Achieving Zero Net in California –Balancing Energy Efficiency and On-site Renewable Generation

Marshall Hunt, Pacific Gas and Electric Company
Marc Hoeschele and Alea German, Davis Energy Group
Ken Nittler, Enercomp

ABSTRACT

The California Energy Commission (CEC) enacted the Standards in 1978 and has aggressively revised the Building Energy Efficiency Standards every three years. Zero net energy for new residential construction is the state's target for the 2019 round of standards which are slated for implementation in January 2020. California utilizes a unique Time Dependent Valuation (TDV) energy metric for defining the zero net target.

Using the 2016 Standards as a starting point for the proposed 2019 revisions, additional energy efficiency measures will be evaluated for cost effectiveness using the CEC methodology. Measures under consideration include further envelope improvements, improved water heating distribution system performance, and enhanced heating, ventilation, and cooling (HVAC) strategies. The stringent 2016 Standards make further traditional energy efficiency improvements challenging. With a Zero Net TDV target for 2020, renewable energy will naturally play a prominent role in offsetting plug loads and other appliance demands. Photovoltaic (PV) prices have continued to fall over the past ten years, raising questions of where efficiency and on site renewable generation will intersect in terms of cost effectiveness.

This paper will present preliminary cost effectiveness evaluations of select energy efficiency measures and photovoltaics in three representative California climates. The cost effectiveness of heating and cooling measures is highly dependent on climatic conditions. In the cool San Francisco Bay region, cooling measures are not cost effective, while in the low lying hot desert region where Palm Springs is located high efficiency furnaces are not cost effective.

Introduction

According to the US Energy Information Administration, buildings account for almost 39% of total energy consumption in the United States (EIA 2012). Reducing the impact from the built environment is an important goal for reductions in national energy use and is a focus of an increasing amount of legislation and energy codes, particularly in California. In 2008 the California Public Utilities Commission (CPUC) adopted the California Long Term Energy Efficiency Strategic Plan (CPUC 2011) which included the aspirational goals that all new residential construction in California is zero net energy (ZNE) by 2020, and all new commercial construction is Zero Net Energy (ZNE) by 2030.

ZNE can be defined in several different ways, and how it is defined may affect strategies to achieve it, ultimate long term building performance, and associated costs (Torcellini et al. 2006). Three definitions are considered: zero net site energy (ZNE-Site) zero net source energy (ZNE-Source), and ZNE-TDV.

ZNE-Site balances building energy consumption and renewable energy production at the site with all energy inputs and outputs converted to a similar metric (i.e. kBtu). This is the most straightforward definition in all-electric buildings where onsite electricity consumption is offset by onsite renewable electricity generation. This has led to the misperception that only all electric dwelling can be ZNE.

ZNE-Source takes into account energy generation and delivery losses through the grid. The net effect of accounting for these generation, transmission, and distribution inefficiencies is the source energy value of electrical energy being about three times the site value. In this approach onsite renewable electricity generation assigned the same site-to-source factor as grid electricity provided the system is grid connected. This source energy characterization is what the Department of Energy (DOE) calls "full fuel cycle" and DOE has adopted this as a common definition for zero energy buildings. (National Institute of Building Sciences) [1]

ZNE-TDV is used by California. For 2019 a dwelling will comply with the standards when TDV on an annual basis is equal to zero. California uses Time Dependent Value (TDV) as the metric for energy consumption and production by a building. TDV has been used since the 2005 Title 24 energy code for code compliance. It values energy use differently depending on the fuel source (gas, electric, and propane), time of day, and season it is used (Horii et al 2014).

In the early 1980s the structure of the Title 24 Residential Building Energy Efficiency Standards (named for the section of the California regulations where it is located) changed from being prescriptive to being performance based. Each three year code cycle update generates a revised prescriptive package of cost effective measures which generates a performance energy (or TDV) budget that the proposed building must achieve. California state policy follows a "loading order" whereby all cost effective energy efficiency must first be implemented, before renewables can be applied. An hourly computer simulation is used to evaluate a proposed building's energy performance. For each hour the energy demand is multiplied by the TDV value for the location where the dwelling will be built. Electricity used during peak periods of the summer has a much higher value than electricity used during off-peak periods, as is shown in the Figure 1 example. TDV is low in the nighttime hours and rises during the day with a peak around 3pm. Electric TDV peaks are higher on hotter days. TDV was developed to reflect the "societal value or cost" of energy including long-term projected costs of energy such as the cost of providing energy during peak periods of demand and other societal costs such as projected costs for carbon emissions. Natural gas TDV values vary on a seasonal basis. A thorough discussion of TDV and its development for the 2016 Title 24 Standards can be found at Horii et al (2014).

