The Technical Feasibility of Zero Net Energy Buildings in California

December 2012

For Pacific Gas and Electric Company

CALMAC Study ID - PGE0326.01

On behalf of:

Southern California Edison

San Diego Gas and Electric Company

Southern California Gas Company

ARUP

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1 Executive Summary

This study is a forward-looking “stress test” of the Zero Net Energy (ZNE) new construction goals set forth by California’s energy agencies. The California Public Utility Commission established ZNE new construction goals in its Long Term Energy Efficiency Strategic Plan (CPUC, 2008). The California Energy Commission’s 2011 Integrated Energy Policy Report creates parallel Zero Net Energy new construction goals (CEC, 2011). This report refers to the CPUC and Energy Commission goals collectively as the “ZNE goals”.

Those goals establish a 2020 target for all residential new construction to reach Zero Net Energy and a 2030 target for all commercial new construction to reach Zero Net Energy. This study assesses the potential performance of best-in-class building designs in 2020 for both residential and commercial structures. The analysis refined and simulated an integrated package of efficiency features and on-site renewable energy systems that could move each of twelve prototype buildings as close as is reasonably possible to ZNE.

The study’s central finding is that ZNE buildings will be technically feasible for much of California’s new construction market in 2020.

1.1 Impact of Metric Choice

To assess the technical feasibility of Zero Net Energy, critical definitions need to be established. “Zero” is perhaps the clearest part of the goal. “Net” and “Energy”, however, both have significant levels of variance across different metrics and different definitions. That variance can affect design decisions and has a notable impact on the amount of renewable energy required to reach ZNE.

Critically, this report seeks to assess the technical feasibility of ZNE before the State establishes a full range of ZNE definitions and metrics for California policy-making purposes. The research, therefore, must make assumptions on ZNE definitions to complete the necessary calculations. The reader should not interpret those calculations as a final assessment of technical feasibility; they are, of necessity, placeholders. Likewise, the reader should not interpret the calculations as an endorsement of any given metric; the metrics are likewise placeholders. The report seeks to inform the State’s eventual choice of suitable ZNE definitions and metrics by assessing ZNE technical feasibility across a number of metrics.

1.2 Introduction to Time Dependent Valuation

Time Dependent Valuation (TDV) is a core metric for California’s Building Energy Efficiency Standards and is a likely starting place for the State’s eventual ZNE definition. The Energy Commission’s 2011 Integrated Energy Policy Report references “time-dependent valuation” as a recommended ZNE metric (CEC, 2011).

TDV is, therefore, used as a default metric in much of this report, although significant analysis is also performed in the context of Site-kBtu. TDV, as used by the Energy Commission, is a modified participant cost test, reflecting a combination of consumer costs and statewide societal costs. Because it incorporates variables beyond energy (such as retail rates, carbon allowances, and transmission capacity), it is ultimately an economic metric and as such can be expressed as dollars.

Because the Energy Commission's Title 24 (Part 6) Building Energy Efficiency Standards have historically targeted efficiency, not renewable energy generation, the Title 24 TDV metric was developed solely to assign a value to the *import of electricity*. Consequently, it does not assign a value to the *export of electricity*. Nevertheless, this study uses TDV for that purpose – measuring the relative value of photovoltaic (PV) exports hour by hour – because a set of TDV values designed specifically to measure the value of onsite PV production has not yet been developed.

TDV, while expressed in dollars, is not an appropriate basis for a billing rate analysis (average utility rates are just one of many inputs). This study does not assess the potential billing rates for the prototype buildings.

Table 1 provides a brief summary of the metrics used in this report and critical caveats associated with those metrics:

Table 1 – ZNE Energy Use Intensity (EUI) Metrics

ZNE Metrics and Embedded Assumptions

	Strengths and Limitations	Further Discussion
Site-kBtu	**Familiarity:** The most commonly used ZNE metric nationally	
	Analytical Scope: Does not account for source energy conversion issues	
	Export Equivalency: Values energy imports and exports equally, not accounting for potential additional costs of energy exports	*Section 3.1.5.1*
	Flat Hourly Valuation: Does not adjust energy valuation based on capacity issues related to grid scale supply and demand balancing	
	Fuel Equivalency: Assumes natural gas imports can be offset with electricity exports	*Section 3.1.5.1*
TDV$	**Familiarity:** Specific to California; utilized explicitly by only a small group	
	Regulatory Precedence: Used for Title 24 compliance calculations	*Section 3.1.2*
	Economic Metric: Does not measure energy directly, measures the value of energy use across multiple variables	*Section 3.1.2.1*
	Variable Hourly Valuation: Adjusts hourly energy values based on capacity issues related to supply and demand balancing	*Section 3.1.2*
	Export Equivalency: Values energy imports and exports equally, not accounting for potential additional costs of energy exports	*Section 3.1.5.1*
	Fuel Equivalency: Assumes natural gas imports can be offset with electricity exports	*Section 3.1.5.1*
	Reference Grid Profile: Demand impacts based on 2010 grid load profiles, which will soon be dated; 2020-2050 load profiles will have a much later peak demand period due to high solar electric saturation on the grid	*Section 3.1.5.1*
	Clarity: Modified participant cost test can be confused with billing rates	*Section 1.2*

1.3 Summary of Results

Table 2 provides a snapshot of the study results in three representative climate zones using the TDV metric.

- "Load" values represent the optimized efficiency levels of the research prototypes.
- "Solar" values represent the potential energy that can be produced using up to 80% of a building's roof area, but not exceeding the "Load".
- "Net" represents the combination of "Load" and "Solar", indicating whether the building is capable of reaching Zero Net Energy.

The study looked at likely 2020 levels of best-in-class building performance.

Table 2 – Sample of 2020 Performance Data for Climate Zones 15, 12, and 13

Technical Feasibility Summary — TDV$/ft^2 (30 yr)

	Percent of 2020 New Build	15: Palm Springs			12: Sacramento			3: Oakland		
		Load:	Solar:	Net:	Load:	Solar:	Net:	Load:	Solar:	Net:
Single Family Home	47%	12	-12	0	10	-10	0	8	-8	0
Multi-family Low-rise	8.5%	20	-20	0	15	-15	0	14	-14	0
Multi-family High-rise	3%	30	-11	19	23	-11	12	17	-12	5
Medium Office	2.1%	24	-24	0	19	-19	0	16	-16	0
Large Office	6.9%	22	-7	15	17	-7	10	15	-8	7
Strip Mall	6.7%	27	-27	0	24	-24	0	22	-22	0
School	2.8%	32	-32	0	27	-27	0	22	-22	0
Large Hotel	1.5%	47	-14	33	41	-13	28	41	-14	27
Grocery	1.8%	69	-69	0	68	-68	0	64	-64	0
Sit-down Restaurant	1.0%	150	-95	55	132	-93	39	114	-99	15
Hospital	1.9%	64	-16	48	61	-15	46	61	-17	44
Warehouse	6.6%	9	-9	0	7	-7	0	7	-7	0
College	1.7%	41	-40	1	36	-36	0	31	-31	0
Other Commercial	7.9%	32	-22	10	28	-20	8	25	-19	6

Three prototypes that cannot reach ZNE using rooftop solar might reach ZNE using parking lot PV systems – Multi-family High-rise, Large Office, and Sit Down Restaurant. See Section 4.2.1.3 for further discussion of the potential contribution of parking lot PV systems in pursuing the ZNE goals.

This study is not a cost effectiveness evaluation, but rather a test of technical feasibility to determine whether California's building stock can achieve ZNE in 2020 as measured by various metrics.

There are a few challenging building types, and the dependency of ZNE on solar energy will make many sites impractical. But overall, this research suggests that a wide portion of California's new construction can move to Zero Net Energy by

2020 for homes and by 2030 for commercial buildings. Moreover, with only a few exceptions, most of the technologies modeled in this study are available and being utilized today, demonstrating the applicability of this analysis to today's new construction market.

Most buildings that were able to reach a ZNE goal using the TDV metric were also able to reach the goal using the more challenging Site-kBtu metric. But a significant difference exists between the two metrics as to the amount of PV required to reach a ZNE goal. The Site-kBtu metric requires 80% more photovoltaic solar capacity to reach ZNE on residential buildings as compared to the TDV definition. The difference is 30% for commercial buildings in the study. The additional PV capacity required to reach ZNE using a Site-kBtu definition can add a substantial first cost in reaching a ZNE goal when compared to a TDV definition.

While this research suggests that California's ZNE goals should be largely achievable, that does not mean that it will be easy. It remains an aggressive target, requiring vigilance in almost all aspects of equipment engineering, building design, and construction. Building operations will also be critical to ensure buildings designed to meet a ZNE metric achieve net zero performance levels.

1.4 Presentation of Results

This research produced a significant volume of data across various building types, climate zones, efficiency measures, and building subloads. While there is insight to be gained from the full data set, much of it is also highly redundant.

To make the results more approachable, this report includes subsets of the overall data pool. For example, the report provides a more extensive set of data for certain representative buildings – e.g. Single Family Residence and Medium Office – and less data for other building types.

1.5 Recommendations

This report highlights a number of building strategies that can support the pursuit of the State's Zero Net Energy goals. This section summarizes those technical strategies and highlights broader research priorities that reach beyond specific technologies to address the challenges confronting the ZNE goals. Chapter 7 discusses these strategies in more detail.

1.5.1 Technical Strategies

The design packages outlined in this study represent one potential approach to reach ZNE goals. The "best" answer to reach any ZNE metric will differ for each specific building, owner, and site. ZNE design solutions will also progress with evolving technologies and industry understanding. Given the dynamic nature of the ZNE design process, tapping into flexible performance drivers – or market-based mechanisms – is likely to create the greatest breakthroughs for the field. For instance, increasing the investment in performance incentive programs such as

Savings by Design, and thereby increasing the number of ZNE, or ZNE ready buildings, will drive widespread advancements in the ZNE market. (See recommendation in Section 7.2.2).

While the greatest market transformation value may come from incentive programs tied to performance benchmarks, there are certain systems and design strategies identified by this research that are likely to create the big system efficiency gains necessary to reach ZNE goals (See Section 7.1 for further discussion):

Load Reductions:

- LED lighting performance improvements, which may move to over 200 lumens/Watt by 2020.
- Sensor controlled equipment that minimizes "just in case" usage.
- Further minimize heating of cooled air, and cooling of heated air.
- Minimizing plug loads will be critical to meeting the ZNE goals.
- Vertical transportation systems – elevators and escalators – show significant room for efficiency improvements.

Passive Systems:

- Much of California has an excellent climate for natural ventilation. Harnessing this resource should be further encouraged.

Active Systems:

- Move residential ducts out of the unconditioned attic.
- Heat recovery, whether from exhaust air or mechanical equipment, can offset a significant portion of heating loads in some buildings.

Renewable Energy:

- The challenge of ZNE is often one of available space for photovoltaics; increasing PV panel efficiency, thereby increasing power density, will help to address this challenge.
- Including parking lot PV installations in the ZNE equation can greatly increase a building's ability to offset load and reach ZNE.

Technologies and strategies that can be applied across a significant subset of the building volume will also show the greatest overall gains in moving the state toward its ZNE goals. These "universal" improvements include LED lighting efficiency, equipment integrated "auto-off" functions, PV panel efficiency improvements (offsetting all loads), and PV panel optimizers (also offsetting all loads). Another example, not modeled in this study, is transformers. This is true whether the transformers are integrated into a commercial building or sitting on the grid to supply smaller buildings. Transformers are especially worthy of design optimization in a ZNE context as high performance transformers perform notably better than conventional transformers when operating at low loads.

1.5.2 Research Priorities

- Future policy-related cost effectiveness analyses could better address the ZNE goals by analyzing integrated packages of efficiency strategies, rather than the present methodology that often completes such analyses on a measure-by-measure basis. (Section 7.2.1)
- As noted in Section 1.5.1, accelerate whole building design incentives, focusing where possible on ZNE and near ZNE projects. Match "whole building" design incentives with ever-greater training efforts in the area of integrated design and construction. (Also see Section 7.2.2)
- Federal preemption will continue to pose a notable impediment to regulation-based strategies for achieving the State's ZNE goals. State energy regulators and the Investor Owned Utilities (IOUs) should continue to investigate creative ways to achieve the regulated energy efficiency levels that the State needs to reach its ZNE goals without violating federal law. (Section 7.2.4)
- Future research should assess the variables that could impact PV sizing requirements for a ZNE building, such as ZNE metric choice and alternate valuation scenarios for electricity exports. (This assumes that PV is the primary on-site generation resource. See also Section 7.2.5)
- The level of distributed generation implicated by the State's ZNE goals could have significant impacts on the electricity grid. Statewide research should seek to estimate those impacts. (Section 7.2.6)

2 Purpose

The CPUC's Long Term Energy Efficiency Strategic Plan includes two "Big Bold" strategies that establish the following ZNE new construction targets: 1) all residential buildings by 2020, and 2) all commercial buildings by 2030. The Energy Commission adopted parallel goals in its 2011 IEPR.

California's IOUs have been working with the CPUC and the Energy Commission to pursue the ZNE goals. The IOUs have sponsored demonstration projects, provided efficiency incentives for high performance systems, and sponsored critical research to help the State progress towards its goal. PG&E's Zero Net Energy Pilot Program is a part of that effort.

This technical feasibility study is a deliverable for the ZNE Pilot program. The study was jointly funded by the four IOUs: PG&E, SCE, SDG&E, and SoCalGas. The IOU Evaluation, Measurement and Verification staff supervised the research, with additional oversight from the Energy Division at the CPUC.

The study seeks to provide guidance to the IOUs and to the State as follows:

2.1 Feasibility of ZNE

This study is a preliminary "stress test" of the California ZNE goals on a building-by-building basis. Most of the building types explored pass that test. Single family residences and low-rise multi-family residences can be designed to meet ZNE goals using strategies and technologies available today. Those two residential building types alone comprise over 50% of construction volume on a square foot basis.

This is a technical feasibility study, and as such, evaluates what the research team considered likely best-in-class building performance in 2020. Design decisions were not constrained by cost, although overall "constructability" was a notable driver in implementing energy efficiency features in the prototypes. For example, the engineers on the research team have essentially specified every building component embedded in these models on previous building projects.

2.2 ZNE Design Strategies

A secondary purpose of the research was to identify the feasible design strategies and technologies most likely to enable Zero Net Energy buildings in California in the coming decades. The research team implemented these design strategies through a series of 12 building types selected to represent a broad selection of California's building stock. The prototypes, with ZNE optimized efficiency and renewable energy features, are known as "exemplar prototypes" within this research. See Section 3.3 for more background on the exemplar prototypes.

The report details the design strategies as a series of improvements to the relevant energy models. Chapter 4: Methodology and Chapter 8: Exemplar Prototypes explain the research team's design process.

In identifying design strategies that explore the boundaries of technical feasibility, this research does not intend to be a design guide for all of the building types explored. It illuminates one possible approach to reach the lowest possible energy use intensity (EUI) in each building type, and its outputs are necessarily constrained by the nature of this prototype driven research.

Moreover, the research focused on optimizing energy performance, not on optimizing overall cost effectiveness. An effort was made to estimate the overall cost of the exemplar design changes, although it is not a rigorous or precise estimate. (See Chapter 5)

2.3 Technical Challenges, Strategies, and Research Priorities

Along with the identification of ZNE enabling design strategies, this study also identifies some of the more important technical challenges to quickly advancing standard construction practices to meet the ZNE goals. This study provides a series of technical strategies and research priorities to address those challenges (See Chapter 7).

2.4 ZNE Scenario Analysis Tool

Although not included in the original project scope, a companion output of this research is the Scenario Analysis Tool software that will allow the California IOUs to explore alternative design and performance combinations other than those outlined in the exemplar prototypes. The research team developed the tool during the course of the project as an optimization resource that provided an estimate of the relative change in energy performance across a number of metrics, looking at the interactive effects of the building subcomponents.

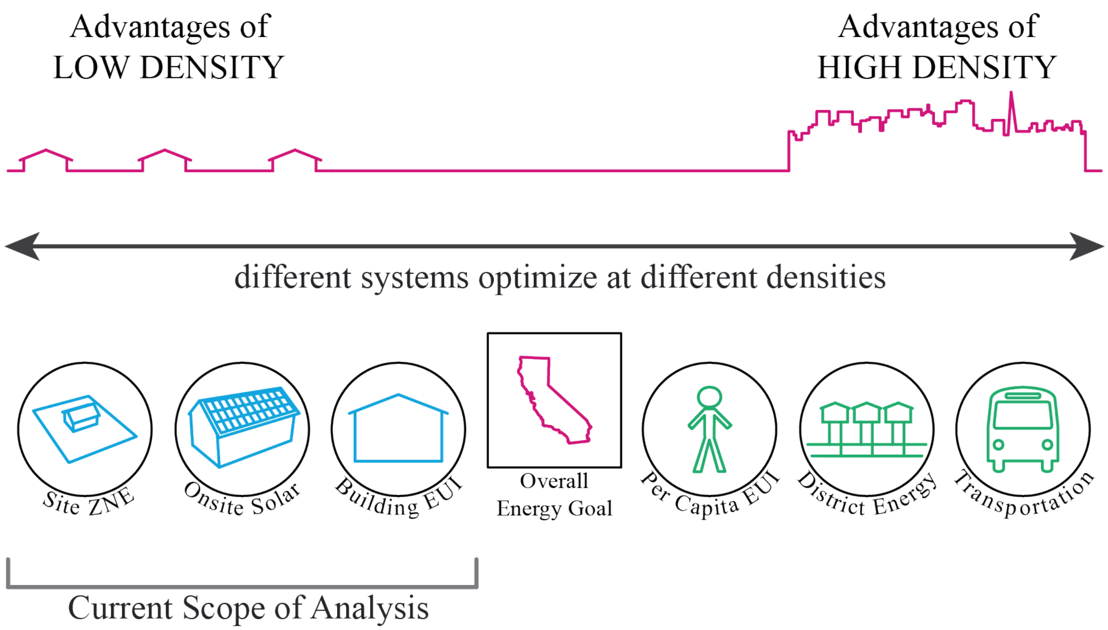
This tool has been alternately described as the "what if" database, providing technical feasibility answers if, for instance, plug loads increase in volume rather than decrease, or if LED performance only moves to 180 lumens/Watt rather than the projected 220 lumens/Watt.

Documentation on the Scenario Analysis Tool methodology will accompany the software itself. As the tool's creation was a byproduct of the research effort and not an intended output, as of the writing of this report, it is not clear how or whether this tool will be publicly available due to the lack of funding and administrative infrastructure to accomplish such a task.

2.5 A Note on Density

Although not a direct topic of exploration in this research, density plays an important role in both overall energy use – generally decreasing per capita energy use – and the ability of a building to reach ZNE. This creates an inherent tension. More people in an office building requires less lighting *per capita* and results in less envelope gains *per capita*. However, those higher occupant densities also increase energy use per square foot, which is the standard metric for assessing building performance. Assessed more broadly, dense urban environments have much lower vehicular energy use per capita. Taken together, these notes suggest a complicated set of tradeoffs associated with densely populated buildings that could result in high energy use intensities.

At the same time, an on-site ZNE definition is heavily dependent on photovoltaics. Photovoltaics thrive on space. Photovoltaics can offset the greatest amount of load when paired with low-density occupancies and low-density planning.



Despite these complications, the widespread feasibility of ZNE demonstrated in this study suggests that, with proper planning, the tradeoff between high density planning and distributed photovoltaic production might be a concern in the minority of cases.

3 Background

This section outlines some of the fundamental parameters of the research, whereas Chapter 4, Methodology, provides greater depth on the design process.

The research looks strictly at on-site solutions to achieving Zero Net Energy on a building-by-building basis. That is, the research does not estimate or consider off-site sources of energy from district systems, renewable generation, etc.

Also, ZNE in the context of this study is an energy model based definition. It is not an operational definition. While this study finds that homes and many commercial buildings can be built to meet the ZNE goals in 2020, this study is not saying that it can be done cost effectively nor is this study saying that the buildings will be operated to achieve annual zero net energy. The cost and operational questions require further research.

3.1 Metrics

This research used two primary metrics for assessing the performance of buildings: Site-kBtu and Time Dependent Valuation (TDV):

Table 3 – Energy Use Intensity (EUI) Metrics for ZNE Building Assessment

EUI Metric:	Attributes:
Site-kBtu	• *Units: kBtu/ft^2/yr* • *This is a site metric and the metric by which the performance of many ZNE buildings have historically been evaluated.*
TDV (generic) *or* **TDV$** (for values specifically given in dollars)	*"Time Dependent Valuation"* • *Units: Dollars, based on 30-Year Net Present Value of energy.* • *TDV is a modified participant cost test, with average annual values equal to retail rates, but with hourly variations adjusted in accordance with statewide, or "societal", energy costs.* • *TDV does not provide information on building-specific energy bills.* • *Generally considered a "source" metric, with additional multipliers for factors other than natural gas delivery and electricity generation.* • *Section 3.1.2 discusses the subcomponents of this metric in further detail.* • ***The terms "TDV" and "TDV$" are interchangeable throughout the report.***

3.1.1 Site-kBtu (kBtu/ft^2/yr)

Site-kBtu is the most commonly used EUI metric for national ZNE discussions. It does not, however, value the time-of-use element of energy or take into account source-to-site energy conversion factors.

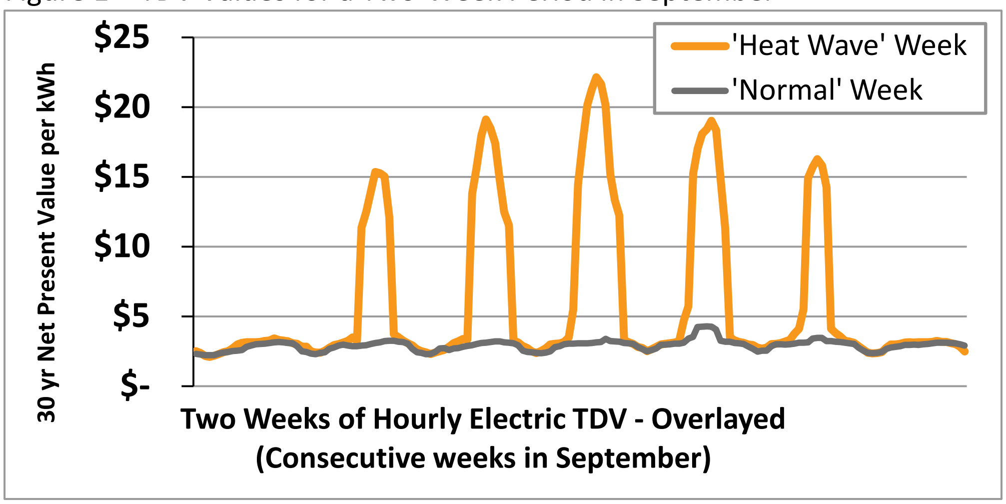
3.1.2 Time Dependent Valuation (TDV)

TDV is a robust metric, accounting for source energy values, demand reduction values, the emitted carbon from energy production (valued at projected carbon market prices), and a host of other variables. It is an elegant way to optimize building performance across a number of overlapping State and consumer objectives using a single metric. TDV was developed specifically for California's Title 24 (Part 6) Building Energy Efficiency Standards.

This research has optimized building energy efficiency systems to minimize TDV. TDV was the guiding metric used during the design process for the exemplar prototypes so that design strategies would "address" and minimize the various costs embedded and balanced within the TDV metric. This methodology aligned the study's prioritization process with that used by the California Energy Commission in the updates of Title 24.

As the name implies, TDV assigns a different cost to energy use for each hour of the year. Most variation is comparatively small throughout the year. However, for the 250 hours of the year that the TDV methodology recognizes as the driver for new generation and transmission needs, the valuations can spike notably.

Figure 1 – TDV Values for a Two-Week Period in September



Natural gas values are flat on a monthly basis, but are modestly higher in the winter as compared to summer values (natural gas not pictured here). As a "source energy" metric, TDV values electricity far higher in relation to natural gas than does Site-kBtu, in comparison.

3.1.2.1 An Economic Metric

TDV is ultimately an economic metric, aggregating costs for fuel, generation turbines, transmission systems, carbon, etc. Although the metric is sometimes reported as TDV kBtu, this is a policy implementation anomaly rather than TDV's native units. The term "TDV$" is used on occasion to make clear that it is the fiscal valuation being reported. This study uses exclusively the 30-year values for TDV$.

The 30-year net present values were derived from one year of energy modeling (8760 hours), but they do not represent "per year" values. The 8760 hours of energy modeling were used to extrapolate to 30 years of energy use.

Interestingly, the 30 year TDV$ values for building performance are surprisingly close to the corresponding kBtu/ft^2/yr values. While the metric scales are similar, the two metrics respond to energy loads in distinct ways: buildings with higher levels of on-peak electricity use will tend to have a higher TDV$ value as compared to Site-kBtu, whereas buildings with more off-peak usage will tend to have higher Site-kBtu values.

This correlation – mostly a convenient coincidence – means that 30 year TDV$ values can generally be viewed on the same "Great" / "Good" / "Not quite there" scale that design and policy professionals are currently using to evaluate building performance based on a Site-kBtu metric.

A few matched sets, by way of example:

Table 4 – Sets of Site-kBtu vs. TDV$

Metric:	Bldg 1	Bldg 2	Bldg 3	Bldg 4	Bldg 5	Bldg 6	Avg.
Site-kBtu	*13.0*	*17.0*	*73.8*	*18.3*	*19.7*	*36.8*	***29.8***
TDV$	*11.9*	*18.9*	*66.7*	*21.1*	*10.3*	*40.2*	***28.2***

One note of caution: the TDV$ values will change over time, with inflation and with evolving projections on the future cost of energy. At least for now, however, the two metrics' respective scales closely align.

3.1.2.2 TDV as a Renewable Energy Metric

Because TDV was developed to assess the value of energy efficiency measures, it is not yet clear that it is the best metric, without further modification, to value photovoltaic exports back onto the grid. This report offers consumption and production values in both Site-kBtu and TDV to provide some clarity on the policy implications of using those respective metrics. It is possible that a third, more appropriate metric will emerge for balancing energy consumption with energy exports back to the grid.

