Figure 39. Improved Fenestration Detailed Costs

Component	Base Case (U-factor/SHGC)	Proposed Update (U-factor/SHGC)	Unit	Units/Building		IMC ($/unit)
				SF	MF	
Residential Window	0.32/0.25	0.30/0.23	ft^2 window	480	1,044	$0.20
Residential Window	0.32/0.50	0.30/0.50				$0.20[1]

Source: Nittler, K. (2017). Codes and Standards Enhancement (CASE) Initiative: Residential High Performance Windows and Doors – Draft Report.
[1] The incremental cost for 0.30/0.23 windows is conservatively used for 0.30/0.50.

Figure 40. Insulated Door Detailed Costs

Component	Base Case (U-factor)	Proposed Update (U-factor)	Unit	Units/Building		IMC ($/unit)
				SF	MF	
Residential Door	0.50	0.20	ft^2 door	20	160	$1.30

Source: Nittler, K. (2017). Codes and Standards Enhancement (CASE) Initiative: Residential High Performance Windows and Doors – Draft Report.

Figure 41. High Performance Wall Detailed Costs

Component	Base Case (U-factor)	Proposed Update (U-factor)	Unit	Units/Building		IMC ($/unit)
				SF	MF	
Wall Framing	2x4 @ 16”	2x6 @ 16”	ft^2 wall	1,574	3,760	$0.29
Cavity Insulation	R-15	R-21	ft^2 wall	1,574	3,760	$0.05
Continuous Exterior Insulation	R-4	R-7.5	ft^2 wall	1,574	3,760	$0.20
Additional Sill Flashing (for R-7.5)	1”	1.5”	linear ft window perimeter	404	1,114	$0.22

Source: Rasin, J. and F., Farahmand. (2015). Codes and Standards Enhancement (CASE) Initiative: Residential High Performance Walls; German, A. (2017). Codes and Standards Enhancement (CASE) Initiative: High Performance Walls – Draft Report

Figure 42. High Performance Attic Detailed Costs

Component	Base Case	Proposed Case	Unit	Units/Building		IMC/unit ($/unit)
				SF	MF	
Below Deck Insulation (Batt)	R-0	R-19	roof deck ft^2	2,130	4,176	$0.97
Below Deck Insulation (Batt)	R-13	R-19	roof deck ft^2	2,130	4,176	$0.12
Cabling	none	installed	labor hrs	2	4	$44

Source: Hoeschele, M. (2017). Codes and Standards Enhancement (CASE) Initiative: High Performance Attics – Draft Report; Online retailers; RS Means 2017.

Figure 43. Reduced Infiltration Detailed Costs

Component	Base Case	Proposed Case	Unit	Units/Building		IMC/unit ($/unit)
				SF	MF	
Reduced envelope infiltration	5.0 ACH50	3.0 ACH50	CFA	2,400	6,960	$0.11

Source: Davis Energy Group, Inc., Enercomp, Inc., Misti Bruceri & Associates, LLC. (2016). *CALGreen Cost Effectiveness Study*.

Figure 44. Compact Domestic Hot Water Distribution Detailed Costs

Component	Base Case	Proposed Case	Unit	Units/Building		IMC/unit ($/unit)
				SF	MF	
¾” PEX piping (insulated)	Standard	Compact Design	linear ft	(17)	-	$2.23
1” Gas piping	Standard	Additional	linear ft	20	-	$7.18
5” Vent piping	Standard	Additional	linear ft	14	-	$21.79
Venting	Standard	Additional	labor hrs	1	-	$93.25
HERS Verification	Standard	Verified	-	-	-	See HERS verification

Source: Online retailers and RS Means 2017

Figure 45. Drain Water Heat Recovery Detailed Costs

Component	Base Case	Proposed Case	Unit	Units/ SF Building	IMC/unit ($/unit)
Vertical DWHR device + installation	None	1 device	# devices	1	$771.28

Source: Esser, M et al. (2017). Codes and Standards Enhancement (CASE) Initiative: Drain Water Heat Recovery – Draft Report.

Figure 46. Reduced Fan Watt Draw Detailed Costs

Component	Base Case	Proposed Case	Unit	Units/Building		IMC/ unit	
				SF	MF	SF	MF
ECM Motor	0.58 watts/cfm	0.30 watts/cfm	# motors	1	8	$143	$104

Source: Davis Energy Group, Inc., Enercomp, Inc., Misti Bruceri & Associates, LLC. (2016). *CALGreen Cost Effectiveness Study*.

Figure 47. Increased Duct Insulation Detailed Costs

Component	Base Case	Proposed Case	Unit	Units/Building		IMC/ unit
				SF	MF	
Duct Insulation	R-6	R-8	linear ft duct	248	718	$0.86

Source: Wei, J et al. (2015). Codes and Standards Enhancement (CASE) Initiative: Residential Ducts in Conditioned Space/ High Performance Attics.