Historically energy compliance in California has focused on what is referred to as the "regulated" loads, which include space heating, cooling, ventilation for IAQ, and water heating end uses. In 2019, when the CEC is looking to move all residential new construction to ZNE-TDV, all energy usage in the house must be accounted for in the compliance calculations. These additional end uses due to lighting, appliances, and plug loads are referred to as the unregulated loads.

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[1] National Institute of Building Sciences: A Common Definition for Zero Energy Buildings, September 2015, Prepared for the U.S. Department of Energy .
http://energy.gov/sites/prod/files/2015/09/f26/bto_common_definition_zero_energy_buildings_093015.pdf

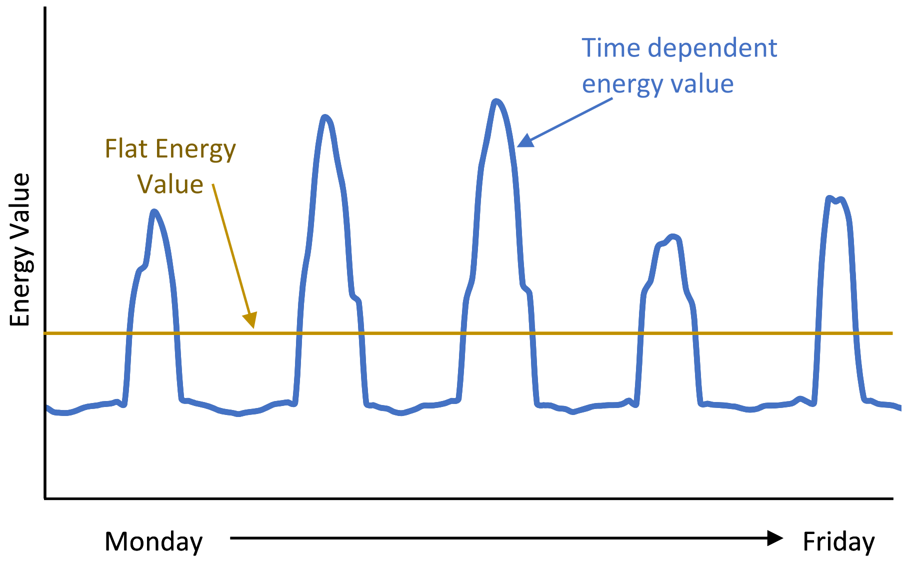


Figure 1. Example hourly electrical energy TDV for a week in July.

The choice of ZNE-TDV definition has several advantages. It is compatible with Title 24 procedures that have been in place for over 30 years. It is fuel-flexible since there are TDV time series values for electricity, natural gas, and propane. The hourly analysis gives appropriate weighting to the timing of energy demand.

The ZNE specification has a dramatic impact on the PV required to achieve ZNE TDV. To demonstrate the impact, a two-story 2,700 ft^2 prototype house was evaluated using a pre-release version of the Title 24 CBECC-Res compliance tool. The home is minimally compliant with the 2016 Title 24 energy code and uses natural gas for space heating, water heating, clothes drying, and cooking. Table 1 indicates that close to 6.5 kW of PV is required to meet ZNE on both a source and TDV basis. Over 5kW of additional PV is necessary to offset all household consumption when evaluating on a site energy basis. In this particular example, Source and TDV are close but for other dwellings in other Climate Zones there will be differences as loads, TDV, and timing of energy use varies.

ZNE Definition	PV Capacity (kW DC)
Site	11.59
Source	6.50
TDV	6.48

Table 1. Sample comparison of PV capacities to meet ZNE goals

CBECC-Res Simulation Tool

The CBECC-Res simulation model development began in 2011 as collaboration between the California Energy Commission and California's investor-owned utilities (IOU) with funding approve by the California Public Utilities Commission (CPUC) using public purpose money.

CBECC-RES is a first principles residential building simulation tool with significant enhancements in modeling capabilities over previous versions of the Title 24 compliance software. Several key modeling enhancements integrated into CBECC-RES include improved modeling of solar gains, sophisticated thermal mass modeling, a fully integrated airflow network model, and detailed duct distribution system modeling (Ferris, Froess, and Ross 2015; Barnaby, Wilcox, and Niles 2013). California's development of the CBECC-RES tool was driven primarily by a desire to have an open source software tool that would simplify future software enhancements and allow a single simulation engine to be shared among multiple vendors who provide user front ends to the marketplace (Brook and Criswell 2012 and Ross 2016). Alternative existing public domain software, such as EnergyPlus, was considered, but EnergyPlus lacks needed features (e.g. a detailed duct loss model) and has many capabilities that are extraneous to the needs of a residential compliance tool, resulting in a product that is less practical to deploy in a compliance context.