3.1.3 Impact of Metric Choice

As can be seen in the "Incremental Reductions by Measure" graphs for some prototypes (throughout Chapter 8), Site-kBtu tracks TDV$ quite closely at the level of comparable improvement (on a percent basis) for a given efficiency measure. The most notable exceptions relate to measures that reduce cooling loads while simultaneously increasing some heating loads, such as window overhangs. More often than not, either metric will point towards the same optimal design decisions.

The biggest impact of ZNE metric choice is in scaling a building's photovoltaic production to get to ZNE. PV production gets more "credit" in comparison to a building's energy consumption using the TDV$ metric as compared to a Site-kBtu metric. Consequently, in many cases, PV sized for a building based on the TDV$ metric would be smaller than PV sized for the same building using the Site-kBtu metric.

For buildings that are more consistently off-peak, such as homes, the choice of metric can be significant, with Site-kBtu requiring a PV system approximately 80% larger as compared to using a TDV$ ZNE metric. A weighted average across a number of commercial building prototypes shows that the Site-kBtu metric would require 30% more PV capacity than would be required to meet a ZNE goal using the TDV$ metric. The additional solar capacity necessitated by a Site-kBtu metric, as compared to a TDV metric, could add significant additional first costs in moving buildings towards the State's ZNE goals.

For buildings where loads track more closely to PV production curves – such as 8:00 am to 6:00 pm office buildings – using either metric to specify a Zero Net Energy PV system would result in essentially the same size of PV system.

3.1.4 Time of Use Electricity and Natural Gas Consumption

The study also documents kWh and therm energy use data by summer and winter as well as on-peak and off-peak time periods for further analysis from the perspective of utility customer billing rates. This report provides data for a few representative buildings, such as Single Family Residence and Large Office. See Section 8.1 for further explanation of this data. Both building load and solar production data are provided.

3.1.5 TDV, Export Valuation, and ZNE

With the exception of this subsection, this study compares energy consumption to photovoltaic production on a direct unit-to-unit basis without regard to the direction that energy is flowing into or out of a building. Because the California ZNE goal entails zero "NET" energy, the study must assume that some type of valuation of energy exports occurs within the energy calculations. For the sake of simplicity, the study assumes that *energy exports* are valued at 1:1 parity with *energy imports* for the ZNE calculations. That 1:1 ratio serves as a baseline for analysis of alternate import/export valuation ratios in Section 3.1.5.2.

3.1.5.1 Limitations of the ZNE accounting used in this study

The energy accounting assumptions used in this study entail a number of caveats to provide a complete view of the study results. Understanding those caveats provides insight as to how different assumptions might affect the results of this technical feasibility analysis.

Natural Gas and Electricity "Trading": A key trait of most ZNE calculations is that electricity overproduction can be readily "traded" in the analysis with natural gas consumption. Through this tradeoff, the "Net" of ZNE is fully realized. There is not presently, however, a way for this type of netting to occur from a consumer's perspective. For consumers, electricity and natural gas are metered and billed separately.

Electricity Exports Measured as Equivalent to Electricity Imports: A potential shortcoming with the "netting" methodology of this study is that the 1:1 valuation of energy imports and exports is not necessarily an appropriate way to value photovoltaic exports to the grid, at least from the perspective of statewide electricity production and distribution costs. TDV, which this study used for both imports and exports, was specifically designed to assess only the statewide production and distribution costs of *energy imports* to a building.

There are potentially additional costs for *energy exports* from a building if those exports push the grid to perform in a manner for which the grid is not presently designed. Those costs, once understood, could be incorporated into specific TDV$ values for solar electricity exports. Those grid impact costs could also grow along with the rapidly increasing saturation of distributed photovoltaic generation.

TDV Schedules Based on Current Peak Grid Conditions: Compounding these estimation issues are the underlying inputs of the Title 24 2013 TDV schedules used in this study. The peak hour valuations of those TDV schedules are based, largely, on the current state of grid supply and demand. The level of solar electricity expected to be on the grid in 2020-2050 – when the ZNE buildings contemplated in this study will be operating – will be far in excess of that seen today. As a result, the hours of peak electric demand will shift ever further into the evening, occurring primarily once the sun starts to set. (See Figure 17 for the California Independent System Operator's [CAISO] outlook on the likely peak shift by 2020.)

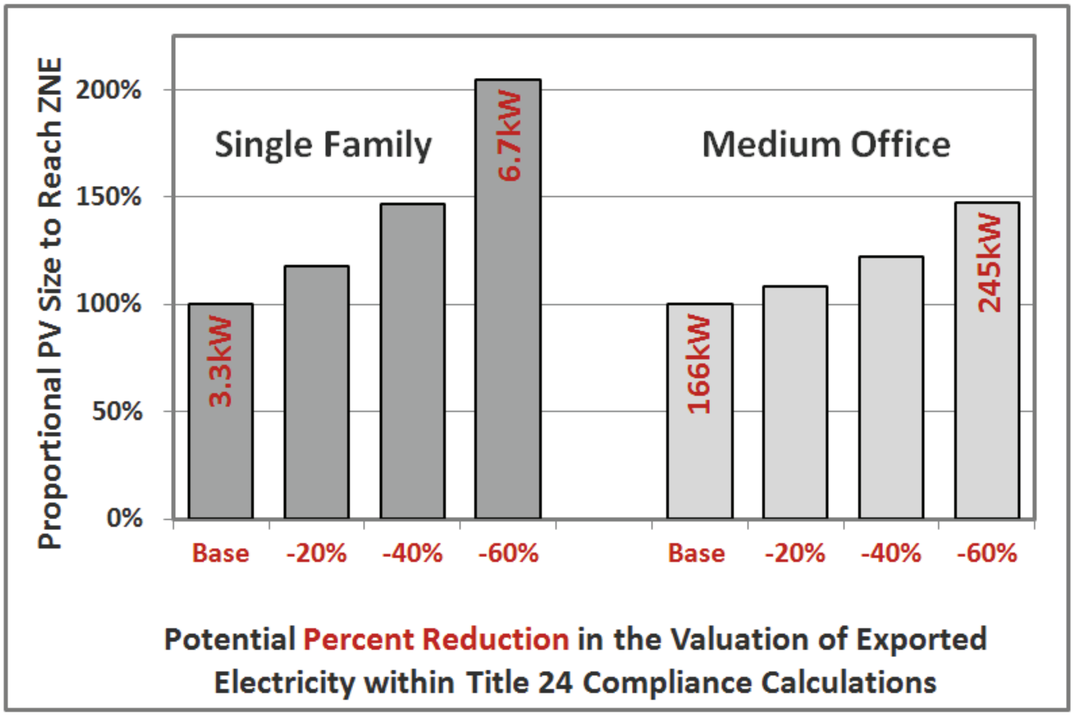
That shift in grid peak towards early evening will cause a decline in the relative value of solar electricity production using a TDV metric (*See* Mills, 2012 for related conclusions). Considering a probable 2020-2050 TDV schedule, solar electric production will see diminishing correlation with the types of extremely high peak demand TDV values illustrated in Figure 1. The shift in TDV peak values towards early evening could necessitate greater levels of PV capacity installation to reach ZNE on a given building than is stated in this study.

3.1.5.2 PV sizing implications of valuing electricity exports differently than electricity imports

The State would likely pursue the ZNE new construction goals, in part, through the Title 24 Building Energy Efficiency Standards. Complying with those standards will require a compliance calculation. That calculation will need to assign a value to modeled electricity exports in relation to modeled electricity imports. While that valuation could be done on a 1:1 basis (treated here as the "Base Case"), there are likely to be additional electricity grid management costs associated with the export of electricity from ZNE buildings that would point towards the use of a different ratio. That ratio would likely value electricity exports at a lower level than electricity imports.

Figure 2 illustrates the respective sizes of PV systems that would be required to reach a ZNE goal based on differing levels of valuation of *electricity exports* as compared to *electricity imports*. This analysis assumes that the valuation adjustments are being applied to the standard Title 24 TDV schedule within the compliance calculation process (T24 2013 in this case). To illustrate this point, export valuation adjustments were chosen for the scenario analysis in Figure 2 to demonstrate the potential magnitude of the variance.

Figure 2 – PV Sizing to Reach ZNE under Alternate PV Export Valuation Scenarios



This comparison calculation is constrained in many ways, most notably by the hourly resolution of the building and PV energy models used in this study. The variability within a real building is likely to be far greater than what is observed in the hourly models, and that variation would likely lead to an even greater proportion of PV generation in the export condition, and thereby a greater devaluation of the PV production.

The *larger system sizes* needed to reach ZNE in the “modified export valuation” cases are still producing *the same total value of energy for the building*, as that production is by definition equal to the value of the energy consumption in the building (which is fixed in the analysis). Because there is more PV producing the same amount of value to the building in the -20%, -40% and -60% scenarios, the cost effectiveness of the PV in those scenarios is simultaneously reduced.

The likely grid management costs of distributed generation exports is presently being reviewed by the CPUC and others to help determine the appropriate billing rate for electricity that is exported from a building. The eventual resolution of that process will provide greater clarity in calculating Zero Net Energy feasibility. Given the potential energy accounting adjustments that might be utilized in future ZNE policies, the TDV based results of this study should be seen as a likely low-side estimate of the required photovoltaic system size to move a building to Zero Net Energy.

This PV sizing analysis suggests that while there are multiple variables in the ZNE equation that could affect PV sizing requirements, export valuation will be one of the most impactful. For recommendations on research to further investigate the PV sizing implications of differing metric choices and valuation scenarios, see Section 7.2.5 – PV Sizing Sensitivity Analysis.

3.1.6 Weather

All modeling for this study was conducted using the Title 24 2013 weather files (Huang, 2010). These files represent a notable improvement on earlier weather files in that there is correlation between the weather that drives building energy use with the weather driving the performance of the overall utility grid. This correlated modeling of both buildings and the utility grid allows for a proper accounting of the monetary impact of energy use during peak summer days.

This correlation is further implemented through the Title 24 2013 TDV schedules. The average temperature within the Title 24 2013 weather files is 1 degree Fahrenheit warmer than earlier Title 24 weather files.

3.1.7 Demand

This analysis reports peak demand for the exemplar prototypes using the “250 Hour Method” that calculates the weighted average peak for energy consumption across the 250 hours of the year with the highest overall demand on the grid. This schedule of hours is the same as that used to assign capacity values to the TDV schedules.

Because many ZNE buildings can actually be net exporters during those peak events, their demand valuation can be negative. The buildings would certainly have a net positive demand at other times, on cloudy days or at night, but those net positive demand days would not align with the peak grid hours. As such, the “250 hour” demand values should not be used for estimating demand charges.

This analysis reports peak solar exports for the exemplar prototypes as the single highest hourly value.

3.1.8 Carbon

One driver of the State’s ZNE strategies is the desire to reduce carbon emissions, as directed by California AB32 (the Global Warming Solutions Act of 2006). This analysis reports carbon emissions for the exemplar prototypes once rooftop PV offsets are sized to accommodate the estimated energy consumption. The analysis used the following carbon values:

Table 5 – Carbon Values for Electricity and Natural Gas

Electricity		Natural Gas	
MWh	0.27 tonnes	Therm	0.006 tonnes

The emissions value for electricity consumption is based on the projected efficiency levels of the marginal generation procurement resources of utilities in California, which are likely to be 1) 67% gas turbines with a heat rate of approximately 6,900 and 2) 33% renewable resources, per the Renewable Portfolio Standard (RPS).

A building that is ZNE using a TDV metric will generally produce more carbon than a building that is ZNE using a Site-kBtu metric. This difference is more notable for residential buildings than for commercial buildings. The difference relates to the relative sizes of installed PV systems (kW of capacity) necessary to move a building to ZNE under the two metrics.

Using the carbon values in Table 4, electricity emits 30% more carbon per Site-kBtu of energy use than does natural gas. But in situations where electricity and natural gas are somewhat fungible – such as space heating – the much higher efficiency of heat pumps (COP = 3.0 = 300%) as compared to condensing combustion technology (max efficiency = 97%) means that electrically driven heating can have a lower carbon footprint than natural gas heating. This somewhat surprising result derives from the comparatively low carbon/kWh content of California's energy supply relative to other U.S. states. This analysis does not mean that heating with electricity will be less expensive in California, only that such heating might result in lower carbon emissions.

3.2 Research Prototypes

This research uses 12 prototypes from three sources. The research then extrapolates from those 12 building types to two more composite building classes documented in the construction volume forecasts: "College" and "Other Commercial".

Table 6 – Prototype Sources

Building Type:	Source:
Single Family Residence	*CEC Prototype adapted for use in EnergyPlus*
Multi-family Low-rise	*New model based on common multi-family projects*
Multi-family High-rise	*DOE EnergyPlus research prototype – ASHRAE 90.1-2010* [1]
Medium Office	*DOE EnergyPlus research prototype – ASHRAE 90.1-2010*
Large Office	*DOE EnergyPlus research prototype – ASHRAE 90.1-2010*
Strip Mall	*DOE EnergyPlus research prototype – ASHRAE 90.1-2010*
Secondary School	*DOE EnergyPlus research prototype – ASHRAE 90.1-2010*
Large Hotel	*DOE EnergyPlus research prototype – ASHRAE 90.1-2010*
Grocery	*DOE EnergyPlus research prototype – ASHRAE 90.1-2004*
Sit-down Restaurant	*DOE EnergyPlus research prototype – ASHRAE 90.1-2010*
Hospital	*DOE EnergyPlus research prototype – ASHRAE 90.1-2010*
Warehouse	*DOE EnergyPlus research prototype – ASHRAE 90.1-2010*
College	*Energy use estimated via composite of related buildings*
Other Commercial	*Energy use estimated via composite of all commercial bldgs.*

The Department of Energy (DOE) research prototypes were chosen as the basis for the commercial research for a number of reasons:

- Uniformity with other building performance research projects.
- A high level of energy efficiency as a starting point when structured to meet ASHRAE 90.1-2010.
- The models are EnergyPlus files, and EnergyPlus is one of the few energy modeling engines that can simulate almost all of the ZNE design strategies explored in this research.
- Integrated operational assumptions that are derived from CBECS[2], incorporating everything from lighting schedules, to equipment power densities, to occupant entry driven infiltration rates. This standard operational data derived from CBECS is critical to establish “normal” patterns of building occupancy and operations.

The use of the EnergyPlus research prototypes did impose some challenges for the project. EnergyPlus is a very sophisticated platform, but it can be much more laborious to manipulate than other modeling tools. The challenges of changing parameter settings within EnergyPlus, particularly for complex HVAC systems, limited the overall number of design strategies that the research team could explore.

[1] ANSI/ASHRAE/IESNA Standard 90.1-2010.
[2] Commercial Buildings Energy Consumption Survey (CBECS), U.S. Energy Information Administration

Detailed information on the baseline model attributes can be found in Excel "Scorecards" available from the DOE. As of December 2012, those files can be found through links at the following websites:

For the Grocery prototype, originally designed to meet ASHRAE 90.1-2004: http://www1.eere.energy.gov/buildings/commercial/ref_new_construction.html

For all other commercial prototypes, originally designed to meet ASHRAE 90.1-2010: http://www.energycodes.gov/development/commercial/90.1_models

3.3 Representative Climate Zones

The research optimizes building performance for five distinct climate zones. The research also used the prototypes optimized for CZ12 and simulated their energy performance in CZ13. Likewise, the optimized prototypes for CZ10 were modeled using CZ7 weather files.

Table 7 – Representative Climate Zones

Climate Zones			
15	**Palm Springs**	Hottest climate "bookend"
13	**Fresno**	Central Valley climate with less nighttime cooling
12	**Sacramento**	Baseline climate for the research; highest projected construction
10	**Riverside**	Warmer inland climate
7	**San Diego**	Mild coastal climate south
3	**Oakland**	Mild coastal climate north
16	**Blue Canyon**	Coldest climate "bookend" (Sierras)

3.4 2020 Reference Year

The analysis used 2020 as the focal point for the commercial analysis as well as the residential analysis, even though the commercial ZNE goal is 2030. The use of 2020 as the universal analytical point is due, in large measure, to the challenges of projecting system performance levels and measure costs beyond 2020. At the modest pace that the construction industry moves new technologies to market, most of the systems that would be used in a market-ready ZNE design in 2020 are likely to be in early stages of development and testing today. The research team used that information to make estimates of performance and prices in 2020.

4 Methodology

The objective of this research was to minimize the overall TDV of the exemplar prototype buildings, focusing primarily on energy efficiency. Therefore, the research team executed its design processes, largely, in the same manner that firms design high performance buildings for "standard" ZNE or high performance construction projects.

In this way, the research borrowed heavily from the experience of the lead engineering firms. Design contributions, modeling methodologies, and assumption validations came from around the world via Arup's internal knowledge sharing network. Davis Energy Group and Sun Light and Power have also worked on a number of Zero Net Energy projects in recent years and have incorporated lessons from those projects into this research.

4.1 Efficiency First, Then Renewables

In designing the ZNE or near ZNE prototypes, the research team prioritized energy reduction measures as follows:

Table 8 – ZNE Design Steps

Stage:	Design Focus:	Example:
Step 1:	***Reduce Loads***	Triple-silver low-e fenestration
Step 2:	***Passive Systems***	Natural ventilation
Step 3:	***Active Efficiency***	Chilled beams
Step 4:	***Energy Recovery***	Integrated heat pump water heater w/ AC
Step 5:	***On-site Renewables***	Roof-top photovoltaics
Step 6:	***Cogeneration***	Fuel-cells for taller buildings

(Note: Many design strategies span multiple categories.)

This prioritization of the design process matches the priorities embedded in the State's loading order (2003 California Energy Action Plan). That loading order views efficiency as the primary tool for meeting California's energy needs, followed by renewable energy production.

Although the Technical Feasibility Study looked to establish the technical feasibility for ZNE design regardless of cost, this staged design methodology included the added benefit of focusing design efforts first on those solutions that are likely to have the lowest life-cycle costs in 2020.

The analysis combined parametric modeling, professional experience, and industry best practices derived from case studies to determine the best design strategies. To help guide the analysis, the Energy Division of the CPUC created and led a Project Advisory Group (PAG). The goal of this group was to regularly brief Energy Division on the status of the ZNE studies and to collect input for consideration on major project milestones.

While the objective of the research was to minimize energy use without adhering to a strict cost effectiveness test, the research made every effort to implement technologies and design solutions that already are widely available or could be widely available with likely future improvements.

4.1.1 Measures Tested, but Not Implemented

The exemplar prototypes outlined in this report represent the "final cut" of the modeling teams' design process. Far more measures, strategies, adjustments, and schedule assumptions were tested and eventually left behind than were incorporated into the final models. These measures include:

- Radiant cooling in the Medium Office (VAV outperformed radiant at low sensible loads)
- Insulated residential roof deck (performance and constructability of ducts in conditioned space and insulation at ceiling were found superior)
- Lower Solar Heat Gain Coefficient (SHGC) levels on the office windows (found to decrease overall performance when paired with widow shading)
- Solar thermal (photovoltaics achieved equal or better energy offsets , but utilizing only one solar renewable system [photovoltaics] simplified this analysis and would simplify constructability). Certain policy choices, not explored here, might create a structural preference for solar thermal systems in the ZNE context.
- Sawtooth daylighting configurations for some of the commercial roofs (heating and cooling penalty outweighed the daylighting advantages)
- Dynamic glazing products (the SHGC to Visible Transmittance (VT) balancing properties of high performance low-e windows were thought to come close to matching the performance of dynamic glazing, while presenting fewer constructability and maintenance issues)

4.2 Renewable Energy and Combined Heat & Power

The analysis covers a range of renewable energy systems in the analysis: rooftop photovoltaics, parking lot photovoltaics, and solar thermal systems. Window overhang photovoltaics were also analyzed. The research looked into the benefits of combined heat and power systems on buildings that were unlikely to reach ZNE targets using on-site photovoltaics.

4.2.1 Photovoltaic Systems

Photovoltaic systems were analyzed in a number of configurations:

1. Commercial rooftop installations

2. Parking lot installations using a single-axis tracker
3. Building integrated window shading installations
4. Residential installations

The standard assumption across all building types was that 80% of the south facing roof was available for the installation of photovoltaic systems. This number was reduced to accommodate skylights in some of the models. With creative installation practices and roof design strategies, 2020 photovoltaic systems will offset the loads of the exemplar ZNE prototypes in most cases.

Window overhang PV installations did not prove sufficiently beneficial to include in any of the models at present. There are certainly circumstances in taller buildings where they might prove fruitful in closing the consumption / production gap.

Although the residential prototype has a roof with four hips to make it orientation neutral, the PV modeling assumes that the roof has a ridgeline running east to west, with solar on the southern slope. Similarly, the PV modeling assumed that the Multi-family Low-rise building had a flat roof even though the prototype had a sloped roof. Both roof types are seen in California. Asymmetric residential roofs, with a longer run on the southern slope, are also a viable design strategy to increase PV output.

4.2.1.1 Photovoltaic Performance Assumptions

A key challenge of ZNE from the perspective of renewable energy systems is power density. A combination of panel optimizers, panel efficiency, and improved racking will continue to increase the overall production of energy for each square foot of available space.

This study considered 80% of a building's total roof space available for PV installations. Panels are sloped at 10% for commercial applications and spaced at 15% (counted as panel space usage when progressing to 80% roof usage). Panels are sloped at 20% for the Single Family Residence without spacing.

The modeling used 20% efficient panels, and assumed a further 20% increase (to 24% efficiency) by 2020. Ten percent of additional production was assumed to come from panel optimizers integrated with the system. The PV production numbers also assume an average degradation of 10% over the system lifetime. These performance adjustments amount to 60% greater production than is observed with the standard 15% efficient panels generally installed today.

The reporting on solar attributes by building type indicates the amount of solar that would need to be installed, in kW of capacity, to get to ZNE using a Site-kBtu or a TDV metric. The previously noted PV efficiency improvements do not change the required amount of kW that needs to be installed, but the PV efficiency improvements do impact the necessary space needed to achieve a given kW target.

4.2.1.2 The Future of PV

While it is difficult to predict the future for solar PV, there is promise for notable improvements in the technology's production efficiency. The best production modules only operate at 20% efficiency now, leaving significant room for improvement. Top performing modules in 2020 are likely to reach the 24% efficiency levels estimated for this technical feasibility research.

The primary breakthrough for PV in recent years has been in cost reduction. Price points for crystalline solar PV modules in 2012 are at about half of what they were in 2010 and about a quarter of the prices from 2005. Prices for the systems assessed for this report already range as low as $3.00/W installed for a 500 kW system.

4.2.1.3 Parking Lot Photovoltaics

Parking lots represent a significant opportunity for energy production in furtherance of the State's ZNE goals. If a parking area is part of the same property as the associated building load, PV systems installed over parking spaces can produce "behind the meter" energy that comports with the Energy Commission and CPUC "on-site" definitions of ZNE (extending beyond the building footprint to the contiguous property boundary).

Table 9 provides a coarse estimate of parking lot sizes associated with each building type and the PV production potential of those parking lots.

Table 9 – Estimated 2020 Parking Lot Solar Production Capabilities Using 35% of Standard Available Parking Area, Weighted by Associated Building Area

Solar PV on Parking Lots	Total Building Area (ft^2)	Average Parking Spaces	kWh/ bldg-ft^2	Site kBtu/ bldg-ft^2	TDV$/ bldg-ft^2
Grocery	45,000	180	19.5	66.4	76.42
Hospital	241,410	200	4.0	13.6	15.64
Large Hotel	122,132	80	3.2	11.0	12.65
Multi-Family High-rise	84,360	120	6.8	23.0	29.79
Multi-Family Low-rise	14,700	20	5.8	19.8	25.65
Large Office	498,600	750	7.1	24.3	27.99
Medium Office	53,600	180	15.6	53.1	61.16
Sit Down Restaurant	5,502	60	52.5	179.2	206.19
Secondary School	210,900	280	6.3	21.5	24.78
Strip Mall	22,500	120	25.9	88.4	101.74
Single Family	2,100	N/A	N/A	N/A	N/A
Warehouse	49,495	50	4.5	15.5	17.81

Note: kWh/parking space estimated at 3800 kWh/yr, with the high output coming from the use of trackers, high efficiency panels, optimizers, and other improvements that will arise through 2020.

Two methods were used to calculate average parking lot sizes. Aerial imagery of parking lots in Berkeley, Fresno, and San Diego were collected for each building type. Parking lot sizes for each city varied: the more urban Berkeley and San

Diego areas had generally smaller lots than Fresno. Lot sizes (in ft^2) across the three cities were averaged to produce an estimated number of spaces available. A Los Angeles zoning ordinance is the reference for the second parking lot data point. These two data sources were generally consistent, and an average of the two was taken to produce the final estimate.

Based on these parking space estimates, the building types that offer the most energy production potential include large offices, schools, hospitals, and grocery stores. Note that in more urban areas, buildings often have parking structures and therefore only a portion of the spaces (those on the roof of the garage) would be available for PV installation.

The final Site-kBtu and TDV$ production numbers relate parking lot production at 35% coverage of estimated parking area to the square feet of floor area of the corresponding prototype building. (In other words, the estimated parking lot PV production provides the numerator of the "energy/ft^2" figures, and the building square footage provides the denominator of the "energy/ft^2" figures.)

The study assumed tracking PV systems in parking lots. The tracking systems both increase overall yield per installed watt and spreads production across a wider range of hours. Tracking systems will help offset loads during evening peaks.

Applied to the prototype buildings that were unable to reach the ZNE targets using rooftop PV alone, the parking lot PV resulted in the following TDV$ EUIs:

Table 10 – ZNE Technical Feasibility with the Addition of Parking Lot PV

Technical Feasibility w/ Parking PV — **TDV$/ft^2** (30 yr)

Percent of 2020 New Build		15: Palm Springs			12: Sacramento			3: Oakland		
		Load:	*Solar:*	*Net:*	*Load:*	*Solar:*	*Net:*	*Load:*	*Solar:*	*Net:*
Multi-family High-rise	**3%**	**31**	-11	19	**23**	-11	12	**17**	-12	5
w/ parking PV			*-31*	***0***		*-23*	***0***		*-17*	***0***
Large Office	**6.9%**	**22**	-7	15	**17**	-7	10	**15**	-8	7
w/ parking PV			*-22*	***0***		*-17*	***0***		*-15*	***0***
Large Hotel	**1.5%**	**47**	-14	33	**41**	-13	28	**41**	-14	27
w/ parking PV			*-26*	***20***		*-25*	***16***		*-26*	***15***
Sit-down Restaurant	**1.0%**	**151**	-95	55	**131**	-93	39	**114**	-99	15
w/ parking PV			*-151*	***0***		*-131*	***0***		*-114*	***0***
Hospital	**1.9%**	**63**	-16	48	**61**	-15	46	**60**	-17	44
w/ parking PV			*-32*	***32***		*-31*	***30***		*-32*	***28***

The results in Table 9 indicate that the Multi-family High-rise, Large Office, and Sit-down Restaurant building types could achieve ZNE TDV$ if parking lot PV were included in the analysis. Other building types not modeled in this study – including stadiums, theaters, other entertainment centers, airports, and large commercial malls – likely represent even larger opportunities for installing parking lot PV.