6. APPENDIX B – UTILITY RATE SCHEDULES

TRC selected electric and natural gas rates from the major utilities to evaluate customer costs for the measure packages. Rate schedules were coordinated with experts at each utility to ensure appropriate interpretation of net energy metering policies. The rates were applied to climate zones within the utility territory. Detailed rate schedules are provided in subsequent tables.

Figure 48. Rate Schedules for Each Utility

Utility	Commodity	Rate Schedule	Climate Zones	Link
PG&E	Electric	E-TOU Option A	1, 2, 3, 4, 5, 11, 12, 13, 16	https://www.pge.com/tariffs/tm2/pdf/ELEC_SCHEDS_E-TOU.pdf
	Gas	G1		https://www.pge.com/tariffs/tm2/pdf/GAS_SCHEDS_G-1.pdf
SCE	Electric	TOU-D-T	6, 8, 9, 14, 15	https://www.sce.com/NR/sc3/tm2/pdf/CE220.pdf
SCG	Gas	GR		https://www.socalgas.com/regulatory/tariffs/tm2/pdf/GR.pdf
SDG&E	Electric	DR-SES	7, 10	http://regarchive.sdge.com/tm2/pdf/ELEC_ELEC-SCHEDS_DR-SES.pdf
	Gas	GR		http://regarchive.sdge.com/tm2/pdf/GAS_GAS-SCHEDS_GN-3.pdf

6.1 Electric Rate Schedule

Figure 49. PG&E Residential Electric Rates

Pacific Gas & Electric (PG&E) Residential TOU Electric Rates	
Rate E-TOU Option A	
Summer ($/kWh) (June 1 through Sep 31)	
On-Peak	0.39336
Off-Peak	0.31778
Winter ($/kWh) (Oct 1 through May 31)	
On-Peak	0.27539
Off-Peak	0.26109
Additional Charges	
Baseline Credit (per kWh)	$0.08830
Customer Charge ($/meter/day)	$0.32854
CA Climate Credit ($/month in April and October)	-$17.40
Net Surplus Compensation (NSC) – NEM	$0.0276
Non-bypassable Charges (NEM 2.0) ($/kWh)	
Public Purpose Program, Nuclear Decommissioning, California Department of Water Resources, Energy Cost Recovery Amount, Competition Transition Charge	$0.0233

Figure 50. SCE Residential Electric Rates

Southern California Edison (SCE) Residential TOU Electric Rates		
Rate TOU-D-T		
Summer ($/kWh) (Jun 1 through Sept 31)		
On peak- Level 1		$0.35425
On peak- Level 2		$0.39242
Off peak- Level 1		$0.18132
Off peak- Level 2		$0.21949
Winter ($/kWh) (Oct 1 through May 31)		
On peak- Level 1		$0.23425
On peak- Level 2		$0.27242
Off peak- Level 1		$0.17515
Off peak- Level 2		$0.21332
Additional Charges		
Basic Charge	Single Family	$0.031
	Multi Family	$0.024
Customer Charge ($/meter/day)		$0.329
CA Climate Credit ($/month in April and October)		-$31.00
Net Surplus Compensation (NSC) – NEM		$0.0257
Non-bypassable Charges (NEM 2.0) ($/kWh)		
Public Purpose Program, Nuclear Decommissioning, California Department of Water Resources, Competition Transition Charge		$0.0233

Figure 51. SDG&E Residential Electric Rates

San Diego Gas & Electric (SDG&E) Residential TOU Electric Rates	
Rate DR-SES	
Summer ($/kWh) (May 1 through Oct 31)	
On-Peak	0.50629
Mid-Peak	0.25108
Off-Peak	0.22721
Winter ($/kWh) (Nov 1 through Apr 30)	
Mid-Peak	0.23619
Off-Peak	0.22171
Additional Charges	
Customer Charge ($/meter/day)	$0.3290
CA Climate Credit ($/month in April and October)	-$29.62
Net Surplus Compensation (NSC) – NEM	$0.0279
Non-bypassable Charges (NEM 2.0) ($/kWh)	

Public Purpose Program, Nuclear Decommissioning, California Department of Water Resources, Energy Cost Recovery Amount, Competition Transition Charge	$0.017

6.2 Natural Gas Rate Schedule

Figure 52. PG&E Residential Natural Gas Rates

Pacific Gas & Electric (PG&E) Residential Natural Gas Rates	
Rate G-1	
	Per therm
Baseline charge	$1.28697
Non-baseline charge	$1.82246
Other charges	**Per therm**
NonCARE	$0.09589
CARE	$0.06743
Average PPS surcharge	$0.08166

Figure 53. SCG Residential Natural Gas Rates

Southern California Gas (SCG) Residential Natural Gas Rates	
Rate GR	
	Per therm
Baseline charge	$0.88512
Non-baseline charge	$1.21357
Other Charges	
Customer charge (per meter per day)	$0.16438

Figure 54. SDG&E Residential Natural Gas Rates

San Diego Gas & Electric (SDG&E) Residential Natural Gas Rates	
Rate GR	
	Per therm
Baseline charge	$1.28450
Non-baseline charge	$1.47184
Other Charges	
Minimum Bill Charge	$0.0986