Title 24 provides a package of mandatory requirements, such as minimum wall insulation, which define the minimum performance level for various features installed in all new California residences. A prescriptive package for each climate zone (CZ) is developed which is deemed to be cost effective using the CEC's life cycle cost methodology and can be used for compliance only if a project meets or exceeds all components of the package. However, the restrictive nature of these package requirements (for example, west facing glazing area must be less than 5% of total conditioned floor area, all glazing must meet maximum U-factor and SHGC requirements, etc.), makes it advantageous for virtually all builders to use a performance path that allows for tradeoffs and therefore offers considerable design flexibility. In the performance approach, CBECC-Res is used to compare the performance of the proposed building design to that of a "standard" building design which assumes the prescriptive package of measures for that specific climate zone. If the annual energy budget of the proposed design is equal or less than that of the standard design, the proposed building design complies. The user inputs design specifics about the building following the rules defined in the Alternative Calculation Methodology (Ross 2016).

The CEC has defined 16 unique CZs that encompass the state as shown in Figure 2. The CZs vary from the cold mountain CZ16 to the hot desert region represented by CZ15. In the hotter CZs, lower SHGC windows, cool roofing materials, and whole house fans are prescriptively required. The variations in the prescriptive requirements by climate zone are detailed and can be found in Table 150.1-A of 2016 Building Energy Efficiency Standards (CEC 2015). A more general characterization is provided here in Table 2 to give the reader a sense of key energy efficiency measure prescriptive levels for both "typical" mild and hot climates.

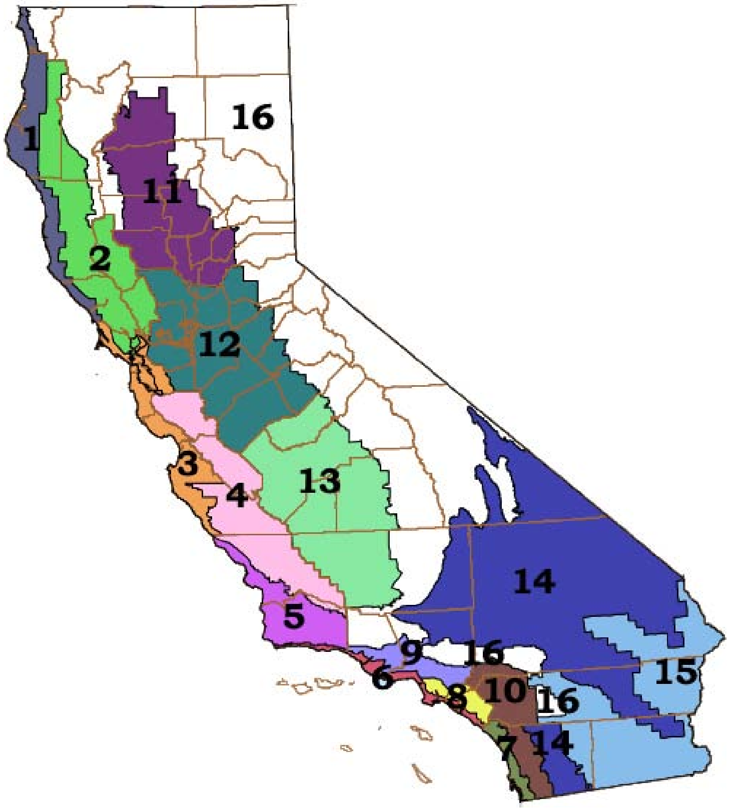


Figure 2. Map of California climate zones (CEC 2015)

Table 2. General Characterization of Prescriptive EEMs by Climate Type

Measure	Milder CZs (1 – 9)	Hotter CZs (10 – 15)
Walls	U-factor of 0.065	U-factor of 0.051
Windows	0.32 U-factor; no requirement on SHGC	0.32 U-factor; 0.25 SHGC
Ceiling	R-30	R-38
Ducts	R-6, 5% leakage verified	R-8, 5% leakage verified
Water heating	0.82 EF gas instantaneous water heater or equal	0.82 EF gas instantaneous water heater or equal
Lighting	All High Efficacy (LED)	All High Efficacy (LED)
Roofing	No Requirement	Cool Roof; R-13 under roof deck
Cooling	Standard AC meeting federal minimum efficiency requirements SEER 14/ EER 12.2 up to 3.5 tons and 11.7 above 3.5 tons	Standard federal minimum efficiency AC + Whole House Fan
AC refrigerant charge verified	No	Yes

Figure 3 plots how the various end uses for an example house break down and clearly show that the unregulated loads are a major part of the house energy use. These can only be met by on site PV and requires a 3.0 kW DC system for this sample building.