4.2.1.4 Parking Lot Net Impacts

While it is important to consider the use of parking lots for renewable energy production when working on a ZNE project, parking lots inevitably facilitate transportation via cars. This could make parking lots a net energy consumer, depending on how the impact is measured, even if covered with a photovoltaic system. This relates to the density issues discussed in Section 2.5.

4.2.2 Solar Thermal

Solar thermal systems were analyzed for this analysis, but PV was generally considered a better strategy in the context of this study for offsetting consumption loads. The energy produced by solar thermal systems on a per square foot basis is comparable to that of PV systems (from a source energy perspective). Many ZNE projects may prefer a solar thermal system for thermal applications over a PV system, but the overall technical feasibility of a building should be essentially the same with either technology.

Policy decisions on how PV production can offset thermal loads that are being met by on-site natural gas combustion will have a significant impact on the role of solar thermal systems in meeting the State's ZNE goals.

4.2.3 Combined Heat and Power

Combined Heat and Power (CHP) systems were assessed for buildings where rooftop PV and parking lot PV could not meet the ZNE performance goal. CHP systems were sized to meet the remaining load after rooftop and parking PV offsets. The analysis generally used the following assumptions:

Table 11 – CHP Modeling Assumptions

CHP Component:	Modeling Assumption:
Electric efficiency:	45%
Thermal efficiency:	65% conversion of waste heat
Load tracking:	Thermal load

CHP is applied to relatively few buildings in this study, and due to the CHP system sizing assumptions to maximize CHP efficiency, CHP performance affects only a small portion of the load in the applicable buildings. CHP is not renewable energy. It needs fossil fuels to run. Consequently, even as a CHP system reduces TDV$ usage (a source energy metric), it increases a building's Site-kBtu.

The reduction in TDV$ with the use of CHP reflects a shifting of energy production costs from the grid side of the meter to the building side of the meter.

Under optimal operating conditions, the carbon emissions of behind-the-meter CHP appear to be equal to that of grid supplied power. In most operating conditions, however, CHP systems in California in 2020 and beyond are likely to increase carbon emissions when compared to procuring the same energy from the grid. Once again, this is a product of California's comparatively low carbon-per-kWh electricity supply. How CHP systems fit into the State's overall ZNE goals needs further analysis.

CHP systems improve overall system efficiencies through the use of otherwise wasted heat from electricity production. They may serve a particularly useful role in urban environments where potential uses for the waste heat are more likely to be proximate to the CHP system. Photovoltaic or solar thermal systems are also more difficult to install at scale in urbanized areas.

CHP systems were included in the exemplar designs for Hotels (Section 8.9) and Hospitals (Section 8.12). The CHP results can be found at the end of those respective subsections.

4.3 Key Research Inputs and Assumptions

The research used the following assumptions and inputs:

Occupants. Building design as well as equipment purchasing and installation were optimized to minimize energy use, but occupants will use the buildings in the manner that average occupants use a building.

> Occupant densities and behavior patterns affect an energy model through the "schedules" utilized in the modeling process. These schedules define the fraction of a particular building component's full power used by the simulation for each hour.
>
> This research used the standard schedules provided with the commercial research prototypes by the Department of Energy, which are informed by CBECS and other occupant pattern research. The residential schedules are derived from the standard Building America energy modeling assumptions incorporated into BEopt, which is also a product of the Department of Energy.

Building Shape. The overall building shape of the research prototypes was kept constant (as developed by DOE or other sources) to facilitate research comparisons. This limitation also acts as a proxy for site and client design restrictions.

> Manipulating the form of the buildings to better facilitate daylighting and natural ventilation would likely lead to even greater energy efficiency. However, it could decrease the solar installation potential of a building by increasing the perimeter area of the roof that must be kept clear. Such a decrease in available PV space would have a non-trivial impact on the "net" energy use of the building.

Available Roof Area. Eighty percent of the non-skylight roof area is available for solar power installations. This requires creative racking systems on roofs with significant mechanical systems.

Natural Ventilation. Natural ventilation systems will operate close to optimally in opening available vents in response to internal and external conditions. Fans continue to run at a reduced rate during the natural ventilation mode to ensure sufficient ventilation of core zones within a building.

Optimization for TDV. Model efficiency features were optimized for TDV.

Not Cost Effectiveness. Cost effectiveness was not a restriction on design decisions, although every effort was made to recommend widely implementable design strategies.

ZNE Project Experience. A key driver in the selection of design strategies was looking to the technologies and strategies used by the pioneering ZNE buildings being designed and constructed today. Arup, Davis Energy Group, Sun Light and Power, and the New Buildings Institute all have exposure to Zero Net Energy projects or near Zero Net Energy projects, and through that exposure have come to understand many of the most promising mixes of measures to reach a ZNE target.

Equipment. Equipment is often specified with performance levels above federal minimums. (See Section 7.2.4 for further discussion on federal preemption.)

Plug Loads. Plug loads were projected based on consultations with a number of internal and external sources. The New Buildings Institute provided leadership on the office plug load assumptions. Projected plug load reductions were most significant in building types where the research team thought improvements could be most readily implemented.

> The research assumed close to a 50% reduction in office plug loads, with an even greater reduction in nighttime loads through robust auto-off controls. As discussed, the modeling assumes "best-in-class" purchasing choices, which drives much of the 50% reduction as compared to the average purchasing choices assumed in the baseline.
>
> The research assumed a 20% reduction in residential plug loads through the smart selection of high-efficiency equipment and through industry-wide improvements in equipment efficiency.
>
> The research assumed no improvement in the plug loads for hospitals. It is difficult to project if the increasing efficiency in hospital equipment would offset the growing density of such equipment.
>
> Further details on plug load assumptions are provided in Chapter 8. Plug load research needs are discussed in Sections 7.1.2 and 7.1.3.

Density. Issues of density were not explored. Density strategies can range from better desk space allocation systems to making traditionally interior spaces into "exterior" spaces, such as covered circulation areas within schools. This reduces the overall conditioned floor area while providing the same functionality.

4.4 Precision, Estimation, and Extrapolation

The study team has made every effort to provide accurate data on the potential performance of best-in-class buildings in 2020. A number of factors in the research necessitated a host of assumptions, estimations, and extrapolations to calculate the expected performance levels. Those factors include the breadth of buildings and measures covered in this study, the uncertainty of future product development trends, the limits of the energy modeling tools used in this research, including the inability to directly simulate at least some of the measures that were "implemented".

The more significant the potential energy savings of a measure, the more resources were devoted to assuring the accuracy of both the model inputs and the resulting outputs. Where possible, inputs and outputs were cross-referenced with independent data sources including measured building performance data.

The research team made a conscious effort throughout the project to balance optimistic assumptions, such as those for LED performance, with more conservative assumptions, such as those for potential savings associated with natural ventilation. The methodology of the study – building upon the form and architectural program of the DOE research prototypes – created an inherent conservative bias in the results. Designing a building to meet a particular purpose with much more flexibility as to the final shape, program, and orientation would result in additional savings beyond those seen in these models.

The more particularized is a given result of this study, the more caution should be used in relying upon the conclusion. As noted elsewhere, the costing estimates have particularly high levels of uncertainly. The study intended to provide broad guidance on feasibility, design and research priorities, and the policy implications of different ZNE frameworks.

Any uncertainties in the modeling estimates are likely dwarfed by the variability that can be found within actual building projects: construction quality, actual usage patterns, solar access, operational behavior, etc. Those practical realities could make the aggregate performance of building stock built to meet the ZNE goal quite distinct from the building performance levels suggested in this report.

5 Preliminary Cost Estimates

Cost estimates are aggregated in the change logs for the respective building types in Chapter 8. See the "Sample Change Log" chart in Chapter 8 for explanations of the "Incremental First Cost" metric displayed in the change logs.

Costing was not, however, a primary focus of this research. The cost outputs provided in the report are only preliminary estimates. Significant uncertainly surrounds many of the subcomponents of the estimates as well the final numbers.

5.1 Costing Methodology

The research team collected cost data from a number of sources for low and high performance systems to develop per unit cost formulas that were dependent on the projected efficiency levels. Those formulas were used to estimate the overall cost of the efficiency features based on the attributes of the baseline and exemplar building models.

Where possible, the team estimated potential costs savings from ZNE designs, particularly in the area of HVAC system size reductions. The estimates realized significant cost savings through the downsizing of HVAC subcomponents.

Some efficiency features were not costed due to high levels of uncertainty – e.g. the cost of future plug load auto-off controls – or simply due to resource limitations within the research. When a measure was not explicitly costed, its cost was generally assumed to be equal to its projected savings, essentially neutralizing its effect in the comparison of costs and benefits.

Natural ventilation systems were costed as if they were fully automated, with sensors, actuators, and a control system. Such a system can be quite expensive, and the estimates showed that such systems are likely to have costs far in excess of the energy savings. Such systems provide notable additional benefits to occupants through the robust supply of outside air; however, those types of non-energy benefits are not included in the costing analysis.

5.2 Use of 30 year TDV Values to Estimate Savings

As discussed, TDV$ represents the net present value of a given amount of energy use. TDV$ schedules are available for 30 year net present value estimates for residential buildings and for 15 year and 30 year estimates for commercial purposes.

The 30-year schedules were used in this study for two primary reasons:

1. ZNE design strategies are a long-term investment for a building and for the State, with many of the systems and features providing benefits well beyond 30 years.

2. For systems not expected to last 30 years, it is assumed that the replacement system will be of a like performance level, if not far better, such that the projected performance levels and energy cost savings would continue for the full 30 years of analysis. This assumption does not account for the potential replacement costs that would come over 30 years; that is a shortcoming of the limited assessment of costs and benefits in this study.

The 15-year residential TDV schedules are equal, on average, to 55% of the 30 year residential TDV schedule. This approximate parity on a year-to-year basis is driven by a comparatively low discount rate and cost escalations within the underlying commodity costs – from natural gas to carbon emission allowances – that largely offset the discount rate. As a consequence, the TDV$ savings values in this report could safely be scaled by the reader to shorter time horizons using a linear interpolation.

5.3 TDV Estimates Anchored in 2011 Energy Costs

Although this study projects potential 2020 performance levels and 2020 first costs (where notable cost reductions could be projected), no adjustments were made to the TDV schedule to reflect projected long-term energy costs starting in 2020. The TDV development spreadsheet (CEC/E3, 2011) shows 2020 energy costs approximately 40% higher than the 2011 baseline year used for the Title 24 2013 TDV development. As a result, the TDV based calculations are underestimating the fiscal benefits of efficiency measures and renewable energy measures that will be implemented in 2020.

5.4 Sizing Basis for PV Costing

The PV systems incorporated into the first cost analyses in Chapter 8 were sized according to the TDV ZNE definition. First costs for a PV system sized to meet a Site-kBtu ZNE definition would be modestly higher for commercial buildings and substantially higher for residential buildings (See Section 3.1.3).

5.5 Long-term ZNE Cost Trends

Estimating the costs and benefits for zero net energy buildings "in general" is a challenging exercise. There are multiple solutions to the same design objective, and costs can vary widely even within a singular solution. Even the energy savings projections have significant embedded uncertainty, both due to the energy simulation methodologies and often in the energy metrics themselves, whether Site-kBtu, TDV, or another benchmark.

As costing is only an ancillary component of this particular research exercise, coarse data on equipment first costs are utilized with an effort made to recognize potential system wide cost savings as peak equipment capacities are reduced. There are many minor subcomponents of a ZNE building design that are not included in this analysis, and many secondary savings are also not accounted for.

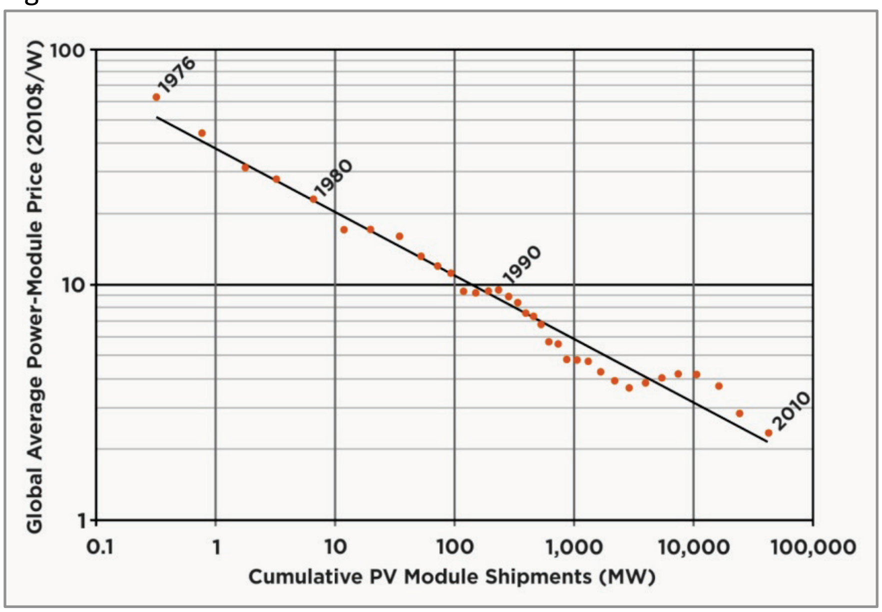
Consequently, the estimates provided in this study are a rather atomistic look at marginal costs and should not be viewed as comprehensive.

While there are reasons to think that the first costs outlined in this report are too low due to potentially missing cost components, there are broader market forces that suggest any estimate is too high. The field of ZNE building design, construction, and operation is still in its infancy, and as ever-greater numbers of buildings seek to meet ZNE targets, simplifications, standardization, and economies-of-scale should bring down costs in ways that are hard to predict.

Two countervailing economic "metaphors" will influence the outcome of ZNE cost effectiveness:

> **The First Metaphor:** "Learning curves" from industries such as photovoltaic module manufacturing, in which each doubling of total installed PV volume has consistently reduced prices another 20%, extending back to the 1970's. (Figure 3).

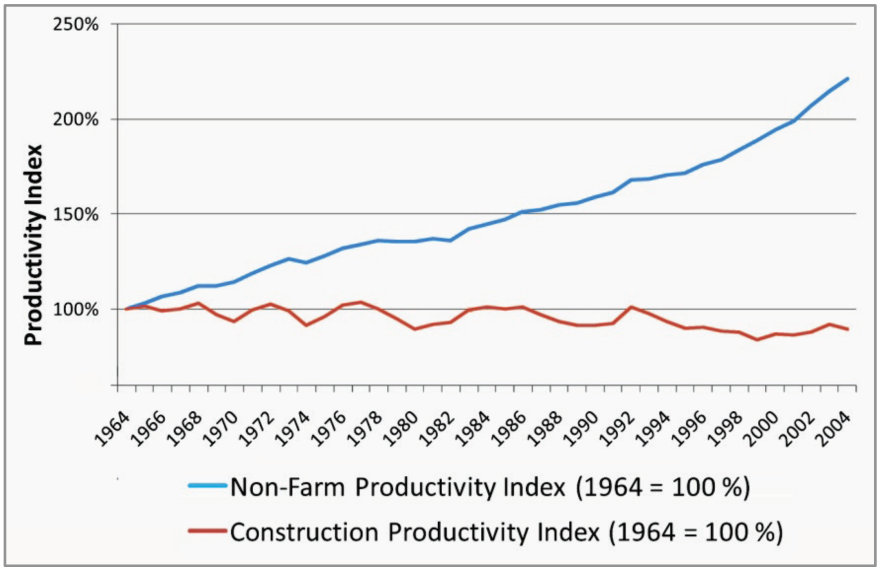
Figure 3 – PV Module Price Reductions with Cumulative Module Production



Long-term cost trend for PV modules (Source: "SunShot Vision Study" 2012, Department of Energy, Pg. 75.)

The Second Metaphor: As the productivity of the American worker has climbed steadily over the last four decades, productivity for the construction trades has remained largely flat. (Figure 4).

Figure 4 – Long-term Construction Sector Productivity



Long-term construction productivity trend (Source: "Metrics and Tools for Measuring Construction Productivity: Technical and Empirical Considerations" 2009, National Institute of Standards and Technology)

The State's ZNE goals will require a combination of technological breakthroughs and improved design and construction processes. Consequently, the likely answer to long-term ZNE cost reductions lies somewhere between these two trends. The solar industry is a microcosm of this tension as steady reductions in module costs have pushed the balance-of-system costs to the fore. Those costs resemble, in many ways, the staging, installation, permitting, insurance, and other logistical costs of the broader construction industry that can be more challenging to reduce than the technical barriers. The construction industry is building structures that will hopefully persist for a century, and as such, the industry is necessarily cautious and slow to shift methodologies.

In his essay on "Tunneling Through the Cost Barrier" in *Natural Capitalism*, Amory Lovins points out that design teams are one of the most important efficiency features of a building. "We can make no better higher-leverage investments for the future than improving the quality of designers' 'mindware'—assets that, unlike physical ones, don't depreciate but, rather, ripen with age and experience." This concept extends from architects to the trades constructing a building.

With an ever-increasing volume of ZNE buildings, the forces apparent in the PV module "learning curve" should take hold, increasing performance, increasing quality, and bringing down costs. How much the repetition – or "reps" – of ZNE and near ZNE project execution will bring down the incremental costs is difficult to predict, but there is reason to anticipate that it will be significant.

Because the "whole" of the ZNE design process is often more important than the subcomponents, one of this study's core recommendations is that future efficiency investments from the State of California and utility programs should focus more so on the design process and on achieving performance benchmarks than on advancing the performance of particular subcomponents. This recommendation could be realized through greater investment in beyond-code incentive programs such as Savings by Design, the California Advanced Homes Program, the New Solar Homes Partnership, or yet to be designed incentive programs that might focus on operational improvements.

Beyond code programs are capable of tapping into market forces and architectural and engineering creativity to develop, refine, and perfect the most promising, holistic ZNE solutions. Letting "the market" chart the specific path taken on any given project to get to the State's ZNE goals will almost certainly lead to better solutions and lower costs than a prescriptive approach. This is the value already seen in a number of related market-based policy platforms, from performance based compliance under Title 24 to the emerging cap and trade market for carbon allowances.

6 Statewide Results

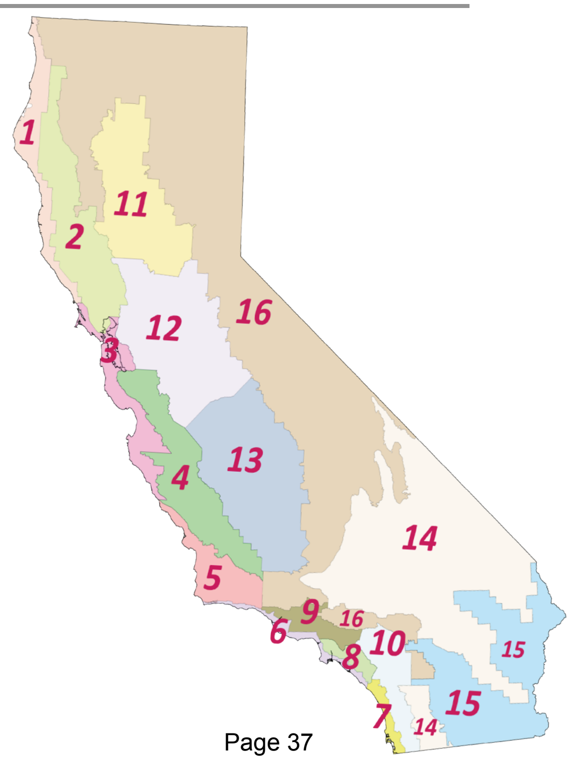
The EUI projections for each building type gain more relevance when viewed in the context of projected construction volume. Table 12 provides projected construction volume for 2020 in California (ordered by volume).

Table 12 –Construction Forecast

Projected 2020 Construction Volume (in Million ft^2)

	Climate Zones																
	12	10	9	13	7	8	4	3	6	11	15	14	16	2	5	1	Total
Single Family Res	42.3	38.7	9.2	30.6	8.8	8.0	11.2	5.0	4.8	14.3	8.6	7.2	6.5	4.9	2.2	1.6	204
Multi-fam Low-rise	4.3	5.3	3.7	3.6	3.6	3.0	1.2	1.6	2.3	1.7	1.6	1.5	1.2	1.3	0.5	0.2	37
Multi-fam High-rise	2.7	1.7	4.0	0.4	1.6	3.4	2.4	2.1	2.4	0.1	0.0	0.0	0.0	0.2	0.2	0.0	21
Other Commercial	3.8	2.5	7.4	1.9	4.6	3.5	1.7	2.4	3.1	0.8	0.2	0.5	0.5	0.7	0.3	0.1	34
Large Office	5.8	0.7	5.7	1.5	1.5	3.1	2.3	4.1	2.2	0.6	0.2	0.3	0.4	0.9	0.4	0.0	30
Strip Mall (Retail)	4.2	1.9	5.7	2.2	3.4	2.7	1.4	2.3	2.3	0.9	0.2	0.4	0.5	0.6	0.3	0.0	29
Warehouse	4.9	2.2	4.3	2.7	4.2	2.2	1.1	2.2	1.8	1.4	0.1	0.3	0.4	0.5	0.2	0.0	29
School	1.8	1.0	2.0	1.1	1.5	1.0	0.6	0.9	0.8	0.5	0.1	0.2	0.2	0.3	0.1	0.1	12
Medium Office	1.2	0.5	1.7	0.6	0.9	0.9	0.6	0.8	0.7	0.2	0.0	0.1	0.2	0.2	0.1	0.0	9
Hospital	1.4	0.3	1.4	0.9	0.6	0.7	0.6	0.8	0.5	0.3	0.0	0.1	0.2	0.2	0.1	0.0	8
Grocery	1.2	0.5	1.5	0.7	0.9	0.7	0.4	0.5	0.5	0.3	0.0	0.1	0.1	0.1	0.1	0.0	8
College	1.0	0.2	1.7	0.5	0.4	0.8	0.5	0.7	0.6	0.2	0.0	0.1	0.1	0.2	0.1	0.0	7
Large Hotel	1.1	0.4	1.1	0.4	0.8	0.5	0.5	0.7	0.3	0.2	0.0	0.1	0.1	0.2	0.1	0.0	7
Restaurant	0.6	0.3	1.1	0.2	0.5	0.6	0.1	0.2	0.5	0.1	0.0	0.1	0.1	0.1	0.0	0.0	4
Total	77	56	51	47	33	31	25	24	23	22	11	11	11	10	5	2	439

Data primarily from CEC forecasts, although minor adjustments were made to the single-family / multi-family mix to better match current U.S. Census data on residential construction in California.



Restaurant EUIs are exceptionally high, but restaurants also have the lowest projected construction volume. Conversely, Single Family Residences have amongst the lowest possible EUIs and nearly half of the total construction volume.

This research simulated buildings in seven climate zones but extrapolated those results across the state using the following associations:

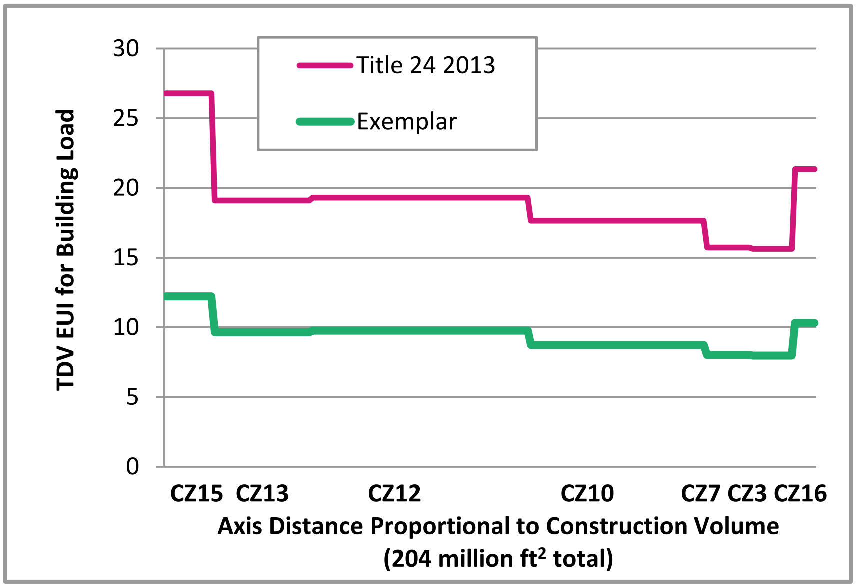
Table 13 – Climate Zone Extrapolations

Climate Zones — Modeled CZ:	Associated CZs:
15	14
13	*none*
12	4, 11
10	8, 9
7	6
3	1, 2, 5
16	*none*

6.1 EUI Distributions by Construction Volume

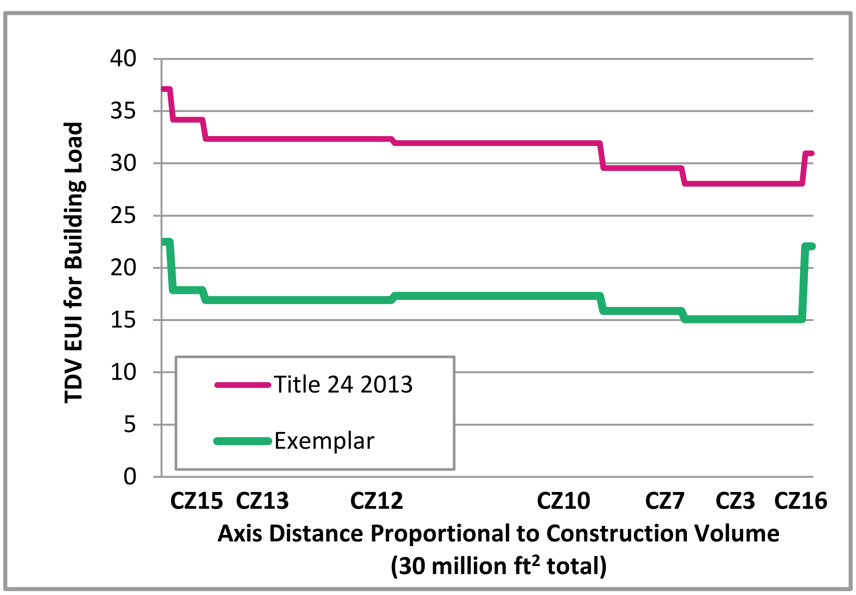
Figure 5 charts the potential energy use of Single Family Residences across seven climate zone groupings. "Exemplar" represents the ZNE optimized buildings before the addition of PV. The scale of the X-axis is proportional to the projected construction volume for the climate zone groupings.