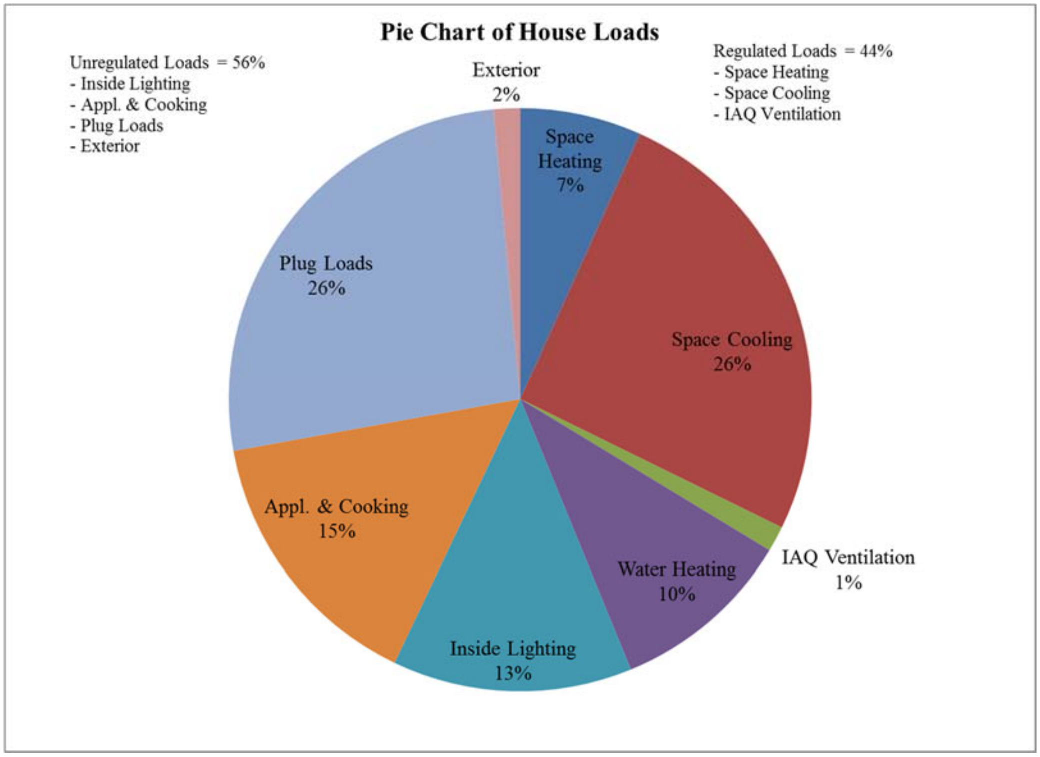


Figure 3. Pie Chart of Example CBECC Output

PV System Modeling

To facilitate ZNE-TDV for production builders who build the same model home in multiple orientations, the CEC has developed a compliance approach under the 2016 Standards called the California Flexible Installation (CFI). When the CFI approach is followed, PV performance is evaluated at a fixed 170° azimuth and a 5 in 12 (23.6°) roof pitch. The builder is then able to install the specified kW DC capacity of PV to meet ZNE-TDV based on the building loads and this solar configuration, but the PV system is allowed to be installed in any orientation between 150 ° and 270 ° azimuth and with roof pitch between 0 in 12 (flat)and 7 in 12 (30.26°). This approach eliminates the need for projects to comply lot-by-lot, which would be very time consuming for large production projects. While this may result in some homes with slightly undersized PV system, the impact of azimuth on solar TDV energy production has been found to be less than a 5% impact. Roof tilt has a higher impact, particular for flat roofs; however, a vast majority of single family production homes in California have pitches between 4 in12 (18.43°) and 6 in12 (26.57°).

Assessment of Energy Efficiency Measures and PV

The process of evaluating the relative cost effectiveness of various energy efficiency measures and photovoltaic systems includes:

- selecting a representative house prototype for modeling,
- identifying a set of potential measures for evaluation,
- completing simulations to document energy (TDV) impacts, and
- applying measure costs to allow for computing cost per unit of TDV saved

During recent Title 24 cycles, the CEC has utilized both a 2,100 ft^2 single story prototype and a 2,700 ft^2 two-story prototype (Nittler and Wilcox 2006). For this modeling evaluation the 2,700 ft^2 two-story prototype house was used as shown in Figure 4.

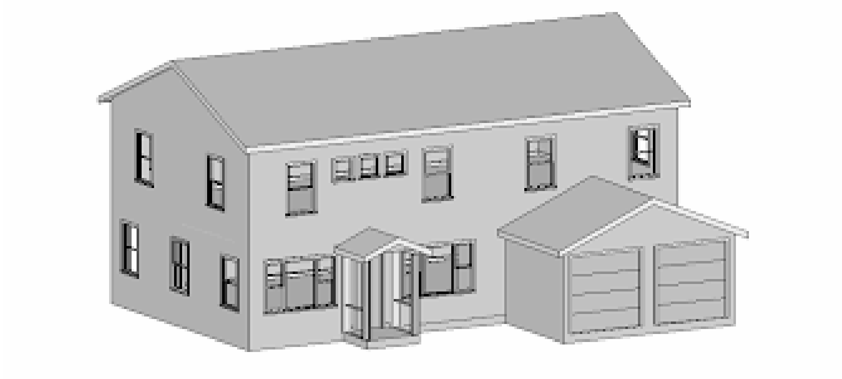


Figure 4. Rendering of 2,700 ft^2 two-story prototype home

To simplify the data presentation, a partial but diverse set of energy efficiency measures were evaluated to assess savings impact and relative cost effectiveness for three different CZs. This exercise was not intended to be an exhaustive study, but includes potentially attractive measures that can currently be modeled in the CBECC-Res software. It does not include any demand response technologies, which may well be considered at a later time. Photovoltaics were also evaluated as an essential part of the ZNE-TDV solution for California under the 2019 Standards. Brief descriptions of the specific measures evaluated in this study are presented below.

1. Windows: For much of California’s climate, higher performance windows relative to the 2016 prescriptive standard would include a lower U-factor and a lower SHGC (to reduce solar gain contributions to house cooling loads). In some mild coastal zones, specifying a higher 0.50 SHGC is appropriate since cooling loads are negligible.
2. Insulated Doors: Insulated doors reduce thermal gains through the typical opaque doors installed as front doors and doors to the garage. Insulated doors use extruded polystyrene or polyurethane to insulate door cavities.

3. Added Exterior Wall Insulation: The 2016 prescriptive standards specify high performance walls (2x6 walls with one inch of rigid exterior insulation) for most CZs. This measure increases the rigid insulation to two inches of extruded polystyrene.
4. Reduced Building Infiltration: Envelope air leakage contributes to space conditioning loads. Reduced infiltration, documented by independent blower door testing, improves building thermal performance.
5. Quality Insulation Installation (QII): QII procedures involve proper installation of insulation in walls and attic space with independent third party verification of compliance with installation procedures.
6. High Efficiency Water Heating: 2016 prescriptive water heating equipment requirements specify a Federal minimum efficiency gas instantaneous water heater (0.82 EF). A conservative 0.91 EF level of condensing efficiency was evaluated to assess potential cost effectiveness for equipment exceeding the Federal minimum efficiency level.
7. Improved Furnace Fan: Effective July 3, 2019, residential gas furnace fans will have an improved fan energy rating based on efficient motor technologies. These technologies are currently available in some products today. A target air flow efficacy of 0.3 W/cfm was assumed.
8. Higher Efficiency Cooling: Split system cooling systems with a 16 SEER and 13 EER were evaluated as an alternative to minimal efficiency equipment.
9. Pipe Insulation: 2016 Title 24 currently requires partial insulation of hot water distribution systems. This includes piping of ≥ ¾" diameter and any hot water lines feeding the kitchen sink). Added energy savings and comfort benefits can be achieved by insulating all hot water piping. The state mechanical code will require that all piping, including ½" diameter pipe, be insulated. The analysis shows the impact of this new mandatory measure.
10. Photovoltaic Systems: PV systems were modeled to meet the California Flexible Installation system which allows production builders to install PV at azimuths between 150 and 270 degrees. CBECC-Res models PV systems using NREL's PVWatts program. The CFI approach assumes TDV benefit based on "standard" performance parameters and an array oriented at 170° (10° east of due South) with a 5 in 12 roof tilt.

Table 3 summarizes the energy efficiency measures and provides the incremental cost assumptions. Defining measure costs is always challenging as production builders work with different vendors, have subcontractors with varying familiarity with the measure, and other factors. The costing presented here is derived from a range of sources including subcontractor price estimates, internet pricing, and prior estimates provided in other Standards development activities. During the 2019 Standards development effort, this costing will be refined and contained in the formal Code and Standards Enhancement (CASE) reports that will be docketed at the CEC website.