Figure 5 – Single-family Residential EUIs Across Climate Zones



What is most notable is that, as with the higher EUI building types, there is comparatively little construction volume in the higher EUI climate zones, such as the inland desert (CZ15). The same comparison for the Large Office:

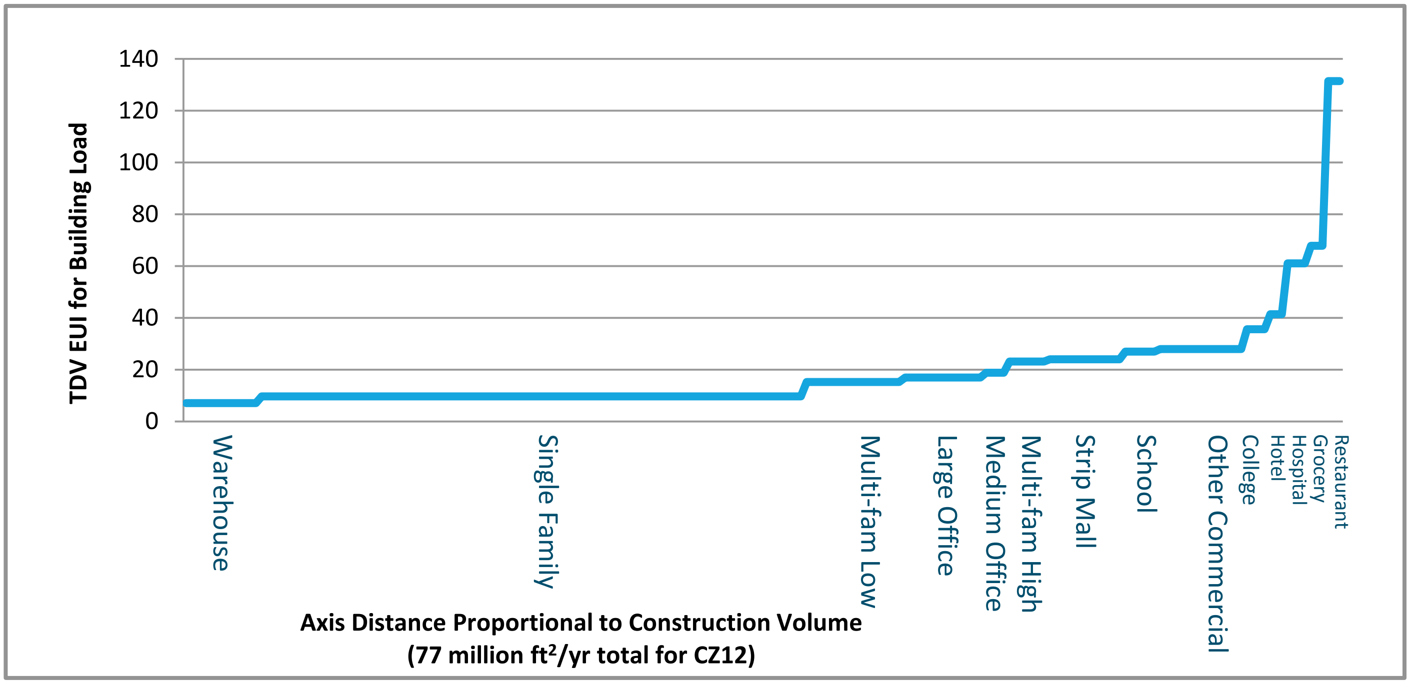
Figure 6 – Large Office EUIs Across Climate Zones



[In making these comparisons, this study used baseline Title 24 2013 model results for 9 building types in 5 climate zones (45 data points) and then used proportional relationships within the exemplar building datasets to extrapolate Title 24 2013 benchmarks to a matrix of 12 building types in 7 climate zones.]

The distribution of EUIs across the exemplar prototypes within a single climate zone gives the following distribution by projected construction volume (X-axis):

Figure 7 – Climate Zone 12 (Sacramento) EUIs by Building Type



An important detail in the previous few graphs is the relative scale of EUI variation in energy use across climate zones and across building types. Placing both construction volume transects on the same scale shows the following:

Figure 8 – CZ12 EUIs by Building Type and Large Office EUIs by Climate Zone

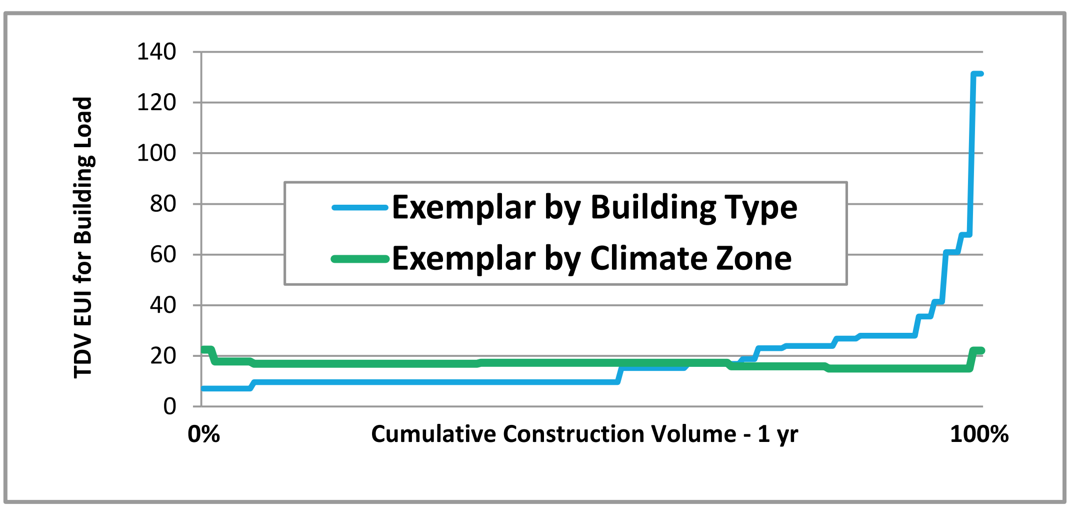
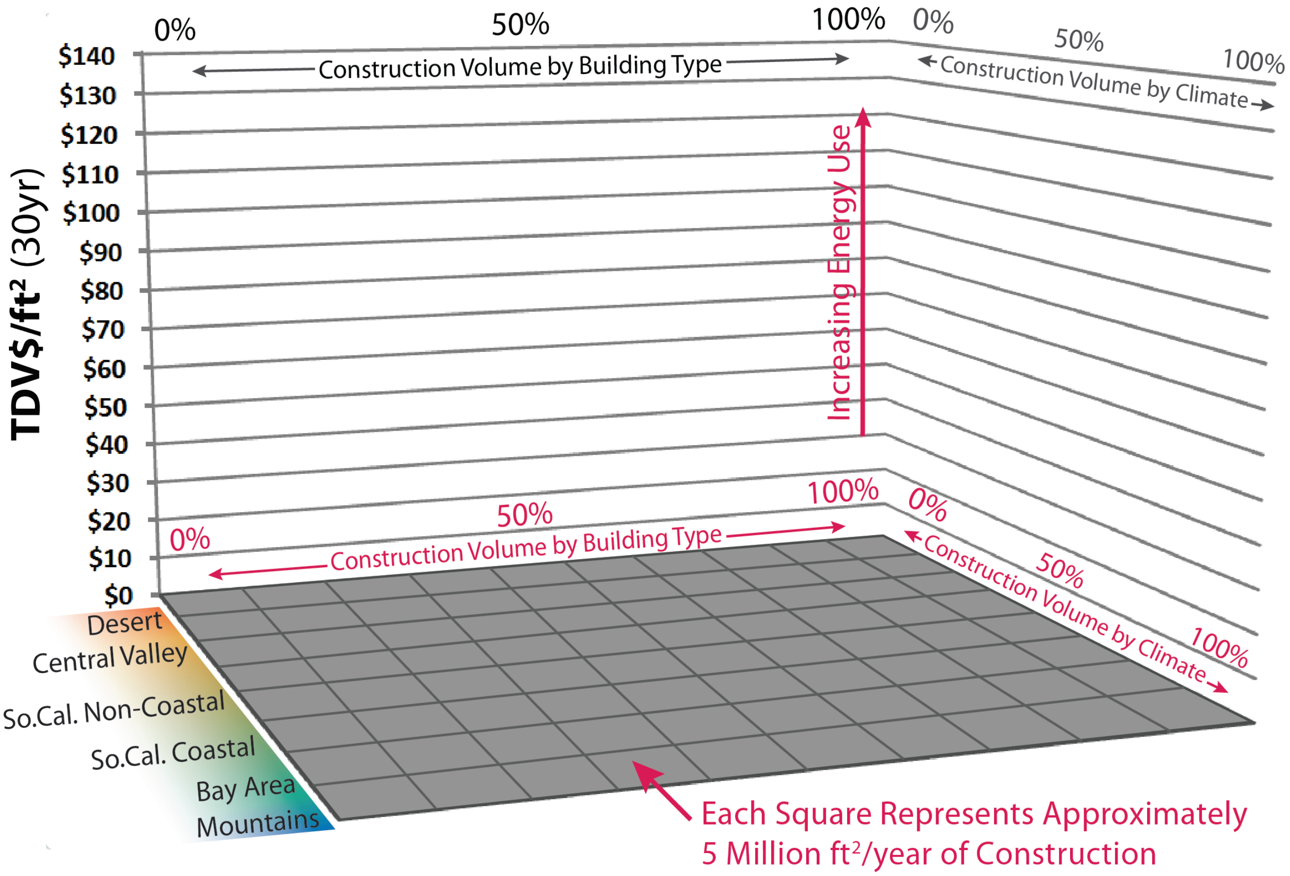


Figure 8 illustrates that the climatic variation (the green line), in TDV values across the various building types has comparatively little variation. Also, the climatic variation in Figure 8 is a small fraction of the building type variation (the blue line).

Graphing this information in three dimensions – across all building types and climate zones – provides a fuller picture of potential EUIs across the state. In the following graphs, the X-Y plane represents one year of projected construction volume, or 440 million ft^2 total. EUIs are charted on the Z axis.

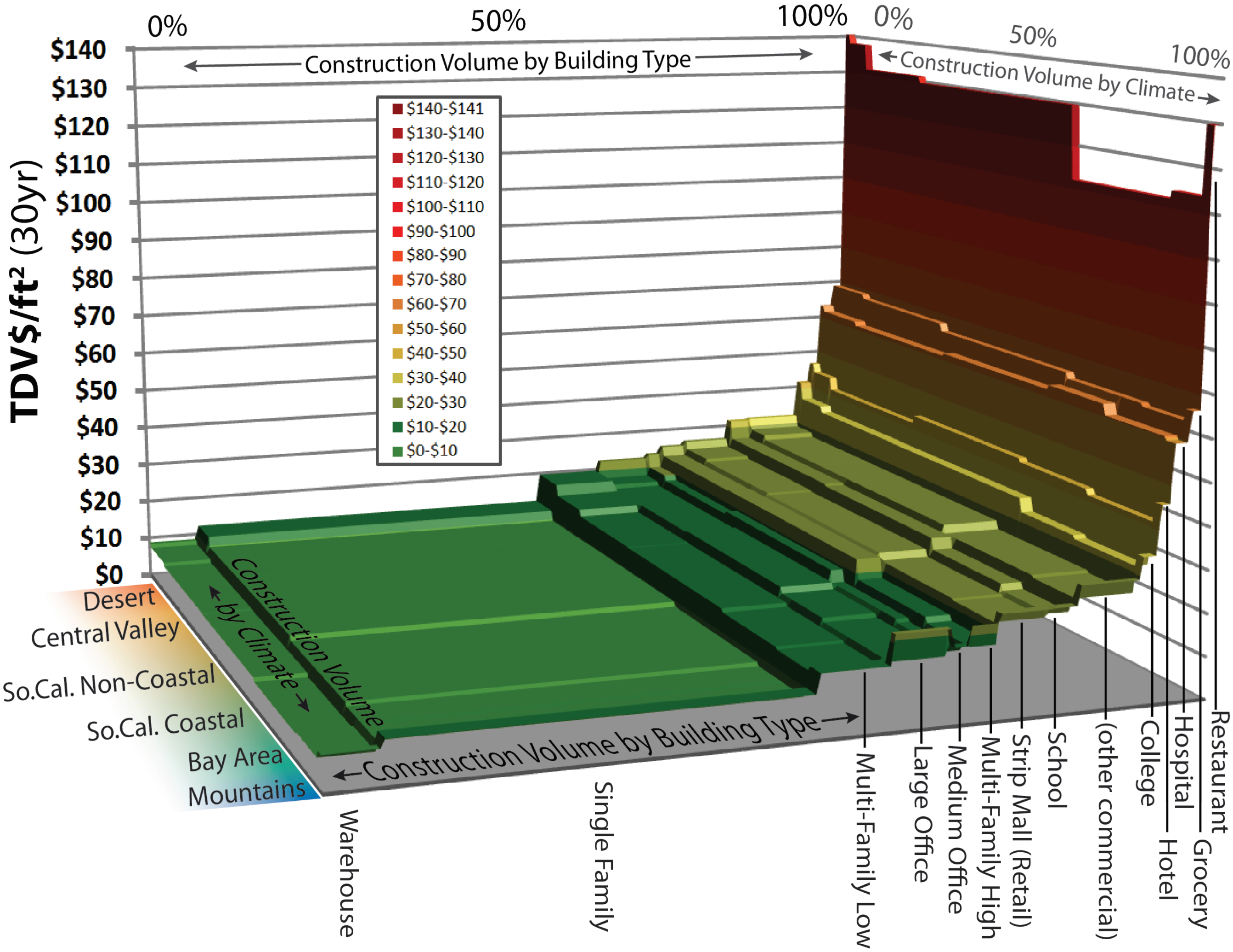
First, a key to reading this data:

Figure 9 – Key to Statewide EUI Charts



In Figure 10 and Figure 11, energy performance data for the prototypes are sorted left to right by ranked energy use. Building performance data are sorted by climate front to back, with the desert climates on the rear axis and the Bay Area and mountain climate zones on the front axis.

Figure 10 – Statewide Technically Feasible **EUIs without Solar** (TDV$) distributed by Projected 2020 Construction Volume

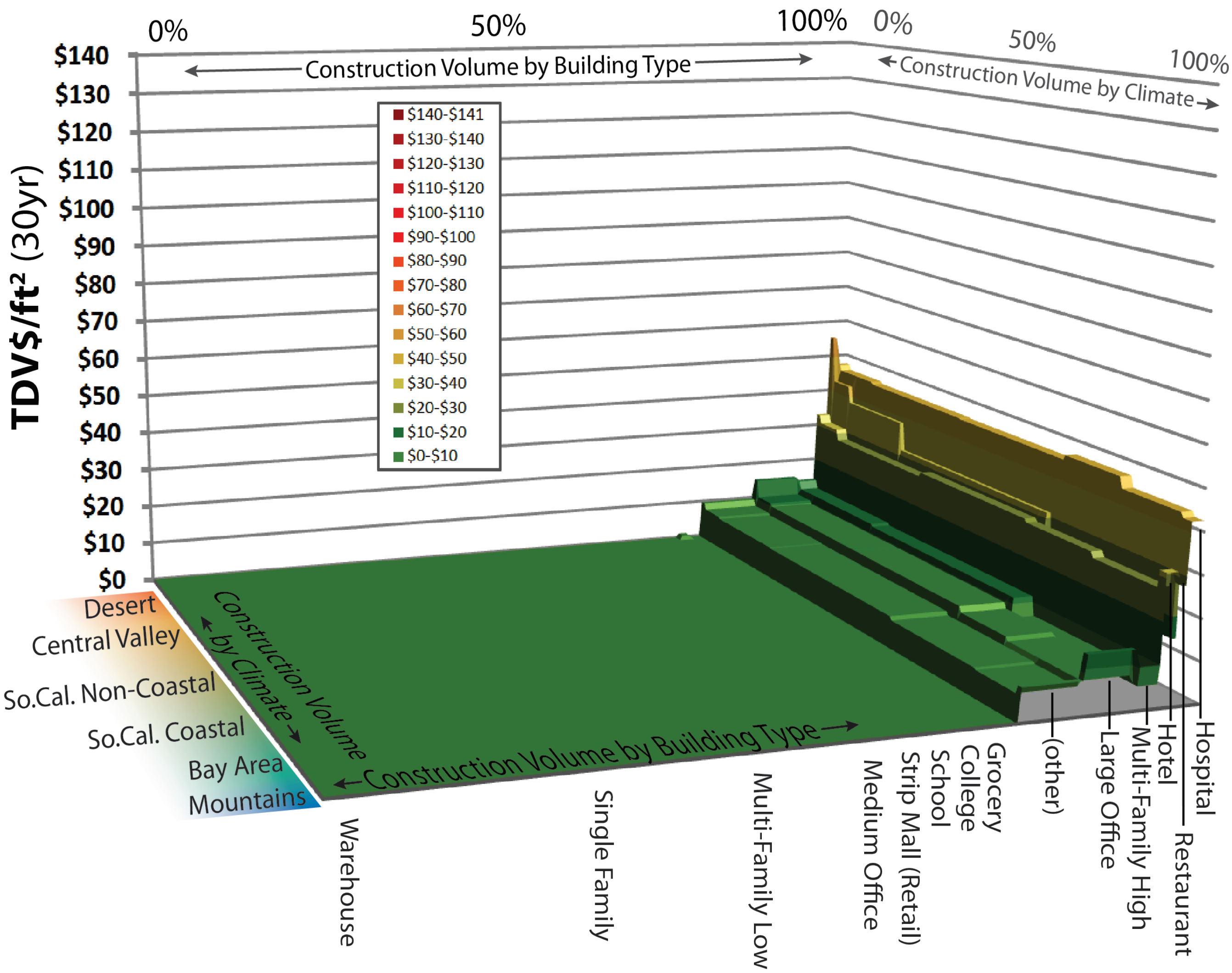


This chart suggests that most building types can reach ZNE by 2020 through the use of "best-in-class" design strategies. Residential buildings make up the bulk of that volume. The last five building types (College through Restaurant) where there is a notable inflection in energy use, represent only 8% of projected construction volume. Those buildings do represent 30% of the energy use illustrated in Figure 10. As was seen in Figure 8, the variation across climate zones (front to back) is minor compared to the variation in TDV$ values across building types (left to right).

The area "under the curve" in Figure 10 is indicative of the energy that will be used over thirty years by all buildings constructed in 2020 if they are constructed on par with the design strategies outlined in this study, but without PV. That total energy consumption would be calculated by multiplying the square footage of the X-Y plane (440 million ft^2) by the EUI on the Z axis for each square foot.

Figure 11 illustrates projected statewide building performance assuming that up to 80% of the roof area on the prototypes can be used for photovoltaic installations. PV is sized for the exemplar buildings up to, but not beyond, the scale of the load. Consequently, a significant portion of the projected building stock "plateaus" (on the low side) at the level of Zero Net Energy (i.e. $0 on the Y axis).

Figure 11 – Statewide Technically Feasible **Net-EUIs with Solar** (TDV$) by Projected 2020 Construction Volume



Building types to the left – Warehouse through Grocery – are capable of meeting the ZNE goal with rooftop PV. With the exception of the Restaurant, the common characteristic of the non-ZNE prototypes is their height. The Large Office and Multi-family High-rise have comparatively low EUIs, but the floor-area to roof-area ratio (12 and 10 floors, respectively) is simply too great for the buildings to reach ZNE within the footprint of the building.

The reductions in statewide energy use illustrated in Figure 11 (as compared to Figure 10) rely upon the forecasted PV installations shown in Table 14. Those PV installations are scaled to move a building's overall performance to a TDV ZNE target where possible and, where not possible, by using all available roof space (up to 80%), but not stand alone parking lot space.

Table 14 – Projected Rooftop PV Installation Volume Across all Exemplars

Annual MW of PV Installations Assumed in "Net" Results								
	Climate Zones							MWs
	15	13	12	10	7	3	16	Total
Single Family Residence	30.8	47.3	108.8	75.4	17.0	16.7	10.1	306
Multi-family Low-rise	9.4	9.8	17.9	28.0	13.2	7.6	2.6	88
Multi-family High-rise	-	0.7	9.7	16.5	7.2	4.6	-	39
Large Office	0.6	1.8	10.3	11.2	4.3	6.4	0.5	35
Medium Office	0.6	1.9	6.3	9.5	4.3	3.0	0.4	26
Strip Mall	2.4	8.7	26.0	37.7	19.6	10.4	1.7	106
Secondary School	1.3	4.7	13.4	16.4	8.5	4.8	0.8	50
Hotel	0.3	0.8	4.0	4.5	2.4	2.3	0.2	15
Hospital	0.4	2.4	5.9	6.2	3.0	3.0	0.5	21
Grocery	1.7	7.7	21.7	27.6	14.0	7.4	1.3	81
Warehouse	0.7	3.4	8.7	9.3	5.6	3.0	0.6	31
Sit Down Restaurant	1.3	3.8	12.1	29.4	16.1	4.8	1.1	69
College	0.9	3.2	9.9	14.8	4.8	5.0	0.7	39
Miscellaneous	2.3	6.3	21.3	43.0	23.5	10.6	1.6	109
Total Across Climate Zones	**53**	**103**	**276**	**329**	**144**	**90**	**22**	**1,016**

6.2 Hourly Load Analysis

This section presents hourly load data, demonstrating how the ZNE buildings designed in this study might interact with the electricity grid. The data are presented for:

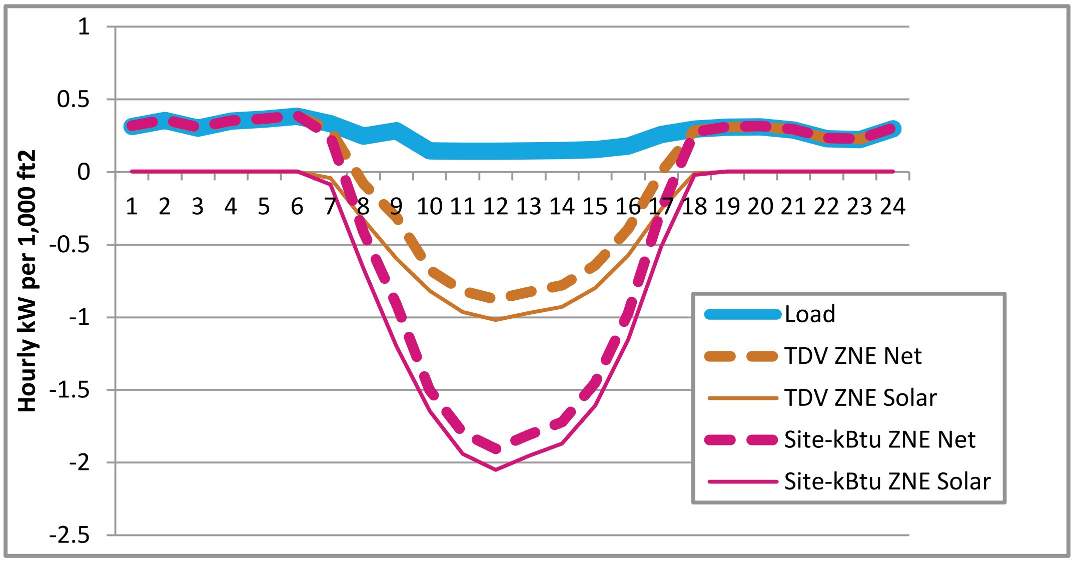
1. Building loads
2. PV production sized to meet a TDV$ ZNE target
3. PV production sized to meet a Site-kBtu ZNE target
4. Net electricity use with PV sized to meet a TDV$ ZNE target
5. Net electricity use with PV sized to meet a Site-kBtu ZNE target

The data presented here are an average across five days in September during peak conditions under the Title 24 2013 weather files. The five days are the Monday to Friday of the week represented by the "Heat Wave" TDV values graphed in Figure 1.

These charts only graph electricity. The overall volume of PV electricity production is greater than the overall "Load" consumption because PV is sized in this ZNE study to also offset natural gas energy use. However, natural gas energy use is not depicted here.

6.2.1 Single Building Load Profiles

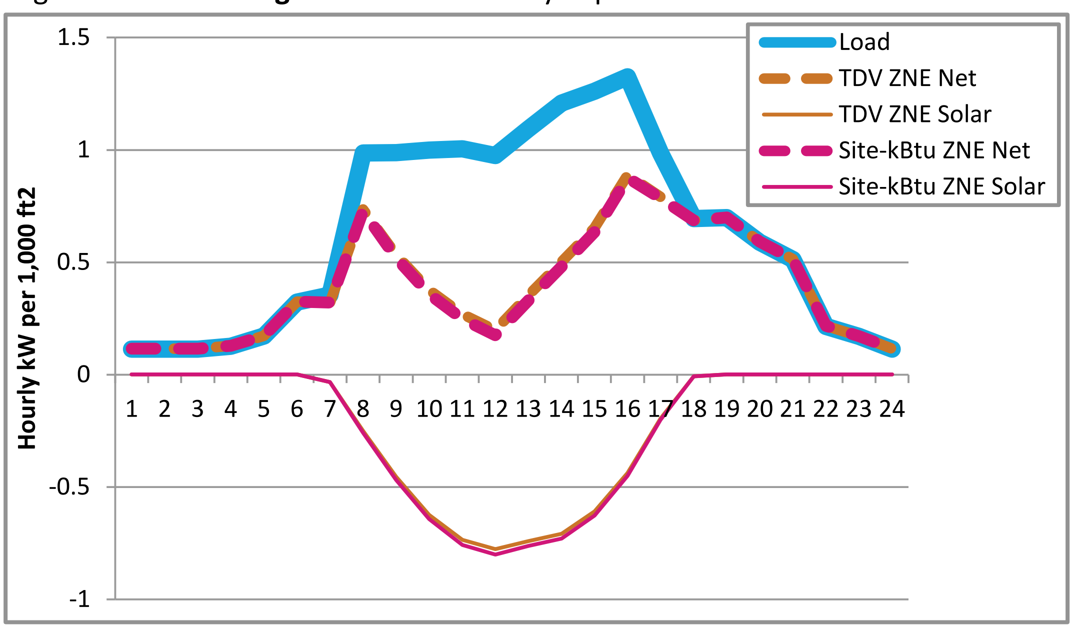
Figure 12 – CZ12 **Single Family Residence** Peak Hourly September Loads



This graph once again illustrates the significantly higher level of PV required to reach a ZNE residential target using a Site-kBtu metric as compared to a TDV metric. Note that the area under the Solar curve is far greater than the area under the Load curve because the solar electricity shown here is used in the ZNE calculations to offset natural gas energy use as well, but the natural gas load is not pictured.