Table 3: Summary of Energy Efficiency Measures and Assumed Incremental Costs

Measure	Description	Estimated Incremental Cost
Windows (hot CZ)	0.30 U-factor; 0.23 SHGC	\$0.15/ft^2 of window area
Windows (mild CZ)	0.30 U-factor; 0.50 SHGC	\$0.15/ft^2 of window area
Insulated Doors	U-factor = 0.20	\$300 for 2 doors
Wall Insulation	Added 1” extruded polystyrene for a total of 2”	\$0.45/ft^2 of wall area
3.0 ACH50 Infiltration	Tighter building envelope with 3rd party inspection	\$377 including inspection costs
QII	3rd party inspected insulation installation	\$659 including inspection costs
Gas Water Heater	0.91 EF condensing instantaneous unit	\$300
Improved Furnace Fan	0.3 Watts/cfm airflow	\$122 – Based on DOE. Furnace Fan Standards
Higher Efficiency Cooling System	16 SEER / 13 EER	\$475 for typical 3 ton system
Hot Water Distribution System Pipe Insulation	All hot water piping insulated	\$460
PV	Standard efficiency PV installation meeting the CFI criteria	\$4.00 per W DC without 30% Federal tax credit; \$2.80 with credit

Table 4 summarizes the projected annual base case energy use for the 2016 prescriptive package when modeled on the 2,700 ft^2 two-story prototype. The climate zone breakdown highlights how new home energy use is projected to vary and also puts the space conditioning loads in context with the miscellaneous loads including lighting, plug loads, and appliances.

Table 4: Projected Annual Energy Use for 2016 Prescriptive 2,700 ft^2 Home

	Electrical Usage (kWh/year)				Gas Usage (therms/year)			
CZ	Fans	Cooling	Plug Loads, Lighting, Appliances	Total	DHW	Heating	Cooking, Clothes Dryer, etc.	Total
1	403	0	5,114	5,517	154	304	60	519
2	342	47	5,114	5,504	142	234	60	436
3	241	3	5,114	5,358	142	116	60	319
4	280	92	5,114	5,486	137	162	60	360
5	214	0	5,114	5,328	145	84	60	290
6	197	86	5,114	5,397	132	65	60	258
7	156	22	5,114	5,292	131	17	60	208
8	169	403	5,114	5,686	128	33	60	221
9	191	741	5,114	6,046	128	58	60	246
10	200	931	5,114	6,245	127	68	60	256
11	329	1,888	5,114	7,331	129	219	60	408
12	332	540	5,114	5,986	134	222	60	417
13	309	2,099	5,114	7,522	127	195	60	383
14	321	1,860	5,114	7,295	130	209	60	400
15	151	6,077	5,114	11,342	103	12	60	175
16	588	166	5,114	5,868	153	521	60	735

Figure 5 plots projected energy savings (reported in terms of kTDV/ft^2-year by compliance software) for each of the measures (identified in Table 2) in three specific climate zones that fall into the mild-moderate-hot criteria. Since TDV is most variable for electric usage and tends to amplify the impact of summer peak demand savings, the savings variability for some measures due to climate is pronounced. For example, the higher efficiency air conditioning (16 SEER/13 EER) shows no impact in the mild zone since there is no cooling, small savings in the moderate zone due to moderate loads, and significant savings in the hot zone. Other measures, such as increased water heater efficiency or hot water pipe insulation, demonstrate an impact that is fairly uniform among all zones. The impact of 1 kW DC of PV ranges from 13.8 to15 kTDV/ft^2-year. This is not unexpected; given that 6.5 kW DC offsets all of the TDV for the house. The high efficiency of the house can be seen by noting that in CZ15 about 0.6 kW DC equal the savings of the high efficiency air conditioner.

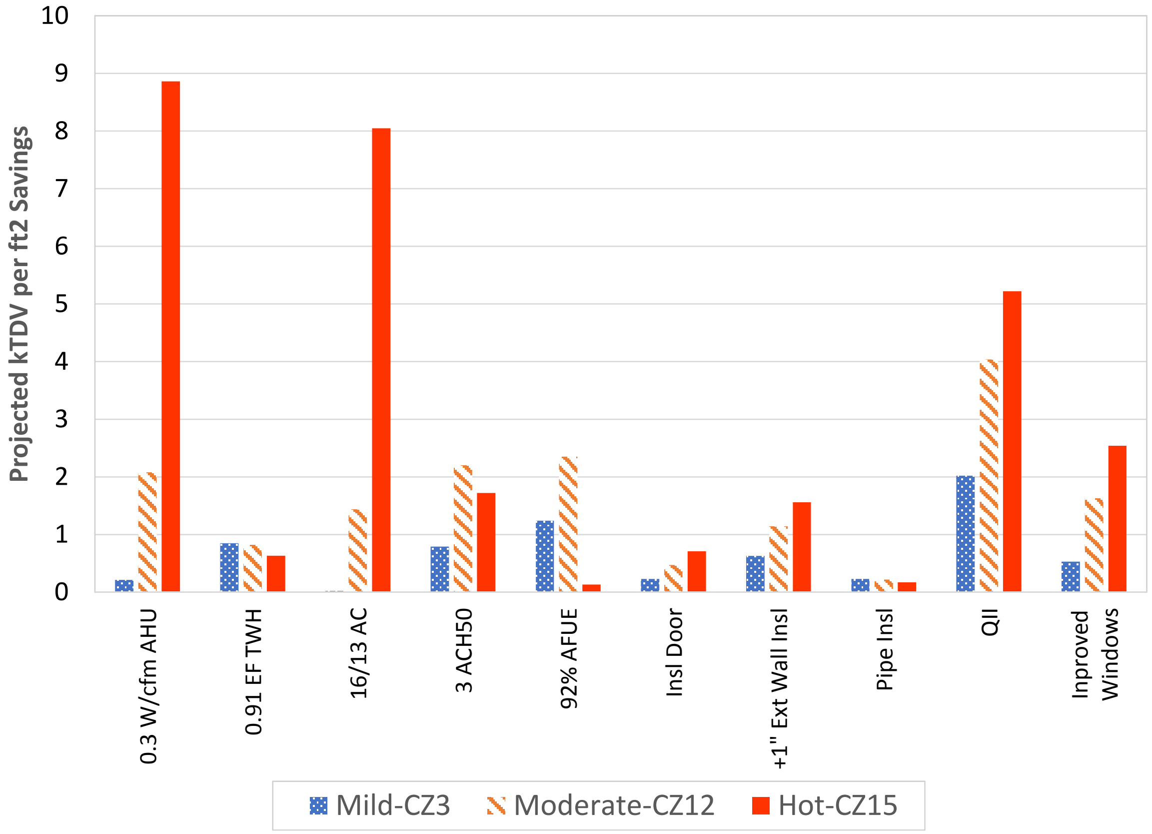
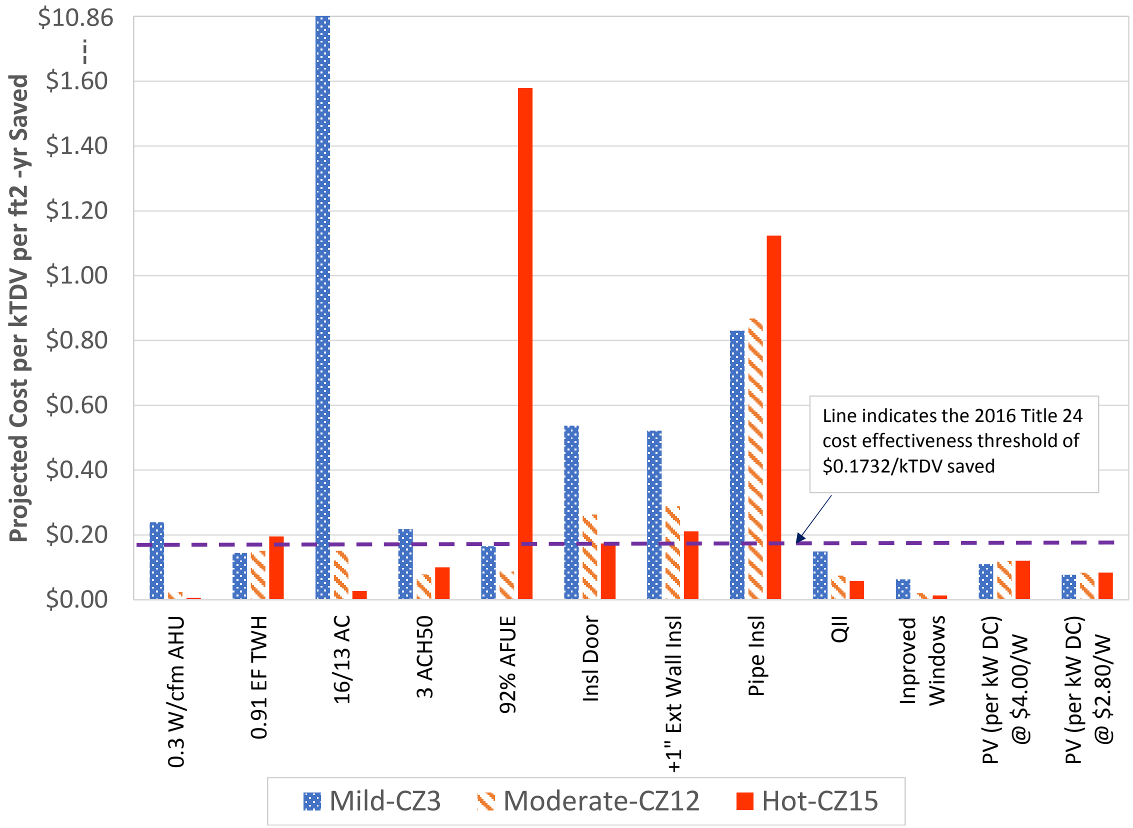