The difference in PV requirements between the two metrics is much smaller in the commercial load curves that follow.

Figure 13 – CZ12 **Large Office** Peak Hourly September Loads



The Site-kBtu and TDV curves are concurrent for the Large Office because the roof area is fully utilized for PV under both metrics, resulting in identical Solar capacities under both metrics. Roof space is fully utilized for the Large Office because the Large Office prototype cannot reach the ZNE goal using rooftop solar alone. (These charts do not include parking lot PV.)

And two load curves from commercial buildings that can reach the ZNE goal:

Figure 14 – CZ12 **Strip Mall** Peak Hourly September Loads

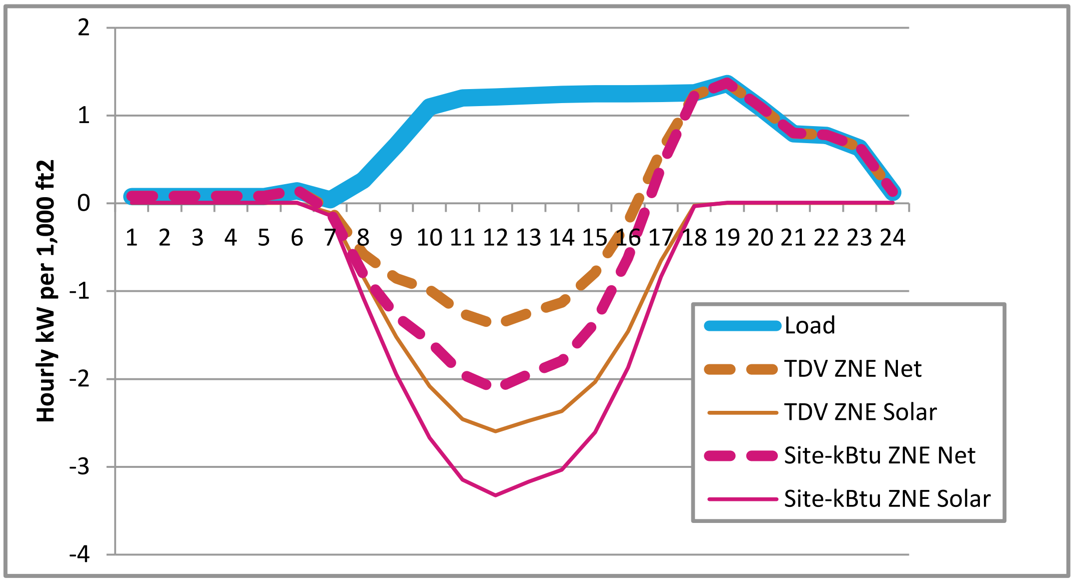
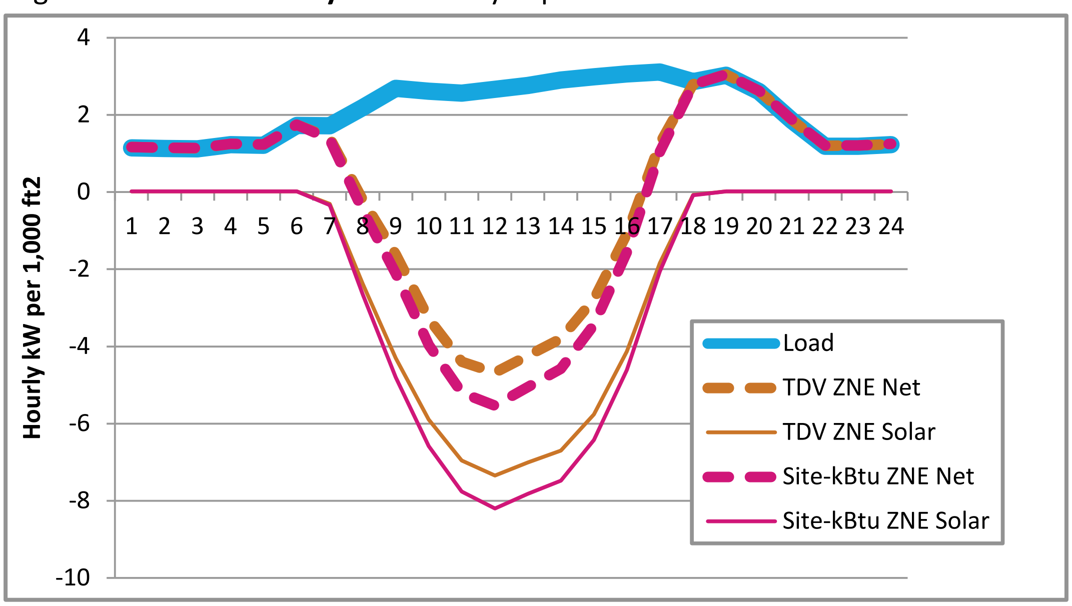


Figure 15 – CZ12 **Grocery** Peak Hourly September loads



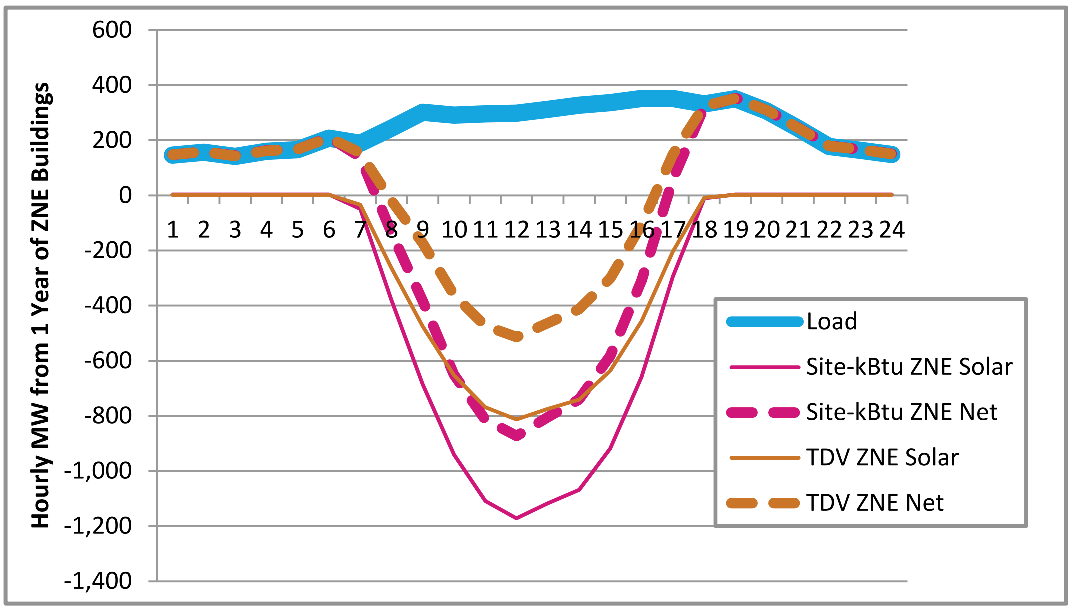
These load curves are dependent on the operations schedules embedded in the building energy models. While those schedules are derived from surveys of actual building operations, the hour-to-hour implications should be interpreted with greater caution than the yearly values.

6.2.2 Aggregate ZNE Building Load Profiles

Figure 16 is a weighted average EUI from the previous four graphs, with the resulting average EUI extrapolated to the annual statewide construction volume of 439 million ft^2/yr. (The weighting is 60% Single Family Residential, 15% Large Office, 15% Strip Mall, and 10% Grocery.) This graph represents a rough approximation of the annual additional load profile for a peak load day if the ZNE new construction goals are fully realized.

The residential ZNE goals are set for 2020, whereas the nonresidential ZNE goals are set for 2030, so it could take a decade beyond 2020 for the load profile in Figure 16 (from a single year of ZNE construction) to fully develop.

Figure 16 –**Weighted Average** Peak Loads for One Year of ZNE Construction



Although this hourly load profile is based on peak weekday demand, many of the load ramping issues illuminated by this data would exist on any sunny day in California, including weekends, when the distributed PV generation rapidly rises in the hours following sunrise and rapidly subsides in the hours before sunset.

As is discussed in Section 3.1.5.1, future TDV schedules may shift the peak valuation hours further into the evening. This would reduce the overall peak reduction valuation of PV using the TDV metric. That reduced PV valuation might, in turn, require a greater level of PV capacity to move a building to ZNE (using a TDV definition). The PV production curve and net consumption curve in Figure 16 would shift downwards a small amount, resetting their levels somewhere between the Site-kBtu and TDV curves shown above.

The grid impacts from high levels of distributed photovoltaic production are compounded, of course, by the coincident ramping of PV resources installed to meet the State's 33% Renewable Portfolio Standard. Note that these "ramping issues" are distinct from the PV "export issues" discussed in Section 3.1.5. Whereas the "export issues" apply only to PV generated electricity leaving a building site (in excess of coincident load), the "ramping issues" apply to all PV generation regardless of coincident load at a building site.

Significant planning and research will be needed to understand the issues associated with integrating the level of PV capacity implicated by the State's ZNE goals into the electricity grid. Those research needs are outlined in Section 7.2.6.

6.2.3 Load Profiles and the Relationship to Energy Efficiency

While the bottom line ZNE analyses presented in much of this report suggest that efficiency measures and photovoltaic production are of equal "value" in reaching the ZNE goals, these load profiles illustrate why the two resources (efficiency and photovoltaics) have significantly different impacts on the broader electrical grid. Therefore, the efficiency benefits and PV production benefits might warrant different hourly valuations per kWh. The implications for PV sizing on a ZNE building from the differential valuation of solar electricity is discussed in Section 3.1.5.

Notably, the PV production does not reduce the late afternoon peak between 6:00 p.m. and 7:00 p.m. shown in these sample load curves. Energy efficiency improvements, in contrast, 1) reduce load, 2) reduce all peaks including the 6:00 p.m. to 7:00 p.m. peak, and 3) reduce the necessary "ramp rate" of dispatchable generation resources (or demand response resources) that are required to offset the rapid shedding of photovoltaic generation in the late afternoon.

The load profiles in the previous section similarly illustrate why efficiency is prioritized over renewable energy resources in this study's prototype design methodology. Clearly, however, efficiency and distributed PV generation must be paired at significant scale on both sides of the ZNE equation to reach the State's goals.

6.3 Exemplar Model Comparison to Title 24 2013

The exemplar designs were compared in overall energy use to prototypes designed in accordance with Title 24 2013. Table 15 shows those comparisons for a subset of the exemplar prototypes: 9 building types in 5 climate zones.

The differences shown in Table 15 derive from a number of adjustments in the exemplar models as compared to the Title 24 2013 models:

- Exemplar models include improvements to systems regulated by Title 24, but in many cases extend beyond the Title 24 requirements.
- Exemplar models include improvements to systems regulated by federal equipment efficiency standards, often exceeding the minimum

performance levels required by federal law. See Section 7.2.4 for further discussion on the relationship of federal preemption to the ZNE design strategies outlined in this report.

- Exemplar models simulate the effect of "best-in-class" equipment purchasing decisions, while the Title 24 models assume average equipment wattages by building type.
- Exemplar models simulate the impact of improved building and equipment control systems, minimizing loads when systems are not needed.

Table 15 – Exemplar Model and Title 24 2013 Comparison

Title 24 2013 Comparisons		TDV$/ft^2 (30 yr)				
		Climate Zones				
		15	12	10	3	16
Single Family Residential	T24 2013	26.78	19.31	17.66	15.64	21.34
	Exemplar	12.23	9.77	8.74	7.97	10.32
	% Difference	**54%**	**49%**	**51%**	**49%**	**52%**
Multi-family Low-rise	T24 2013	36.02	27.97	27.08	22.96	26.37
	Exemplar	19.60	15.16	15.01	13.81	14.98
	% Difference	**46%**	**46%**	**45%**	**40%**	**43%**
Medium Office	T24 2013	43.83	35.03	35.15	28.52	32.47
	Exemplar	23.56	18.75	19.55	15.90	17.71
	% Difference	**46%**	**46%**	**44%**	**44%**	**45%**
Large Office	T24 2013	37.11	32.34	31.92	28.06	30.95
	Exemplar	22.49	16.90	17.30	15.08	22.06
	% Difference	**39%**	**48%**	**46%**	**46%**	**29%**
Strip Mall	T24 2013	64.18	51.97	52.53	40.81	48.00
	Exemplar	26.55	23.94	23.60	21.51	24.33
	% Difference	**59%**	**54%**	**55%**	**47%**	**49%**
Secondary School	T24 2013	51.47	42.29	42.07	35.14	37.54
	Exemplar	31.66	26.88	26.40	22.30	24.46
	% Difference	**38%**	**36%**	**37%**	**37%**	**35%**
Large Hotel	T24 2013	76.32	71.20	69.64	65.73	68.08
	Exemplar	46.72	41.41	43.39	41.28	45.84
	% Difference	**39%**	**42%**	**38%**	**37%**	**33%**
Sit Down Restaurant	T24 2013	238.46	211.74	207.10	186.89	198.45
	Exemplar	150.52	131.43	129.82	113.89	129.90
	% Difference	**37%**	**38%**	**37%**	**39%**	**35%**
Warehouse	T24 2013	12.32	12.54	11.47	11.39	13.11
	Exemplar	8.70	7.08	6.90	6.58	8.30
	% Difference	**29%**	**44%**	**40%**	**42%**	**37%**

7 Recommendations

This research has revealed a number of critical strategies for reaching California's Zero Net Energy goals. The strategies and challenges discussed in this chapter would benefit from further research.

The insights and recommendations fall into two categories:

- Technical Strategies
- Research Opportunities

7.1 Technical Strategies

Table 16 lists some of the most common energy efficiency measures implemented in the commercial and residential prototypes set forth in Chapter 8. The values in Table 16 are weighted averages across all projected construction in 2020. Multiplying any of the TDV$ values by 439 million ft^2/yr will give a rough estimate of the 30 year net present value of energy savings put in place each year if the measure were to be widely implemented (and replaced with same or better when necessary over 30 years).

Table 16 – Common Measures Utilized in the Exemplar Prototypes

Key Measures

Rank	Measure	TDV$/$ft^2$*
1	**LED Efficiency**	-$4.70
2	**Plug Load Reductions**	-$2.57
3	**Fan and Duct Efficiency**	-$0.77
4	**95%+ Efficiency Gas Appliances**	-$0.54
5	**Natural Ventilation**	-$0.41
6	**Windows U Factor and SHGC**	-$0.32
7	**Heat Recovery** (air, mech., and water)	-$0.28

***Values are projected TDV$ reductions per total construction volume.**

Most noteworthy among the key measures are the substantial savings from LEDs that are based on their projected performance in 2020 of 220 lumens/Watt. The following subsections discuss key technical strategies identified by the research team for designing buildings to achieve ZNE.

7.1.1 LEDs

While many building systems are experiencing diminishing gains in terms of efficiency, LED technology has the potential to make revolutionary breakthroughs in the field of lighting. And it may make those breakthroughs in comparatively short order. According to the DOE, LEDs can reach 220 lumens/Watt performance levels by 2020, which can be compared to current linear fluorescent performance of 90 lm/W. (Bardsley Consulting, 2012)

LEDs will not only be more efficient than their fluorescent counterparts, they have the same potential for targeted light delivery as much less efficient halogen fixtures. Using this targeting potential of LEDs, lighting designers will have the ability to combine optimized light targeting strategies with high performance efficiency levels for the first time, further reducing energy use.

LEDs have a notable multiplier effect, creating savings for essentially every square foot of new construction. There are equal or larger savings opportunities for LEDs in building efficiency retrofits as compared to new construction. Even roads and parking lots will benefit from LED advancements.

DOE research tracking the development of LEDs specifically projects a 224-235 lm/W performance level by 2020. This technical feasibility study uses slightly more conservative performance values of 220 lm/W for commercial buildings and 200 lm/W for residential buildings. The price of LED fixtures on a per lumen basis is also projected to be competitive with conventional fixtures by 2020. (Bardsley Consulting, 2012)

Recommendation: Continue to promote and regulate the integration of LED systems across all relevant applications. Work with the federal government and other pertinent parties to ensure that both lighting quality and fixture longevity are maintained in the industry. Help to develop system standards if and when necessary for both mechanical interoperability (facilitating the replacement of light emitting components within a fixture) and system control interoperability.

7.1.2 Turning Off Idle Equipment

Sensors and software are becoming ever more proficient at reducing equipment loads when a piece of equipment is not necessary for occupant use in buildings and homes. The resulting energy savings – a type of automated conservation – are potentially as important as future equipment efficiency gains.

Buildings and equipment are shifting from operating in a constantly ready "*just in case*" mode to a more strategic "*if and when necessary*" mode. To accomplish this, one promising technology integrates occupancy, temperature, and lighting sensors into lighting fixtures on a fixture-by-fixture basis. This allows lighting and HVAC to be "tuned" at a much smaller scale.

Computer systems should have increasingly effective sleep functions that move the systems into a low energy consumption mode when not being utilized but permit both a rapid and remote (for enterprise applications) return to full functionality. In the home, computers, TV recorders, TVs, phone chargers and a host of other equipment can be improved by lowering energy use when idle.

The impact of these sensor systems is expressed in energy models by way of equipment schedules. It is a significant challenge, however, to determine how a given set of sensors linked to equipment will actually impact an equipment schedule, with overlapping control functionality complicating the challenges (e.g.

daylighting sensors and occupancy sensors). Such scheduling improvements were implemented only lightly in this research, and as such represent one of the primary areas of conservative estimation within the research.

Recommendation: Promote and/or regulate the application of control systems in buildings and homes to drive integration with ever more equipment. There are ample opportunities for research in the sector that should bear fruit in short order. Continuing to improve interoperability of the systems as well as installation simplicity is important in making the promise of sensor systems a reality.

Further research establishing how a host of sensor applications will affect building equipment schedules within energy models will facilitate future analysis of the systems in the context of a building's overall energy use.

7.1.3 Plug Loads

As the more permanent subcomponents of a building continue to improve in efficiency (envelope, HVAC, and lighting), the remaining plug loads are becoming a larger and larger portion of the overall load. In this "stress test" of Zero Net Energy design objectives, reducing the plug loads often proved critical to meeting the overall energy use targets. That is also the experience of most architects and engineers working on Zero Net Energy projects.

As with LEDs, improvements in plug load efficiency will have equal if not greater benefits in the existing building market.

Recommendation: Continue to aggressively promote equipment efficiency regulations at the state and federal level. Continue equipment efficiency incentive programs.

Finding new ways to incentivize the *outcomes* of smart equipment purchasing and operations strategies – tapping into submeter data or disaggregated smart meter data for the Measurement & Verification (M&V) – is another pathway worth exploring. This could provide better return on investment to the IOUs and allow building owners more leeway in collaborating with the IOUs in addressing the plug load reduction challenges. (Such outcome based programs could be challenging to implement in new construction projects where there is not a baseline for M&V.)

7.1.4 Minimize Systems Working at Cross-Purposes

Buildings are often working at cross-purposes to maintain occupant comfort. Reheat is a classic example. These processes – such as the heating of previously cooled air – are often the byproduct of efforts to simplify the design and construction of an HVAC system.

In a similar vein, energy is often used in a building to heat or cool air and water when air and water of a similar temperature is simultaneously being rejected from the building. Heat recovery can come from ventilation air, shower drain water, and cooling system heat rejection.

Recommendation: Research and education programs should continue to work towards making HVAC systems that minimize reheat easier to design and implement.

7.1.5 Residential Ducts in Conditioned Space

Similar to the problems with reheat, the State will always be challenged in meeting its efficiency goals, and in particular in meeting its peak load reduction goals, if residential air conditioning systems are operating in high temperature attics. There are a number of viable ways to solve this challenge, and builders should be provided with a host of options to do so. The most promising approach from a constructability standpoint appears to be moving the entire HVAC system out of the attic.

A better insulated home, with high performance windows, proper orientation, and ducts in the conditioned space can have considerably lower air conditioning loads than does a standard home today. That reduced load, in turn, allows for a much smaller duct system to provide the necessary cooling. The reduced duct sizing facilitates installation when the HVAC system is no longer located in the attic. Hydronic delivery systems are another viable strategy, with additional potential fan energy savings.

Recommendation: Rather than continuing to focus on ways to reduce attic temperatures, it appears that residential building standards should instead work towards moving HVAC systems within the conventional building envelope. Isolating the home from attic heat is then a much simpler problem, solved by adding additional blown-in insulation (perhaps with a raised heel truss). A builder could, through the Title 24 performance compliance process, achieve the same energy benefits by providing sufficient insulation at the roof deck if the builder preferred that method.

7.1.6 Natural Ventilation

The use of natural ventilation schemes should be further encouraged throughout much of California. The challenges are considerable for many commercial buildings in designing and implementing an effective natural ventilation scheme that does not also increase air conditioning or heating energy use at some times. Natural ventilation strategies in commercial buildings must also account for a host of fire control and indoor air quality issues to protect occupants.

More sophisticated systems have a combination of automated opening windows, manually opening windows, connections between window sensors and the mechanical control system, and other integrated subcomponents. Because of the number of integrated parts, the most effective systems can be quite expensive and rarely cost effective when analyzed from purely an energy savings perspective. The non-energy benefits that come with effective natural ventilation systems are hard to quantify but could often justify the additional costs. Simpler systems in more mild climates and smaller buildings might be installed more cost effectively.

Recommendation: State energy agencies and IOU emerging technology programs should continue to work on design strategies and training programs to improve the constructability of natural ventilation systems in commercial buildings. For cost effectiveness reasons and due to potential site specific complications – e.g. noise, security, or outdoor air quality – it does not appear that natural ventilation should be a required element of ZNE buildings if ZNE goals are pursued through the energy code. (This caveat does not apply to mechanical variants such as residential nighttime cooling systems and commercial economizers, both of which have proven cost effective in much of California.)

7.1.7 Vertical Transportation

Vertical transportation represents a sizable remaining load within many of the taller buildings. There are a number of measures that can be implemented to reduce the energy use of elevators by up to 50% beyond standard performance levels.

Hydraulic elevators inherently use more energy than traction elevators, so switching to a traction elevator where a hydraulic elevator would normally be used will result in a notable reduction in energy use. While there is a perception that hydraulic elevators must be used in smaller buildings, traction elevators can be used effectively down to two stories.

The location of the elevator itself – placed further from an entrance – can also affect energy use when suitable stairs are provided as an alternative, at least for movement up one or two flights.

Regenerative braking systems, variable-voltage/variable-frequency drives, sleep functions, and advanced dispatching systems can all reduce energy use.

Recommendation: The State and the IOUs should investigate the integration of vertical transportation systems into both efficiency regulations and efficiency incentive programs. Significant reductions can be made, often concentrated in afternoon peak-load hours.

7.1.8 Photovoltaics

The photovoltaic industry continues to advance at a comparatively rapid pace, both in terms of systems costs and in terms of system efficiencies. A critical variable for zero net energy projects, however, is the density of power production and the available space for PV panels (See Section 2.5 for details). Reducing the costs of the highest efficiency panels, increasing overall panel efficiency, and improving operational performance through optimizers will continue to increase the kWh yield per square foot of available space.

Creative racking systems continue to evolve that will increase the square footage of available installation space. At least one building is looking to use a roof canopy systems that cantilevers beyond the building perimeter. Such systems might increase available roof usage beyond 100%. There is obviously a substantial cost for such systems, but as the production density of the panels themselves increases, the mounting costs *per Watt* will correspondingly decrease.

Recommendation: The solar industry appears capable of driving its own performance and cost improvements in the years ahead. Few industries see the year-over-year improvements now seen in the photovoltaic sector. A critical question in moving from ZNE *goals* to ZNE *policies* will be the cost effectiveness of photovoltaic electricity. The cost and performance shifts within the PV industry are happening so quickly, however, that new methods for dynamically assessing the cost effectiveness of the technology might need to be developed.

7.2 Research Priorities

7.2.1 Cost Effectiveness Evaluation

There are at least two cost effectiveness issues that deserve further exploration than this study could afford. (See Section 5.1 for details)

7.2.1.1 Further evaluation of exemplar prototype total costs

A complete costing analysis of the proposed exemplar prototypes would provide valuable additional insight to this energy focused research. Confirmation or adjustment to the costing conclusions outlined in this report, based on a more rigorous costing analysis, would provide significant guidance to the State and IOUs for future efficiency program planning. More precise costing estimates would be particularly valuable as this study relates to future Title 24 and Title 20 advancements. Because the efficiency measures were designed as a package, an evaluation of the integrated costs and benefits of the package of measures would be most valuable.

Recommendation: Conduct a more thorough costing, and cost effectiveness, analysis of the measures and strategies set forth in this study's exemplar designs.

7.2.1.2 Integrated analysis of cost effectiveness in Title 24

The integrated analysis of costs and benefits for ZNE design strategies appears to provide significant benefits as compared to a measure-by-measure approach. An integrated analysis appears both more accurate and more likely to show that there are net benefits for multiple subcomponents when analyzed as whole.

Recommendation: The California Energy Commission, in collaboration with the California IOUs, should explore the regulatory and logistical opportunities associated with conducting a cost effectiveness analyses for Title 24 updates at the level of integrated measure packages. Such an analysis would cover a somewhat different set of measures than is outlined in this study, as this study was not constrained by the same limitations as are present in the advancement of Title 24.

7.2.2 Accelerate Whole Building Performance Programs

As discussed in Section 1.5, a critical component to reaching the State's ZNE goals– at the scale of almost every newly constructed building – is gaining the necessary experience across the construction industry of building ZNE or near ZNE buildings. The building industry is still in the early stages of tackling whole building ZNE challenges. In meeting those challenges, it is not just the performance of individual pieces that will matter, but their proper integration into the whole. The integrated design strategies are where some of the biggest breakthroughs are likely to arise. Furthermore, the proper integration of strategies is where secondary cost savings are likely to arise.

Driving as many ZNE projects as is possible through programs such as Savings by Design is at least as important as improvements to building subcomponent efficiency.

Recommendation: Accelerate whole building design incentives, focusing where possible on ZNE and near ZNE projects. Match "whole building" design incentives with ever-greater training efforts in the area of integrated design and construction.

7.2.3 Minimal Net Reduction in Heating

This research revealed a notable shift in the overall load balance from electric consumption to natural gas consumption in ZNE designs. While efficiency improvements were implemented on the heating systems, reductions in internal gains and envelope gains often created a need for additional heating to meet occupant comfort needs. Similarly, some nighttime natural ventilation pre-cooling strategies led to an increase in morning heating needs.

These strategies resulted in overall reductions in TDV, but often increased natural gas consumption at a level that offset the heating efficiency gains. Reflecting this shift, Site-kBtu sometimes increased as measures were implemented in the prototypes to improve the TDV performance.

Recommendation: If the State would like to see a drop in natural gas consumption commensurate with the potential drops in electricity consumption, it should investigate shifting some heating loads to heat pump mechanisms. Such systems can open up additional opportunities to harvest "free" heat when water heating loads and space cooling loads are simultaneous.

7.2.4 Federal Preemption

This research evaluates purely the technical feasibility of reaching the ZNE goals. As such, this research is not constrained by federal efficiency standards in setting design strategies. If Zero Net Energy goals are to be pursued, as a first priority, through building energy efficiency standards and appliance efficiency standards, federal preemption issues will continue to be a notable barrier. Minimizing the differences between California's efficiency objectives and federal efficiency standards will be critical to achieving ZNE goals at a wide scale. It was beyond the scope of this study to identify strategies for state policies and IOU programs to minimize the impact of preemption constraints.

Recommendation: State energy regulators and the IOUs should continue to investigate creative ways to achieve the regulated energy efficiency levels that the State needs to reach its ZNE goals without violating federal law.

7.2.5 PV Sizing Sensitivity Analysis

Given a fixed amount of building energy load, highly variable levels of on-site renewable generation could be required under alternate ZNE policies to offset the building load. The policies explored in some detail in this study are the choice of primary ZNE metrics – TDV or Site-kBtu (Section 3.1.3) – and alternate valuation scenarios specific to electricity exports (Section 3.1.5.2). A number of other policy factors would affect the total kW of on-site generation capacity required to offset a building's energy load.

Recommendation: A comprehensive analysis of the impact of policy choices on ZNE generation capacity requirements would be valuable. That analysis should use a sampling of residential and commercial building load profiles. The analysis should assess the following variables that will impact potential PV sizing for a ZNE building (assuming that PV is the primary on-site generation resource):

1. Choice of primary metric: Site-kBtu, TDV, TDV without a retail rate adder, etc.
2. ZNE calculation rules for offsetting natural gas consumption with photovoltaic electricity generation
3. Potential future TDV schedules with shifted peak load hours due to widespread solar electricity saturation on the grid
4. Changes in the valuation of electricity exports as compared to electricity imports at a building
5. Potential "under-sizing" allowances in ZNE requirements to minimize the number of ZNE buildings overproducing energy in relation to total consumption (50% of buildings could be over-producers without such an allowance)
6. Other variables not identified by this research

A useful output of this analysis would be a matrix or a dynamic tool for assessing the interactive impact of these policy choices on overall PV sizing requirements for a given structure to reach ZNE. The analysis might touch on related solar thermal sizing requirements as well.

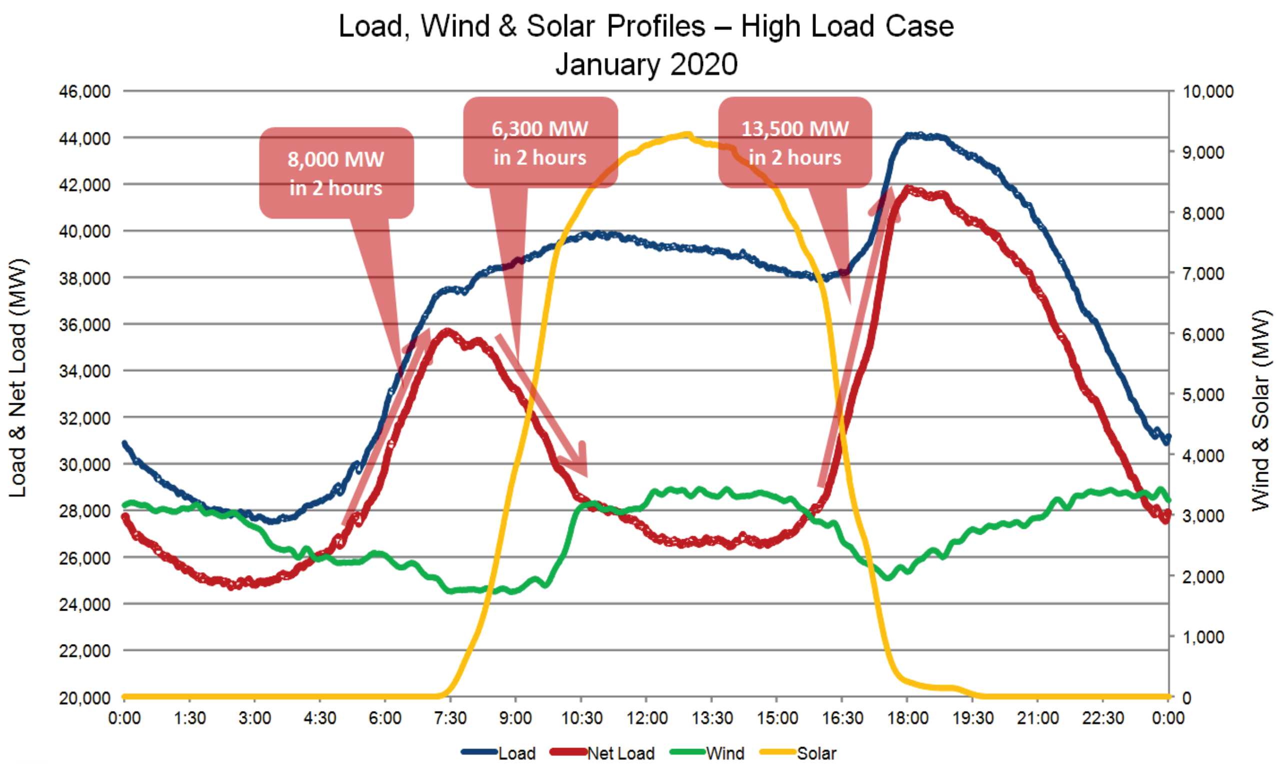
7.2.6 Load Challenges

The significant photovoltaic output of ZNE buildings in 2020 and beyond will present challenges for the energy grid at all scales. A primary challenge for the utilities will be in servicing loads that, until shortly before sundown, are met by ample on-site PV generation.

Figure 16 depicts the challenge for the grid presented by new ZNE construction alone. Figure 17, from the California Independent System Operator (CAISO), depicts projected impacts of high renewable energy distribution in 2020, only magnified to the state level. High ramping rate challenges are highlighted by the arrows in Figure 17, such as the 13,500 MW increase in "Net Load" over 2 hours that must be met by dispatchable generation.

Recommendation: Statewide research should investigate the grid management challenges and cost-of-service implications that will arise from high levels of PV integration. The issues extend beyond the high-ramping rate challenges presented here to include reverse flow issues on the grid and other grid level impacts.

Figure 17 –CAISO Composite Load and Generation Curves for 2020



(From CAISO presentation "R.11-10-023: RA Flexibility Workshop: Flexible Capacity Procurement Proposal", 2012)

8 Exemplar Prototypes

The building-by-building results of the research are presented in this chapter, with each of the 12 exemplar building prototypes in its own subsection. The overall performance of two composite building types – "College" and "Other Commercial" – are also provided to produce a complete match of prototypes with the building type categories used for construction volume forecasts.

The baseline for all of the residential models is Title 24 2013 unless noted otherwise. The baseline for all of the commercial models is ASHRAE 90.1-2010 unless noted otherwise.

The study's central finding is that ZNE buildings will be technically feasible for much of California's new construction market in 2020. Critical findings that span all prototypes are outlined in Chapter 1, Chapter 6, and Chapter 7.

8.1 Exemplar Sample Tables

Each exemplar prototype subsection includes the following components:

Summary table. (See sample below). This table provides a high-level snapshot of the building load, solar production, and net energy use values in all seven modeled climate zones.

Description. This narrative presents the key energy conservation measures applied to the prototypes.

Change logs. (See sample below). The energy conservation measures applied to each prototype appear in order of application and with their corresponding energy reductions.

Representative climate zone change logs are provided; not all climate zones are reported for every building type.

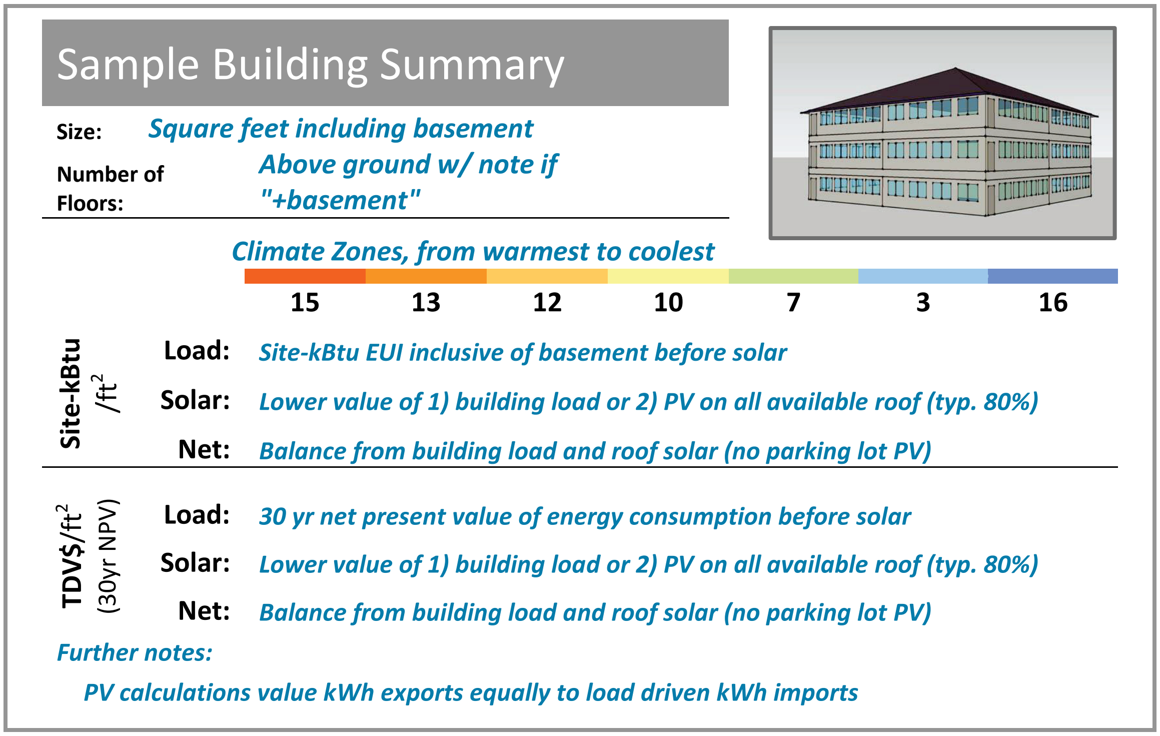
Measure implementation charts. (See sample below). Graph includes the incremental energy reductions by measure for EUI and TDV.

Subsystem loads. Graph includes Site-kBtu information for baseline models and exemplar models across heating load, cooling load, lighting loads, etc.

Building performance data. (See sample below). This table provides more detailed energy metrics for each building type and climate zone.

kWh binning. Raw energy use data for four building types in monthly, hourly, weekday / weekend bins for further analysis of billing rate implications.

*** The asterisk next to the First Cost and Net Cost estimates** at the end of each change log convey that these cost estimates are the coarsest of estimates, assessing only a portion of the likely marginal additional costs and potential system sizing reduction cost savings. It was not within the scope of this study to do a full cost effectiveness analysis.



Sample Change Log

CZ-Sample

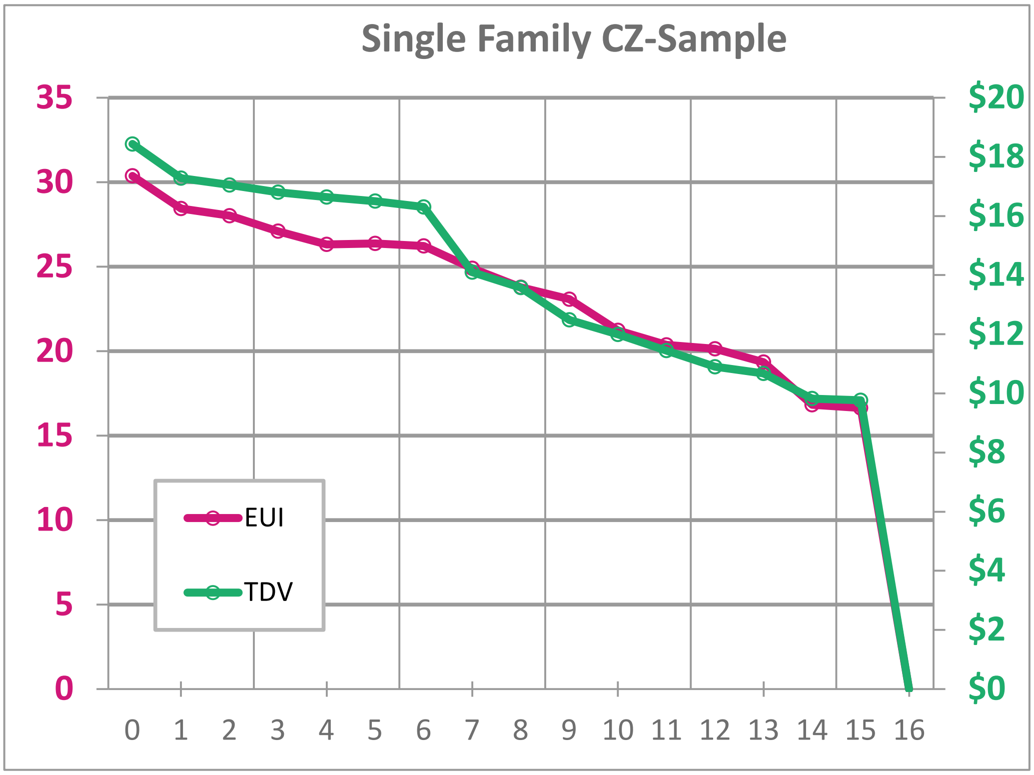
	Strategy *(ref to baseline)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	*Performance of Baseline 90.1-2010 or T24 2013 Model*		
1	Improved Wall Construction: 2x6 walls, R-21 w/ R-4 rigid ext. sheathing. Advanced framing, 24" o.c.	*Incremental reductions in Site-kBtu as compared to prior measure/model.*	*Incremental reductions in TDV$ as compared to prior measure/model.*	*Percent reduction of TDV from Baseline*
2	Ceiling Insulation: R-60 blown-in insulation w/ raised heel trusses			
3	Reduced Building Infiltration: 1.8 SLA / 3.15 ACH50			
4	Improved Windows: U-Factor=0.25 / SHGC=0.20			
5	Cool Roof: Reflectivity=0.40 / Emissivity=0.85			
6	Additional Thermal Mass			
7	Improved Lighting: High efficacy LED lighting and vacancy controls			
8	High Efficiency Appliances: Clothes washer, Dishwasher, Refrigerator			
9	Reduced Plug Loads & Plug Load Control 20%			
10	Low-Flow Shower & Sinks			
11	Ducts in Conditioned Space			
12	High Efficiency 2-speed AC, SEER 21 w/ Integrated Ventilation Cooling			
13	Condensing Gas Space Heating			
14	Condensing Gas Water Heater			
15	Improved HW Distribution: Compact Design, Insulated HW Pipes			
16	Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)			
	Ending EUI:	**0.0**	**0.00**	

Notes

- ***"=Text=" denotes measures that do not change notably between climate zones.***
- ***“N/A” is listed for measures that occur in one climate zone but not in another climate zone to maintain consistency in measure numbers across a building type.***
- ***Note that the “Ending EUI” + “Rooftop PV” = Final Efficiency EUI. For those buildings that can reach ZNE, the Rooftop PV figure is equivalent to the Final Efficiency EUI.***

Total TDV$ Savings:	***Sum of all TDV$ increments (i.e. Ending EUI)***
Incremental First Cost:	***Coarse estimate of marginal first costs to implement strategies, including potential first cost savings due to system sizing reductions and rooftop PV costs.***
Net Life Cycle Cost:	***Total TDV$ Savings + Incremental First Cost***

Incremental Reduction by Measure



The numbers at the bottom of the incremental measure graphs match the measure numbers in the change logs to show the relative gains.

Building Performance Data

Sample Building

Square feet: ***Floor area including basement***

Avail. Roof: ***Typ. 80% of roof***

Climate Zones: 15 | 13 | 12 | 10 | 7 | 3 | 16

Total Building Energy Metrics

kWh/ft^2	Load	***Annual electricity consumption before solar***
	Minimized Site-kBtu	***Consumption w/ PV sized 1) to just achieve Site-kBtu ZNE if achievable within available roof space or 2) to use all available roof space if Site-kBtu ZNE not achievable within available roof space***
	Minimized TDV	***Same as for "minimized Site-kBtu" but with a TDV ZNE target used for rooftop PV sizing***
kW/bldg (250 hr method)	Load	***Weighted average whole building load for the 250 predetermined hours with the highest overall grid load as defined by the TDV development methodology***
	Minimized Site-kBtu	***Same as above but w/ PV sized to achieve Site-kBtu ZNE; note that because a building could be exporting electricity during many of the 250 predetermined hours, this methodology can produce a negative value***
	Minimized TDV	***Same as above but w/ PV sized to achieve TDV ZNE***
Therms/ft^2	Load	***Annual natural gas consumption***

Carbon

CO_2e (lbs/ft^2)	Minimized Site-kBtu	***CO_2 emissions from gas and electric consumption, including solar production as scaled to optimize Site-kBtu performance***
	Minimized TDV	***CO_2 emissions from gas and electric consumption, including solar production as scaled to optimize TDV performance***

Solar Capacity

		15 / 13 / 12 / 10 / 7 / 3 / 16
Solar PV (kW)	Minimized Site-kBtu	***Capacity of PV system used in Site-kBtu ZNE calculations, sized either 1) to offset building load if roof space is available or 2) if ZNE cannot be achieved then to use all available roof space***
	Minimized TDV	***Same as for "minimized Site-kBtu" but with a TDV ZNE metric used for rooftop PV sizing***
Peak Export (kW - bldg)	Minimized Site-kBtu	***Lowest single hourly kW value inclusive of load and PV with PV system sized for Site-kBtu as noted for "Solar PV" metric***
	Minimized TDV	***Lowest single hourly kW value inclusive of load and PV with PV system sized as previously noted for "Solar PV" metric***

% of Avail. Roof Used	Minimized Site-kBtu	*Percentage of the available roof (typ. 80% of roof area) used for PV in the Site-kBtu ZNE feasibility calculations*
	Minimized TDV	*Percentage of the available roof (typ. 80% of roof area) used for PV in the TDV ZNE feasibility calculations*
Building Height Analysis		
Max Floors at ZNE	w/ Site-kBtu Metric	*If all available roof area is covered with PV (typ. 80% of roof area), number of floors that can be built and still achieve ZNE; all floors assumed to have the building average Site-kBtu EUI*
	w/ TDV Metric	*If all available roof area is covered with PV (typ. 80% of roof area), number of floors that can be built and still achieve ZNE; all floors assumed to have the building average TDV EUI*
Max Floors with **Parking PV**	w/ Site-kBtu Metric	*Same as above Max Floors calculation, but with the additional resource of 1-axis tracking PV covering 35% of the parking area; all accounting done on a Site-kBtu basis*
	w/ TDV Metric	*Same as above Max Floors calculation, but with the additional resource of 1-axis tracking PV covering 35% of the parking area; all accounting done on a TDV basis*
	Park. PV Size (kW)	*PV capacity covering 35% of the parking lot, the same under either metric; the tracking PV has a 25% higher capacity factor as compared to the fixed roof arrays*

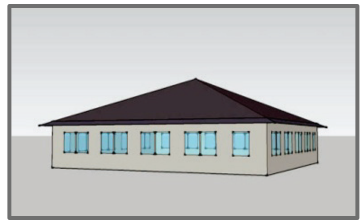
CHP w/ Parking PV	15	13	12	10	7	3	16
CHP system size (kW)	*Size of the modeled CHP system, sized and operating per the parameters outlined in this report; the CHP system is calculated for the remaining load after rooftop PV and parking PV have been maximized.*						
Site-kBtu/ft^2	*Net EUI inclusive of building load, rooftop PV, parking lot PV, and CHP*						
**TDV$**/ft^2 (30yr NPV)	*Net EUI inclusive of building load, rooftop PV, parking lot PV, and CHP*						

Note: Many of the "Minimized Site-kBtu" and "Minimized TDV" metrics in the above chart will be equivalent in buildings that cannot achieve ZNE. The Hospital, Hotel, and Restaurant, for instance. The PV system will be sized the same under both criteria, maximizing available roof space. That PV system equivalency, will not only make the PV metrics equal, but the overall kWh and kW metrics as well.

8.2 Single Family Residential

Single Family Residential

Size:	**2,116**	ft^2
Number of Floors:	**1**	floor



		Climate Zones						
		15	**13**	**12**	**10**	**7**	**3**	**16**
Site-kBtu /ft²	**Load:**	12.9	16.4	16.6	12.9	11.5	12.7	17.3
	Solar:	-12.9	-16.4	-16.6	-12.9	-11.5	-12.7	-17.3
	Net:	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
TDV$/ft² (30yr NPV)	**Load:**	12.23	9.66	9.77	8.74	8.01	7.97	10.32
	Solar:	-12.23	-9.66	-9.77	-8.74	-8.01	-7.97	-10.32
	Net:	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Description:

The Single Family model is a 2,100 ft^2 single story detached home with 3 bedrooms and 2 bathrooms. The building is orientation neutral with both walls and windows equally distributed. The model is based on the Prototype C used in the Title 24 2008 Residential Alternative Calculation Methodology Manual. The 2013 Title-24 Package A prescriptive measures were used to define the base case building including envelope, HVAC, and domestic hot water (DHW) characteristics.

Per Package A, in climate zones 8-14 nighttime ventilation cooling is a base case measure, in the form of a whole house fan. The exemplar model upgrades this measure to integrated nighttime ventilation with a variable speed fan and automatic operation including temperature sensing and setpoint control. Ventilation cooling can also be beneficial in coastal and mountain climates where minimal cooling loads allow it to replace compressor cooling all together.

Exemplar TDV annual energy savings of greater than 45% are achieved through deep reductions in building load both with envelope measures and internal load reductions, and with high efficiency mechanical equipment.

An important characteristic of the exemplar Single Family building is that all ductwork is located within conditioned space. Typically, in homes with vented attics and slab-on-grade construction, the HVAC equipment and associated ductwork is located in the attic and exposed to extreme temperatures, especially during the summer months, resulting in significant energy penalties due to both conduction losses and air leakage. Winter heating losses are also significant.

Re-locating the ductwork inside the home's envelope by itself provides ~30% HVAC site and TDV energy savings. Another equivalent solution is ductless systems such as distributed fan coils, mini-split heat pumps, and radiant systems. In climate zone 3, cooling loads were reduced to the point that mechanical cooling was eliminated.

Integrated design, planning and quality control are critical components of any ZNE building. ZNE solutions are not yet “plug-and-play”. This involves engaging all of the stakeholders and communicating the energy goals and expectations early on in the design process. This allows for potential challenges to be identified and resolved at an early stage, saving both time and money, and encourages participation and creative solutions, taking full advantage of the contribution that each team member has to offer.

Improper installation and lack of system commissioning can result in actual performance varying substantially from the design expectations. For the Single Family case, the assumption is that a HERS rater will verify that all design measures are quality installed and operating per design. These verifications include Quality Insulation Installation (QII), duct leakage, infiltration with blower door, refrigerant charge and airflow, fan watt draw, and HVAC right sizing.

A component of the exemplar specification is a combined hydronic system for space heating and DHW with a condensing gas appliance. Available capacities of traditional gas furnaces are not well suited for the low heating loads in the exemplar model in all climate zones. Proper system design is essential to ensure the system achieves condensing efficiencies during steady-state operation. This is accomplished by supplying lower water supply temperatures than would be supplied with a forced air gas furnace. Careful attention to properly designed supply water temperatures as well as water and air flow rates should provide low enough return water temperatures to ensure condensing efficiencies. It is noteworthy that the performance target established with the combined hydronic system can be obtained through other strategies, including heat pumps.

While substantial reductions were made to the majority of end-uses, considerable uncertainty surrounds miscellaneous electrical use (“plug loads”) and to what degree their annual energy use can be reduced by 2020. The difficulty is in correctly accounting for the continued growth of plug load saturation in homes, for the progress in state and federal appliance regulations, and for the broader market trends that increase equipment efficiencies and control strategies.

Based on a literature review and conversations with others actively looking at residential plug energy use, this analysis applies an average residential plug load energy savings of 20%. With ideal consumer purchasing and behavior patterns there is potential to reduce this number significantly lower, perhaps beyond 50%. The 20% estimate is consistent with the research parameter of modeling best possible system efficiencies paired with average usage patterns.