Figure 5. Projected Annual Energy Savings by Climate for 2,700 ft^2 Prototype (kTDV/ft^2-year)

This view of the results serves to show the climate impact on projected TDV energy use. For the mild CZ3 climate, energy efficiency measure savings are not large. Other coastal CZ'ssuch as 6 and 7 are even milder, reinforcing the idea that further efficiency measure benefits are limited in these zone. Four measures have significant differences by climate zones. The high savings from reduced air handler fan power (0.3 W/cfm) for CZ15 (Palm Springs) correlates with the long run times of the central air conditioner system. The San Francisco Bay Area (CZ3) has low heating system operating hours. Climate Zone 12 (Sacramento) is a moderate winter climate, but typically hot in the summer and has the unique feature of having low humidity and a mesoscale sea breeze from the San Francisco Bay Area which drops the temperature from a high of over 100°F to a nighttime low in the low 60's°F. Cooling energy savings from a high efficiency air conditioner range from zero for CZ3 to eight (8) kTDV/ft2 for CZ15. Quality Insulation Installation (QII) impact relative to climate zones roughly mirrors the fan power impacts as QII benefits are proportional to the space conditioning loads. Finally the impact of improved windows also reflects the severity of the climate. The impact of one (1) kW DC of PV is impressive relative to other measures and shows only a slight variation with climate zone.

Figure 6 shows measure cost effectiveness in terms of cost per kTDV-ft2-year saved. This chart converts the Figure 5 kTDV energy savings into a normalized cost per kTDV saved. In addition, PV has been added at two cost points: \$4 and \$2.80 per W DC. Note that the Y-axis is linear up to $1.60 per kTDV-ft^2-year saved; beyond that the scale has been compressed to improve readability as well as accommodating the one data point approaching $11. The 2016 Title 24 cost effectiveness threshold of $0.1732 per kBtu saved (this value will change for 2019 based on a new set of 2019 TDV values that are not yet available) provides a horizontal reference line to gauge potential cost effectiveness under the 2019 CEC cost effectiveness criteria. Perhaps not surprisingly, PV (at either of the two cost points) is one of the more cost effective options. Builders and their energy consultants work to minimize the cost of achieving the necessary kTDV savings to demonstrate compliance. Builders can apply their own costs and measure preferences in the development of a compliant house. By 2020 fan power and pipe insulation will be code mandatory requirements despite the wide difference in cost effectiveness. In the mild climates, like CZ3, the only measures more cost effective than PV are high performance windows. In the extreme hot climates, like CZ15, there are five (5) efficiency measures that are about as cost effective as PV, including a high SEER air conditioner, reduced infiltration to 3 ACH50, quality insulation installation (QII).



Line indicates the 2016 Title 24 cost effectiveness threshold of $0.1732/kTDV saved

Figure 6. Projected Measure Cost Effectiveness

Conclusions

The analysis presented in this paper highlights the issue of how much energy efficiency can be cost effectively implemented before PV is applied to allow a new (2020) California home to achieve zero annual TDV. Since 1978, California state policy has followed a "loading order" strategy that requires all cost effective energy efficiency come first, followed by renewables. The latest 2016 Title 24 Residential Building Energy Standards further reduced energy budgets by prescriptively requiring high performance wall systems, high efficacy lighting, high performance ducted systems, and gas instantaneous water heating. Using this 2016 benchmark as the stepping off point for the 2019 Standards reduces the number of viable cost effective solutions for the California climate.

Using a pre-release version of the 2016 CBECC-Res simulation model which includes 2016 TDV values, the authors have completed an initial assessment of how a selected set of energy efficiency improvements compare to PV at two levels of $/W DC. The analyses indicates that in the mildest climates the only measures found to more cost effective than PV are high performance windows. In the most extreme (hot) California climate a number of efficiency measures were found to be as cost effective as PV, including high efficiency air conditioning, reduced envelope infiltration, and quality insulation installation (QII) procedures.

The findings presented here should not discourage energy efficiency advocates from implementing codes that require high levels of energy efficiency as done by 2016 Title 24. The analyses indicates that in a mild climates, such as found in California, with a strict statewide energy code and a unique energy valuation approach, the convergence of cost effective energy efficiency and PV is not that far away.

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