The exemplar lighting package assumes 100% LED fixtures with an improved efficacy far above that of current technology. Research by the Department of Energy asserts that by 2020 efficacy of LED fixtures will be greater than 200 lumens/Watt; this efficacy is used in the residential exemplar cases (with an efficacy of 220 lm/W assumed for the commercial prototypes).

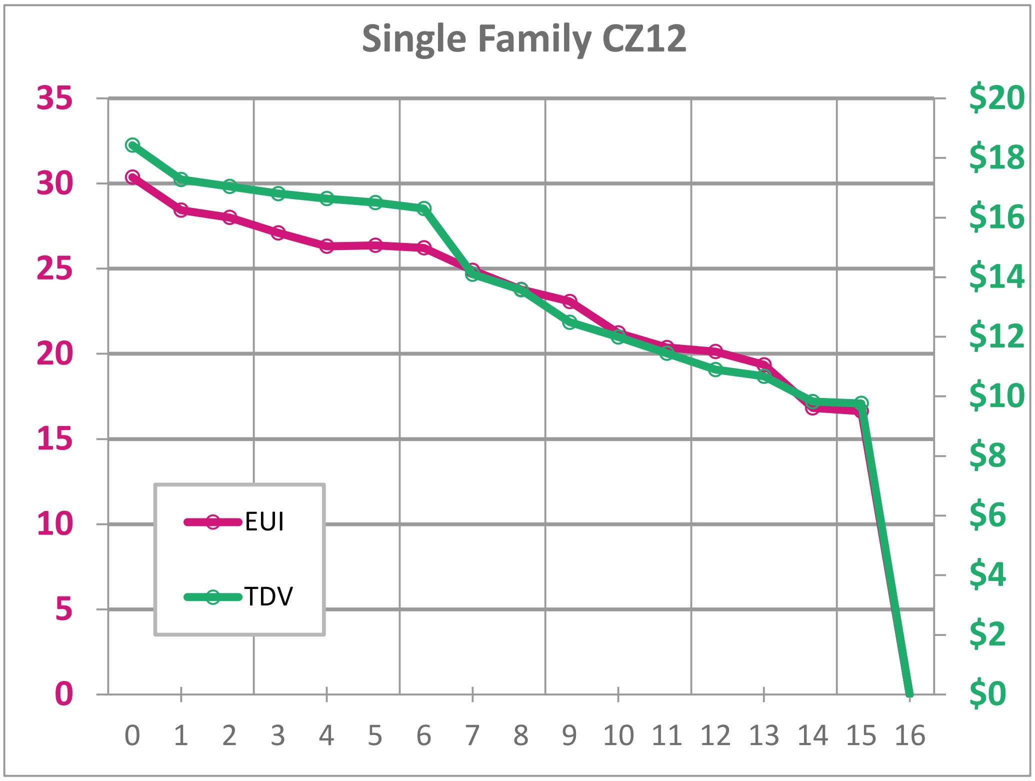
Single Family Residential Change Log

CZ12
Sacramento

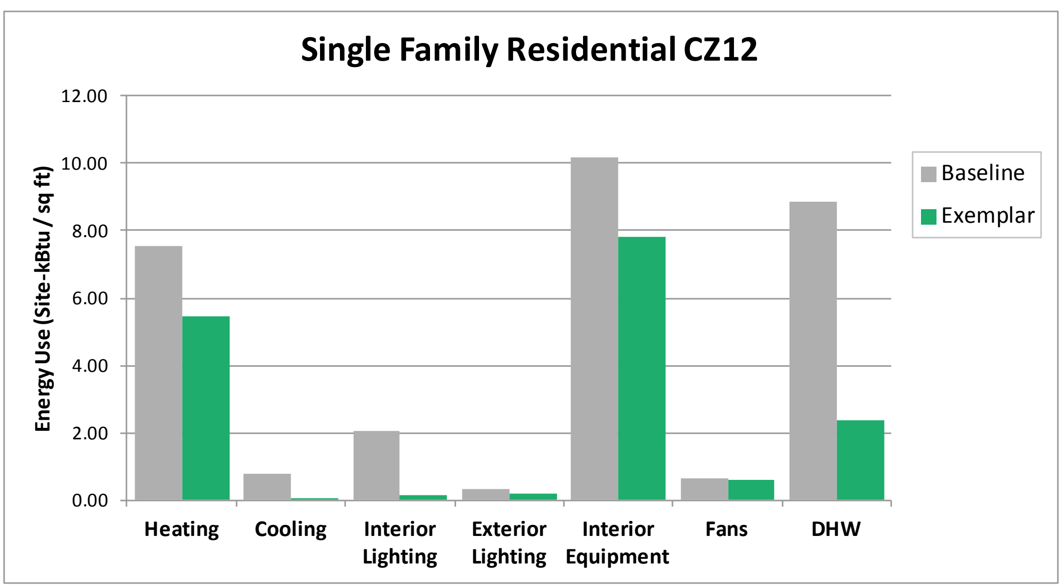
	Strategy *(Baseline is T24 2013 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	30.4	18.4	0%
1	Improved Wall Construction: 2x6 walls, R-21 w/ R-4 rigid ext. sheathing. Advanced framing, 24" o.c.	-1.94	-1.15	6%
2	Ceiling Insulation: R-60 blown-in insulation w/ raised heel trusses	-0.43	-0.23	7%
3	Reduced Building Infiltration: 1.8 SLA / 3.15 ACH50	-0.91	-0.24	9%
4	Improved Windows: U-Factor=0.25 / SHGC=0.20	-0.78	-0.16	10%
5	Cool Roof: Reflectivity=0.40 / Emissivity=0.85	0.06	-0.14	10%
6	Additional Thermal Mass	-0.15	-0.20	11%
7	Improved Lighting: High efficacy LED lighting and vacancy controls	-1.32	-2.20	23%
8	High Efficiency Appliances: Clothes washer, Dishwasher, Refrigerator	-1.12	-0.52	26%
9	Reduced Plug Loads & Plug Load Control 20%	-0.71	-1.09	32%
10	Low-Flow Shower & Sinks	-1.84	-0.49	34%
11	Ducts in Conditioned Space	-0.86	-0.54	37%
12	High Efficiency 2-speed AC, SEER 21 w/ Integrated Ventilation Cooling	-0.23	-0.55	40%
13	Condensing Gas Space Heating	-0.78	-0.22	42%
14	Condensing Gas Water Heater	-2.53	-0.85	46%
15	Improved HW Distribution: Compact Design, Insulated HW Pipes	-0.18	-0.06	46%
16	Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)	-16.65	-9.77	100%
	Ending EUI:	0.0	0.00	

Total TDV$ Savings:	-$18.43
Incremental First Cost:	$9.25*
Net Life Cycle Cost:	-$9.19*

Incremental Reduction by Measure



Subsystem Loads



Single Family Residential Change Log

CZ03
Oakland

	Strategy *(Baseline is T24 2013 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	27.1	15.17	0%
1	=Improved Wall Construction: 2x6 walls, R-21 w/ R-4 rigid ext. sheathing. Advanced framing, 24" o.c.=	-0.55	-0.19	1%
2	Ceiling Insulation: R-49 blown-in insulation w/ raised heel trusses	-0.54	-0.19	2%
3	=Reduced Building Infiltration: 1.8 SLA / 3.15 ACH50=	-1.00	-0.33	5%
4	R-10 Underslab Insulation	-1.27	-0.34	7%
5	=Improved Lighting: High efficacy LED lighting and vacancy controls=	-2.02	-2.49	23%
6	=High Efficiency Appliances: Clothes washer, Dishwasher, Refrigerator=	-1.45	-0.62	27%
7	=Reduced Plug Loads & Plug Load Control 20%=	-0.98	-1.21	35%
8	=Low-Flow Shower & Sinks=	-2.43	-0.67	39%
9	=Ducts in Conditioned Space=	-0.26	-0.05	39%
10	=Condensing Gas Space Heating=	-0.30	-0.10	40%
11	=Condensing Gas Water Heater=	-3.38	-0.94	46%
12	=Improved HW Distribution: Compact Design, Insulated HW Pipes=	-0.25	-0.07	47%
13	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-12.72	-7.97	100%
	Ending EUI:	0.0	0.00	

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Total TDV$ Savings:	-$15.16
Incremental First Cost:	$4.97*
Net Life Cycle Cost:	-$10.19*

Single Family Residential Change Log

CZ10
Riverside

	Strategy *(Baseline is T24 2013 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV**/ft2 (30yr) savings	**TDV** reduction
	Starting EUI:	24.9	17.0	0%
1	=Improved Wall Construction: 2x6 walls, R-21 w/ R-4 rigid ext. sheathing. Advanced framing, 24" o.c.=	-0.40	-0.31	2%
2	Ceiling Insulation: R-49 blown-in insulation w/ raised heel trusses	-0.36	-0.25	3%
3	=Reduced Building Infiltration: 1.8 SLA / 3.15 ACH50=	-0.36	-0.11	4%
4	=Improved Windows: U-Factor=0.25 / SHGC=0.20=	-0.30	-0.45	7%
5	=Cool Roof: Reflectivity=0.40 / Emissivity=0.85=	-0.04	-0.16	8%
6	=Additional Thermal Mass=	-0.15	-0.17	9%
7	=Improved Lighting: High efficacy LED lighting and vacancy controls=	-2.01	-2.28	22%
8	=High Efficiency Appliances: Clothes washer, Dishwasher, Refrigerator=	-1.18	-0.51	25%
9	=Reduced Plug Loads & Plug Load Control 20%=	-0.96	-1.11	32%
10	=Low-Flow Shower & Sinks=	-1.80	-0.45	34%
11	=Ducts in Conditioned Space=	-0.42	-0.46	37%
12	=High Efficiency 2-speed AC, SEER 21 w/ Integrated Ventilation Cooling=	-0.51	-0.93	42%
13	=Condensing Gas Space Heating=	-0.23	-0.06	43%
14	=Condensing Gas Water Heater=	-3.04	-0.94	48%
15	=Improved HW Distribution: Compact Design, Insulated HW Pipes=	-0.20	-0.06	49%
16	=Rooftop PV=	-12.94	-8.74	100%
	Ending EUI:	0.0	$0.00	

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Total TDV Savings:	-$16.99
Incremental First Cost:	$8.44
Net Life Cycle Cost:	-$8.55

Single Family Residential Change Log

CZ15
Palm Springs

#	**Strategy** *(Baseline is T24 2013 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	27.6	26.15	0%
1	=Improved Wall Construction: 2x6 walls, R-21 w/ R-4 rigid ext. sheathing. Advanced framing, 24" o.c.=	-1.11	-1.49	6%
2	=Ceiling Insulation: R-60 blown-in insulation w/ raised heel trusses=	-0.20	-0.27	7%
3	=Reduced Building Infiltration: 1.8 SLA / 3.15 ACH50=	-0.28	-0.37	8%
4	=Improved Windows: U-Factor=0.25 / SHGC=0.20=	-0.11	-0.13	9%
5	=Cool Roof: Reflectivity=0.40 / Emissivity=0.85=	-0.16	-0.24	10%
6	High Reflectivity Walls: Reflectivity=0.70 / Emissivity=0.90	-0.31	-0.47	11%
7	=Improved Lighting: High efficacy LED lighting and vacancy controls=	-2.33	-2.43	21%
8	=High Efficiency Appliances: Clothes washer, Dishwasher, Refrigerator=	-0.90	-0.71	24%
9	=Reduced Plug Loads & Plug Load Control 20%=	-1.13	-1.18	28%
10	=Low-Flow Shower & Sinks=	-1.19	-0.36	30%
11	=Ducts in Conditioned Space=	-1.07	-1.53	35%
12	High Efficiency 2-speed AC, SEER 21	-2.60	-3.58	49%
13	=Condensing Gas Water Heater=	-3.13	-1.12	54%
14	=Improved HW Distribution: Compact Design, Insulated HW Pipes=	-0.18	-0.06	54%
15	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-12.88	-12.23	100%
	Ending EUI:	0.0	0.00	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$26.15
Incremental First Cost:	$9.65*
Net Life Cycle Cost:	-$16.50*

Single Family Residential Change Log

CZ16
Blue Canyon

	Strategy *(Baseline is T24 2013 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	42.8	21.02	0%
1	Improved Wall Construction: Double stud walls, R-28 9.25 in. depth, 24" o.c.	-3.90	-1.50	7%
2	=Ceiling Insulation: R-60 blown-in insulation w/ raised heel trusses=	-0.78	-0.33	9%
3	=Reduced Building Infiltration: 1.8 SLA / 3.15 ACH50=	-2.27	-0.77	12%
4	Improved Windows: Triple Pane U-Factor=0.17. High SHGC on North/South & Low SHGC on East/West	-5.75	-1.80	21%
5	R-10 Underslab Insulation	-3.52	-0.75	25%
6	=Improved Lighting: High efficacy LED lighting and vacancy controls=	-1.04	-1.84	33%
7	=High Efficiency Appliances: Clothes washer, Dishwasher, Refrigerator=	-1.13	-0.50	36%
8	=Reduced Plug Loads & Plug Load Control 20%=	-0.54	-0.90	40%
9	=Low-Flow Shower & Sinks=	-2.04	-0.57	43%
10	=Ducts in Conditioned Space=	-1.18	-0.57	46%
11	High Efficiency AC, SEER 14, 12 EER per Fed. Efficiency Standards	-0.11	-0.19	46%
12	=Condensing Gas Space Heating=	-0.82	-0.26	48%
13	=Condensing Gas Water Heater=	-2.21	-0.65	51%
14	=Improved HW Distribution: Compact Design, Insulated HW Pipes=	-0.20	-0.06	51%
15	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-17.26	-10.32	100%
	Ending EUI:	0.0	0.00	

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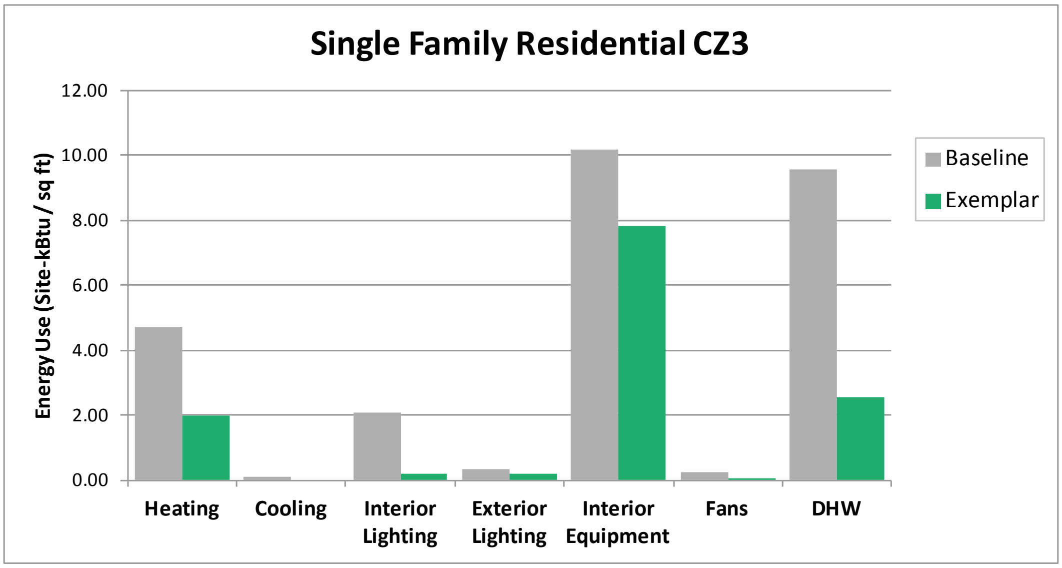
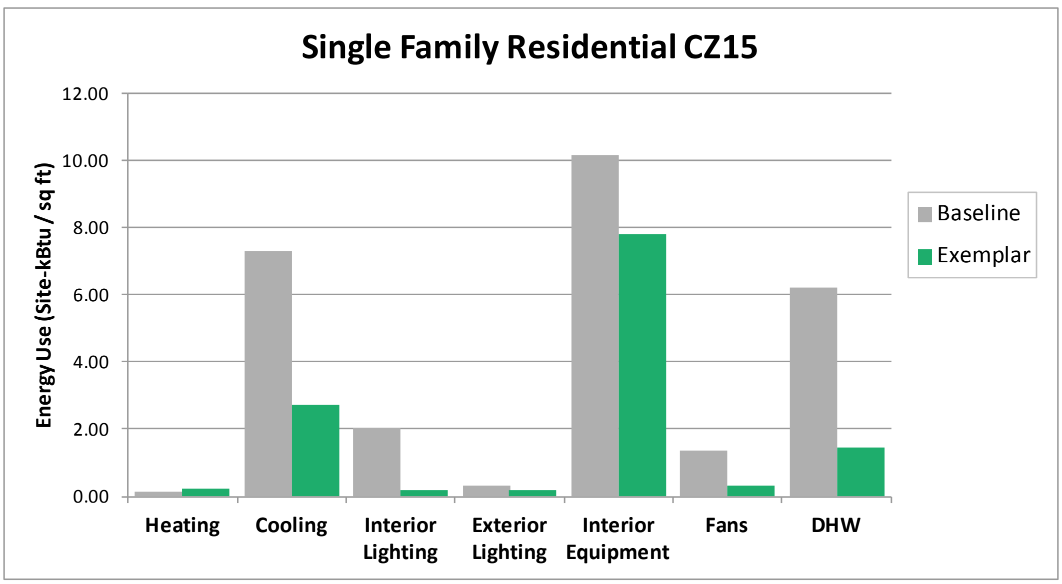
Total TDV$ Savings:	-$21.01
Incremental First Cost:	$12.16*
Net Life Cycle Cost:	-$8.85*

Additional Subsystem Load Charts





Building Performance Data

Single Family Residential

Square feet: 2,116		Climate Zones						
Avail. Roof: 1,040		**15**	**13**	**12**	**10**	**7**	**3**	**16**
Total Building Energy Metrics								
kWh/ft^2	Load	2.57	2.02	1.87	1.90	1.82	1.69	1.85
	Minimized Site-kBtu	-1.21	-2.79	-3.01	-1.89	-1.56	-2.04	-3.21
	Minimized TDV	-0.59	-0.38	-0.55	-0.22	-0.13	-0.17	-0.71
kW/bldg (250 hr method)	Load	1.59	0.46	0.51	0.63	0.44	0.42	0.76
	Minimized Site-kBtu	0.23	-1.86	-1.84	-0.93	-0.96	-1.52	-1.66
	Minimized TDV	0.45	-0.70	-0.66	-0.25	-0.37	-0.55	-0.46
Therms/ft^2	Load	0.04	0.10	0.10	0.06	0.05	0.07	0.11
Carbon								
CO_2e (lbs/ft^2)	Minimized Site-kBtu	-0.16	-0.37	-0.40	-0.25	-0.21	-0.27	-0.43
	Minimized TDV	0.20	1.03	1.03	0.72	0.63	0.82	1.03
Solar Capacity								
Solar PV (kW)	Minimized Site-kBtu	4.8	6.5	6.6	4.9	4.4	5.0	6.4
	Minimized TDV	4.0	3.2	3.3	2.8	2.5	2.5	3.2
Peak Export (kW - bldg)	Minimized Site-kBtu	-3.7	-5.1	-5.1	-3.7	-3.3	-3.9	-4.9
	Minimized TDV	-3.0	-2.4	-2.4	-2.0	-1.8	-1.8	-2.3
% of Avail. Roof Used	Minimized Site-kBtu	21%	28%	29%	21%	19%	22%	28%
	Minimized TDV	17%	14%	14%	12%	11%	11%	14%
Building Height Analysis								
Max Floors at ZNE	w/ Site-kBtu Metric	4.8	3.5	3.5	4.7	5.2	4.6	3.6
	w/ TDV Metric	5.8	7.1	7.0	8.3	9.1	9.2	7.1
Max Floors with **Parking PV**	w/ Site-kBtu Metric	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
	w/ TDV Metric	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
	Park. PV Size (kW)	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*

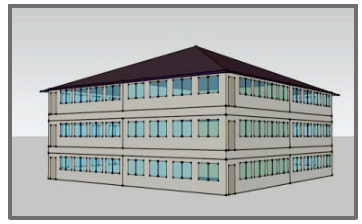
kWh by Bin			Climate Zones								
Single Family Residential			15			12			3		
			Load	Solar	Net	Load	Solar	Net	Load	Solar	Net
May through October	Mon. - Fri.	21:00 - 6:00	794	-30	764	572	-24	548	393	-19	374
		6:00 - 9:00	142	-452	-309	180	-333	-153	140	-211	-71
		9:00 - 12:00	155	-946	-791	126	-804	-679	121	-602	-481
		12:00 - 15:00	300	-870	-571	126	-787	-661	126	-632	-506
		15:00 - 18:00	607	-314	293	197	-340	-144	183	-268	-84
		18:00 - 21:00	506	2	508	235	-8	227	219	-8	212
	Sat. - Sun.	21:00 - 6:00	291	-39	252	239	-29	209	156	-18	138
		6:00 - 9:00	57	-252	-196	66	-211	-146	52	-126	-74
		9:00 - 12:00	70	-384	-314	50	-345	-295	50	-251	-201
		12:00 - 15:00	158	-285	-126	57	-268	-211	56	-211	-155
		15:00 - 18:00	243	-50	193	90	-67	23	83	-52	31
		18:00 - 21:00	184	-1	184	96	0	96	87	0	87
	Gas Therms		36			48			50		
November through April	Mon. - Fri.	21:00 - 6:00	468	-10	457	469	0	469	467	-2	465
		6:00 - 9:00	161	-284	-123	171	-128	43	175	-92	82
		9:00 - 12:00	135	-837	-702	144	-499	-356	142	-406	-265
		12:00 - 15:00	138	-795	-657	141	-532	-391	139	-436	-297
		15:00 - 18:00	203	-210	-8	191	-174	17	189	-146	43
		18:00 - 21:00	271	2	273	263	2	265	262	1	263
	Sat. - Sun.	21:00 - 6:00	173	-20	153	173	-11	162	173	-9	165
		6:00 - 9:00	61	-209	-148	65	-112	-47	66	-80	-14
		9:00 - 12:00	54	-356	-302	56	-239	-183	55	-191	-136
		12:00 - 15:00	59	-263	-204	58	-183	-125	57	-149	-92
		15:00 - 18:00	97	-23	74	90	-23	67	89	-19	70
		18:00 - 21:00	104	1	104	101	1	102	101	1	102
	Gas Therms		51			169			97		

8.3 Multi-Family Low-Rise

Multi-family Low-rise

Size: **14,700** ft²

Number of Floors: **3** floors



		Climate Zones						
		15	**13**	**12**	**10**	**7**	**3**	**16**
Site-kBtu /ft²	**Load:**	18.6	17.8	17.1	16.4	16.0	16.3	17.8
	Solar:	-18.6	-17.8	-17.1	-16.4	-16.0	-16.3	-17.8
	Net:	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
TDV$/ft² (30yr NPV)	**Load:**	19.60	16.81	15.16	15.01	14.25	13.81	14.98
	Solar:	-19.60	-16.81	-15.16	-15.01	-14.25	-13.81	-14.98
	Net:	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Description:

The Multi-family Low-rise model is a 3-story building with twelve 1,225 ft² 3-bed, 1-bath units and exterior entrances. The building is orientation neutral with both walls and windows equally distributed. With the exception of ventilation cooling, the base case is identical to that for the Single Family, which is based on the 2013 Title-24 Package A prescriptive measures. Because of venting difficulties in multi-family buildings, whole house fans are not included in the Title 24 prescriptive package. However, the exemplar model includes an integrated ventilation cooling system in certain climates.

The Multi-family Low-rise model differs from the Single Family prototype as follows: 16”o.c. framing for walls, centralized gas water heating, and drainwater heat recovery from the showers.

Central gas water heating is a common strategy for water heating employed in many multi-family buildings. Centralizing the source simplifies installation in that gas lines and venting do not need to run to and from multiple points within the building. It does include the addition of a recirculation pump. Proper control of the pump is important to minimize energy use. The exemplar model includes a combination of timer and temperature modulation control. Demand control operation can achieve additional savings.

Compact plumbing layout and appropriately stacked drains allows drainwater heat recovery to provide upwards of 30% water heating savings. This evaluation assumes that effective recovery is only captured from the shower drains providing approximately 10% water heating savings.

The EnergyPlus models showed much higher cooling loads and lower heating loads in the Multi-family Low-rise buildings compared to the Single Family due to reduced exterior walls and windows for heat rejection. In some cases, the optimization process returned results that varied between the two building types. For example, in climate zone 10, where the heating loads were all but eliminated, high efficiency condensing space heating was not justified and therefore not included in the Low-rise exemplar model. In climate zone 3, while high solar heat gain coefficient (SHGC) glass is optimal in the Single Family residence, a tuned window package with low SHGC glass on east and west orientation and high SHGC on south and north provided greater TDV energy savings in the Multi-family prototype. Lastly, in climate zone 16 cooling loads remained significant enough that high efficiency air conditioning was justified where it was not in the Single Family model.

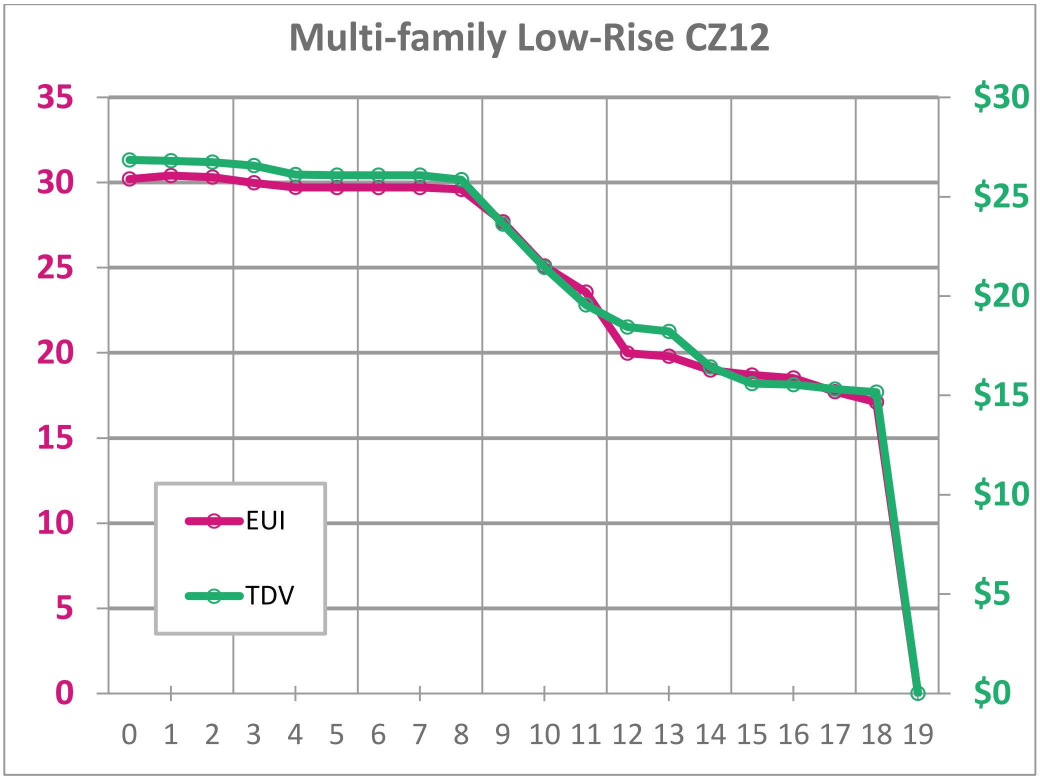
Multi-Family Low-Rise Residential Change Log

CZ12
Sacramento

	Strategy *(Baseline is T24 2013 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	30.2	26.85	0%
1	Improved Wall Construction: 2x6 walls, R-21 w/ R-4 rigid ext. sheathing.	0.20	-0.04	0%
2	Ceiling Insulation: R-60 blown-in insulation w/ raised heel trusses	-0.09	-0.07	0%
3	Reduced Building Infiltration: 1.8 SLA / 3.15 ACH50	-0.33	-0.17	1%
4	Improved Windows: U-Factor=0.25 / SHGC=0.20	-0.27	-0.45	3%
5	Cool Roof: Reflectivity=0.40 / Emissivity=0.85	-0.01	-0.03	3%
6	N/A	0.00	0.00	3%
7	N/A	0.00	0.00	3%
8	Additional Thermal Mass	-0.11	-0.23	4%
9	Improved Lighting: High efficacy LED lighting and vacancy controls	-1.90	-2.24	12%
10	Large Appliances: Clothes Washer, Dishwasher, Refrigerator	-2.59	-2.18	20%
11	Reduced Plug Loads & Plug Load Control 20%	-1.54	-1.89	27%
12	Low-Flow Shower & Sinks	-3.58	-1.12	31%
13	Ducts in Conditioned Space	-0.18	-0.22	32%
14	High Efficiency 2-speed AC, SEER 21	-0.81	-1.79	38%
15	Integrated Ventilation Cooling	-0.30	-0.84	41%
16	Condensing Space Heating	-0.17	-0.05	42%
17	Condensing Gas Water Heater	-0.80	-0.22	42%
18	Drainwater Heat Recovery	-0.62	-0.15	43%
19	Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)	-17.10	-15.16	100%
	Ending EUI:	0.0	0.00	

Total TDV$ Savings:	-$26.85
Incremental First Cost:	$11.24*
Net Life Cycle Cost:	-$15.61*

Incremental Reductions by Measure



Multi-Family Low-Rise Residential Change Log

CZ03 Oakland

	Strategy *(Baseline is T24 2013 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	27.9	22.05	0%
1	=Improved Wall Construction: 2x6 walls, R-21 w/ R-4 rigid ext. sheathing.=	-0.07	-0.04	0%
2	Ceiling Insulation: R-49 blown-in insulation w/ raised heel trusses	-0.05	-0.02	0%
3	=Reduced Building Infiltration: 1.8 SLA / 3.15 ACH50=	-0.03	0.08	0%
4	Improved Windows: U-Factor=0.32 / Tuned SHGC: 0.35 on E/W, 0.50 on N/W	-0.09	-0.23	1%
5	N/A	0.00	0.00	1%
6	N/A	0.00	0.00	1%
7	N/A	0.00	0.00	1%
8	=Additional Thermal Mass=	-0.06	-0.10	1%
9	=Improved Lighting: High efficacy LED lighting and vacancy controls=	-1.88	-2.15	11%
10	=Large Appliances: Clothes Washer, Dishwasher, Refrigerator=	-2.73	-2.15	20%
11	=Reduced Plug Loads & Plug Load Control 20%=	-1.50	-1.77	28%
12	=Low-Flow Shower & Sinks=	-3.49	-0.99	33%
13	=Ducts in Conditioned Space=	-0.05	-0.03	33%
14	Integrated Ventilation Cooling (w/ no AC)	-0.11	-0.44	35%
15	N/A	0.00	0.00	35%
16	N/A	0.00	0.00	35%
17	=Condensing Gas Water Heater=	-0.85	-0.24	36%
18	=Drainwater Heat Recovery=	-0.63	-0.18	37%
19	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-16.31	-13.81	100%
	Ending EUI:	0.0	0.00	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$22.05
Incremental First Cost:	$7.42*
Net Life Cycle Cost:	-$14.63*

Multi-Family Low-Rise Residential Change Log

CZ10 Riverside

#	**Strategy** *(Baseline is T24 2013 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	29.0	26.36	0%
1	=Improved Wall Construction: 2x6 walls, R-21 w/ R-4 rigid ext. sheathing.=	-0.10	-0.16	1%
2	Ceiling Insulation: R-49 blown-in insulation w/ raised heel trusses	-0.05	-0.06	1%
3	=Reduced Building Infiltration: 1.8 SLA / 3.15 ACH50=	-0.03	-0.10	1%
4	=Improved Windows: U-Factor=0.25 / SHGC=0.20=	-0.18	-0.42	3%
5	=Cool Roof: Reflectivity=0.40 / Emissivity=0.85=	-0.02	-0.03	3%
6	N/A	0.00	0.00	3%
7	N/A	0.00	0.00	3%
8	=Additional Thermal Mass=	-0.08	-0.24	4%
9	=Improved Lighting: High efficacy LED lighting and vacancy controls=	-2.13	-2.24	12%
10	=Large Appliances: Clothes Washer, Dishwasher, Refrigerator=	-2.55	-2.11	20%
11	=Reduced Plug Loads & Plug Load Control 20%=	-1.71	-1.87	28%
12	=Low-Flow Shower & Sinks=	-2.99	-0.92	31%
13	=Ducts in Conditioned Space=	-0.12	-0.18	32%
14	=Integrated Ventilation Cooling=	-0.94	-1.72	38%
15	=High Efficiency 2-speed AC, SEER 21=	-0.43	-0.96	42%
16	N/A	0.00	0.00	42%
17	=Condensing Gas Water Heater=	-0.75	-0.21	43%
18	=Drainwater Heat Recovery=	-0.51	-0.13	43%
19	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-16.43	-15.01	100%
	Ending EUI:	0.0	0.00	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$26.36
Incremental First Cost:	$10.90*
Net Life Cycle Cost:	-$15.46*

Multi-Family Low-Rise Residential Change Log

CZ15
Palm Springs

	Strategy *(Baseline is T24 2013 Unless Noted Otherwise)*	kBtu/ft2 savings	TDV$/ft2 (30yr) savings	TDV$ reduction
	Starting EUI:	33.6	35.31	0%
1	=Improved Wall Construction: 2x6 walls, R-21 w/ R-4 rigid ext. sheathing.=	0.19	-0.21	1%
2	=Ceiling Insulation: R-60 blown-in insulation w/ raised heel trusses=	-0.07	-0.12	1%
3	=Reduced Building Infiltration: 1.8 SLA / 3.15 ACH50=	-0.25	-0.53	2%
4	=Improved Windows: U-Factor=0.25 / SHGC=0.20=	-0.47	-0.80	5%
5	=Cool Roof: Reflectivity=0.40 / Emissivity=0.85=	-0.03	-0.05	5%
6	N/A	0.00	0.00	5%
7	Light Colored Siding: Reflectivity=0.40 / Emissivity=0.85	-0.29	-0.37	6%
8	N/A	0.00	0.00	6%
9	=Improved Lighting: High efficacy LED lighting and vacancy controls=	-2.41	-2.49	13%
10	=Large Appliances: Clothes Washer, Dishwasher, Refrigerator=	-2.38	-2.18	19%
11	=Reduced Plug Loads & Plug Load Control 20%=	-1.93	-2.09	25%
12	=Low-Flow Shower & Sinks=	-2.77	-0.99	28%
13	=Ducts in Conditioned Space=	-0.52	-0.81	30%
14	N/A	0.00	0.00	30%
15	=High Efficiency 2-speed AC, SEER 21=	-3.16	-4.80	44%
16	=Condensing Space Heating=	-0.01	0.00	44%
17	=Condensing Gas Water Heater=	-0.58	-0.17	45%
18	=Drainwater Heat Recovery=	-0.33	-0.08	45%
19	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-18.62	-19.60	100%
	Ending EUI:	0.0	0.00	

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Total TDV$ Savings:	-$35.31
Incremental First Cost:	$12.43*
Net Life Cycle Cost:	-$22.87*

Multi-Family Low-Rise Residential Change Log

CZ16
Blue Canyon

	Strategy *(Baseline is T24 2013 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	35.4	25.82	0%
1	=Improved Wall Construction: 2x6 walls, R-21 w/ R-4 rigid ext. sheathing.=	-0.99	-0.44	2%
2	=Ceiling Insulation: R-60 blown-in insulation w/ raised heel trusses=	-0.32	-0.15	2%
3	=Reduced Building Infiltration: 1.8 SLA / 3.15 ACH50=	-1.54	-0.47	4%
4	Improved Windows: U-Factor=0.17 / Tuned SHGC: 0.20 on E/W, 0.50 on N/W	-1.19	0.07	4%
5	N/A	0.00	0.00	4%
6	Increase Slab Insulation: R-10 Underslab + 2ft R-5 Gap	0.06	0.12	3%
7	N/A	0.00	0.00	3%
8	=Additional Thermal Mass=	-0.06	-0.17	4%
9	=Improved Lighting: High efficacy LED lighting and vacancy controls=	-1.79	-2.05	12%
10	=Large Appliances: Clothes Washer, Dishwasher, Refrigerator=	-2.81	-2.15	20%
11	=Reduced Plug Loads & Plug Load Control 20%=	-1.44	-1.73	27%
12	=Low-Flow Shower & Sinks=	-4.16	-1.26	32%
13	=Ducts in Conditioned Space=	-0.33	-0.21	33%
14	=Integrated Ventilation Cooling=	-0.83	-1.11	37%
15	=High Efficiency 2-speed AC, SEER 21=	-0.29	-0.75	40%
16	=Condensing Space Heating=	-0.28	-0.09	40%
17	=Condensing Gas Water Heater=	-0.91	-0.26	41%
18	=Drainwater Heat Recovery=	-0.71	-0.19	42%
19	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-17.81	-14.98	100%
	Ending EUI:	0.0	0.00	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$25.82
Incremental First Cost:	$12.63*
Net Life Cycle Cost:	-$13.19*

Building Performance Data

Multi-family Low-rise

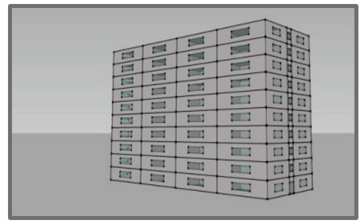
		Climate Zones						
Square feet: 14,700	Avail. Roof: 3,920	**15**	**13**	**12**	**10**	**7**	**3**	**16**
Total Building Energy Metrics								
kWh/ft^2	Load	4.61	3.86	3.61	3.67	3.56	3.47	3.55
	Minimized Site-kBtu	-0.85	-1.35	-1.41	-1.15	-1.14	-1.32	-1.67
	Minimized TDV	-0.45	-0.31	-0.15	0.01	0.09	0.24	-0.16
kW/bldg (250 hr method)	Load	15.9	12.0	8.7	9.9	6.8	6.6	8.6
	Minimized Site-kBtu	2.3	-5.4	-8.1	-3.9	-6.6	-10.6	-8.7
	Minimized TDV	3.3	-1.9	-3.9	-0.6	-3.1	-5.0	-3.7
Therms/ft^2	Load	0.03	0.05	0.05	0.04	0.04	0.04	0.06
Carbon								
CO_2e (lbs/ft^2)	Minimized Site-kBtu	-0.11	-0.18	-0.19	-0.15	-0.15	-0.18	-0.22
	Minimized TDV	0.12	0.43	0.54	0.52	0.57	0.73	0.66
Solar Capacity								
Solar PV (kW)	Minimized Site-kBtu	47.9	48.8	47.0	43.3	42.3	44.6	46.0
	Minimized TDV	44.3	39.1	35.3	32.9	31.2	30.1	32.7
Peak Export (kW - bldg)	Minimized Site-kBtu	-34.6	-34.8	-33.3	-30.4	-29.5	-33.3	-33.6
	Minimized TDV	-31.6	-26.8	-23.8	-22.0	-20.6	-21.5	-23.0
% of Avail. Roof Used	Minimized Site-kBtu	55%	57%	54%	50%	49%	52%	53%
	Minimized TDV	51%	45%	41%	38%	36%	35%	38%
Building Height Analysis								
Max Floors at ZNE	w/ Site-kBtu Metric	5.4	5.3	5.5	6.0	6.1	5.8	5.6
	w/ TDV Metric	5.8	6.6	7.3	7.9	8.3	8.6	7.9
Max Floors with **Parking PV**	w/ Site-kBtu Metric	9.2	9.0	9.3	10.0	10.3	9.7	9.6
	w/ TDV Metric	10.0	11.3	12.5	13.2	13.9	14.3	13.7
	Park. PV Size (kW)	46	46	46	46	46	46	46

kWh by Bin			Climate Zones								
Multi-family Low-rise			15			12			3		
			Load	Solar	Net	Load	Solar	Net	Load	Solar	Net
May through October	Mon. - Fri.	21:00 - 6:00	8,270	-339	7,931	5,394	-263	5,131	4,866	-228	4,638
		6:00 - 9:00	2,113	-5,031	-2,917	2,241	-3,591	-1,350	2,102	-2,543	-441
		9:00 - 12:00	2,567	- 10,539	-7,972	2,169	-8,673	-6,505	2,173	-7,252	-5,079
		12:00 - 15:00	3,566	-9,690	-6,123	2,107	-8,487	-6,380	2,092	-7,603	-5,511
		15:00 - 18:00	6,476	-3,497	2,979	3,454	-3,670	-216	3,016	-3,223	-207
		18:00 - 21:00	5,295	22	5,318	3,328	-90	3,238	2,959	-95	2,864
	Sat. - Sun.	21:00 - 6:00	3,114	-434	2,679	2,203	-313	1,889	1,944	-218	1,727
		6:00 - 9:00	975	-2,811	-1,836	961	-2,280	-1,319	915	-1,518	-604
		9:00 - 12:00	1,156	-4,280	-3,124	934	-3,721	-2,787	936	-3,024	-2,088
		12:00 - 15:00	1,795	-3,170	-1,374	1,002	-2,887	-1,885	962	-2,536	-1,573
		15:00 - 18:00	2,694	-561	2,133	1,520	-722	798	1,332	-622	710
		18:00 - 21:00	1,990	-7	1,982	1,275	-4	1,272	1,175	2	1,177
	Gas Therms		170			268			301		
November through April	Mon. - Fri.	21:00 - 6:00	5,776	-113	5,663	5,513	4	5,517	5,506	-20	5,486
		6:00 - 9:00	2,186	-3,166	-979	2,197	-1,382	815	2,203	-1,113	1,090
		9:00 - 12:00	2,305	-9,325	-7,020	2,310	-5,382	-3,071	2,316	-4,890	-2,573
		12:00 - 15:00	2,321	-8,858	-6,537	2,262	-5,739	-3,477	2,263	-5,245	-2,983
		15:00 - 18:00	3,334	-2,339	995	3,051	-1,873	1,179	3,051	-1,758	1,294
		18:00 - 21:00	3,693	22	3,715	3,462	19	3,481	3,462	16	3,478
	Sat. - Sun.	21:00 - 6:00	2,155	-224	1,932	2,062	-124	1,939	2,061	-108	1,954
		6:00 - 9:00	936	-2,324	-1,387	937	-1,204	-267	941	-965	-24
		9:00 - 12:00	988	-3,959	-2,971	981	-2,579	-1,598	983	-2,294	-1,311
		12:00 - 15:00	1,020	-2,930	-1,910	953	-1,972	-1,019	954	-1,797	-843
		15:00 - 18:00	1,562	-255	1,306	1,409	-252	1,156	1,409	-233	1,176
		18:00 - 21:00	1,432	6	1,438	1,327	8	1,336	1,327	7	1,334
	Gas Therms		258			437			359		

8.4 Multi-Family High-rise

Multi-family High-rise

Size:	**84,360**	ft^2
Number of Floors:	**10**	floors



		Climate Zones						
		15	**13**	**12**	**10**	**7**	**3**	**16**
Site-kBtu /ft²	**Load:**	28.0	24.8	22.8	22.6	19.3	19.6	25.8
	Solar:	-10.0	-9.4	-9.4	-9.8	-9.8	-9.4	-10.0
	Net:	**18.0**	**15.4**	**13.4**	**12.8**	**9.5**	**10.2**	**15.7**
TDV$/ft² (30yr NPV)	**Load:**	30.60	25.45	23.06	23.20	18.43	17.24	22.36
	Solar:	-11.38	-11.38	-11.10	-11.79	-11.75	-11.86	-12.19
	Net:	**19.21**	**14.07**	**11.96**	**11.42**	**6.68**	**5.38**	**10.17**

Description:

The Multi-family High-rise is a ten-story building with 79 units and a small amount of common space.

The Multi-family High-rise design process followed many of the internal efficiency strategies of the other residential prototypes, such as high efficacy LED lighting, modest plug load reductions, and drainwater heat recovery. The glazing matches that of the Single Family Residential model.

The High-rise prototype utilizes a commercial HVAC system. Notable savings were realized through the improvement of air delivery efficiencies, primarily through the reduction in pressure drop of the delivery system.

While the High-rise building cannot reach ZNE with rooftop PV, it can do so with parking lot PV where such space is available.

Table 17 includes comparisons between the three residential building types:

Table 17 – Energy Use Patterns Across the Residential Prototypes

Comparison of Residential Prototypes				
(values are average across high pop. CZs)		**Single Family**	**Low-Rise**	**High-Rise**
	Square feet / unit:	**2,116**	**1,225**	**950**
	Number of units:	**1**	**12**	**79**
Site-kBtu /ft^2	*Per ft^2*	14.0	16.7	21.8
	Per Unit	29,717	20,496	20,719
**TDV$**/$ft^2$ (30yr NPV)	*Per ft^2*	8.83	15.01	21.48
	Per Unit	18,681	18,386	20,403
Peak kW / Housing unit (250 hr method)		0.49	0.74	1.08

A few items are notable:

- From a TDV perspective, there is no reduction in per housing unit energy usage as the housing units get smaller. This relates to similar overall usage patterns within the units on a per capita basis, such that the smaller units have *more intensive* usage patterns on a per square foot basis.
- The Multi-family models are not as well suited to take advantage of California's favorable climate for passive cooling strategies.
- The higher reliance on mechanical systems is shown in peak energy usage that is 50% higher in the Low-rise and 100% higher in the High-rise *on a per housing unit basis* as compared to the Single Family prototype.

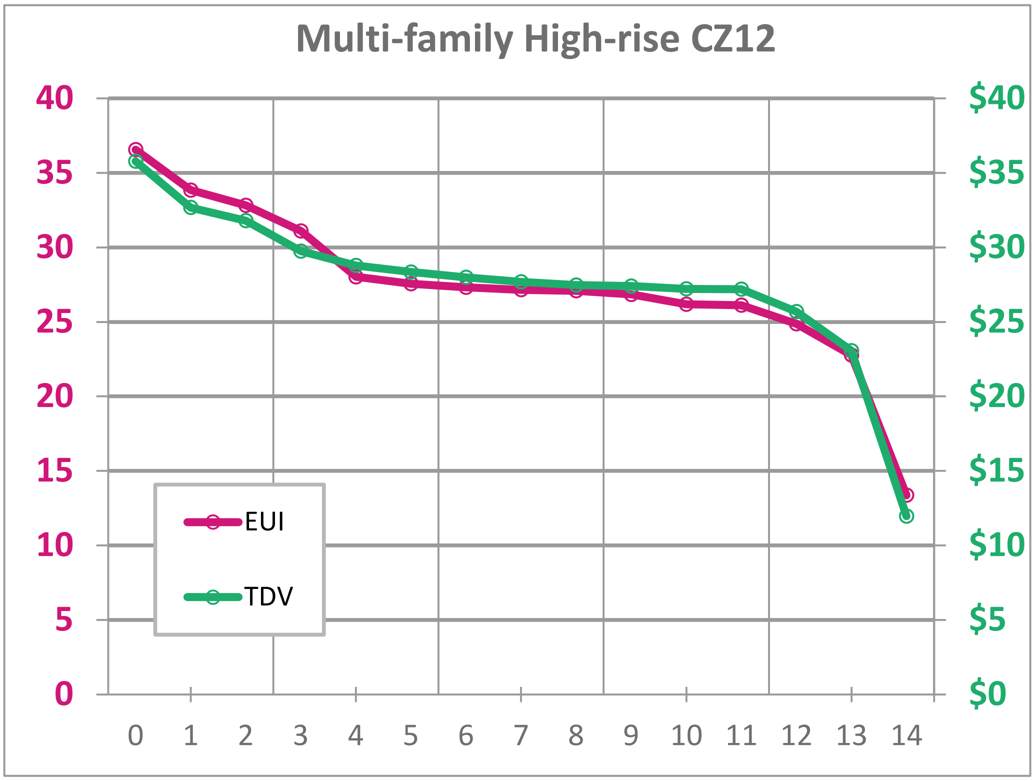
High-Rise Residential Change Log

CZ12
Sacramento

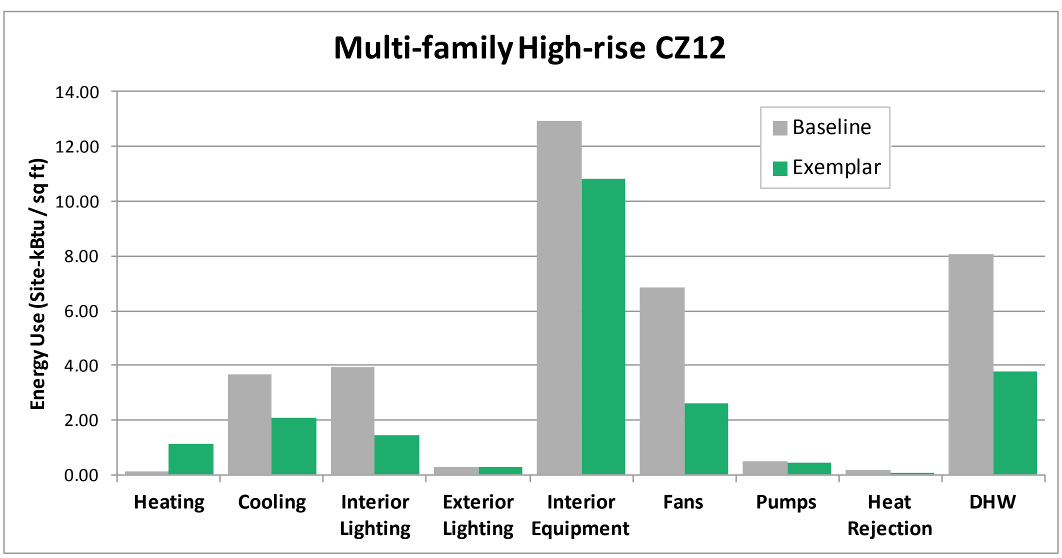
	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	36.6	35.78	0%
1	Use 100% LED lighting, reduced to 0.08 W/sf in apartments, 0.4W/sf in office, 0.36W/sf in corridors. Assumed 200 lumens/watt	-2.72	-3.10	9%
2	EnergyStar Appliances, including refrigerators and dishwashers	-1.02	-0.89	11%
3	Miscellaneous internal electric load reduction	-1.72	-2.05	17%
4	Low Flow showers and sinks	-3.08	-0.96	20%
5	Glazing improved U 0.25 / SHGC 0.2	-0.46	-0.44	21%
6	Added PV panel shading on roof	-0.24	-0.35	22%
7	3 ft overhang on all South-facing windows	-0.16	-0.30	23%
8	Added 4" of thermal mass to each zone	-0.07	-0.22	23%
9	Drain water heat recovery added	-0.25	-0.07	23%
10	Improved water heater thermal efficiency to 0.94 from 0.8 to reflect high efficiency technology currently on market	-0.66	-0.19	24%
11	Changed boiler efficiency from 0.89 to 0.97 (condensing boiler)	-0.06	-0.02	24%
12	Changed fan efficiency from 0.6045 to 0.7	-1.25	-1.51	28%
13	Reduced fan pressure drop by 46% (through use of low-pressure design)	-2.10	-2.62	36%
14	Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)	-9.40	-11.10	67%
	Ending EUI:	13.4	11.96	

Total TDV$ Savings:	-$23.82
Incremental First Cost:	$21.81*
Net Life Cycle Cost:	-$2.00*

Incremental Reduction by Measure



Subsystem Loads



High-Rise Residential Change Log

CZ3 Oakland

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	30.4	25.80	0%
1	=Use 100% LED lighting, reduced to 0.08 W/sf in apartments, 0.4W/sf in office, 0.36W/sf in corridors. Assumed 200 lumens/watt=	-1.73	-1.97	8%
2	=EnergyStar Appliances, including refrigerators and dishwashers=	-0.98	-0.80	11%
3	=Miscellaneous internal electric load reduction=	-1.58	-1.86	18%
4	=Low Flow showers and sinks=	-3.29	-0.97	22%
5	=Glazing improved U 0.25 / SHGC 0.2=	-0.23	-0.09	22%
6	=Added PV panel shading on roof=	-0.13	-0.24	23%
7	=3 ft overhang on all South-facing windows=	-0.23	-0.38	24%
8	=Added 4" of thermal mass to each zone=	-0.09	-0.20	25%
9	=Drain water heat recovery added=	-0.27	-0.08	26%
10	=Improved water heater thermal efficiency to 0.94 from 0.8 to reflect high efficiency technology currently on market=	-0.72	-0.20	26%
11	=Changed boiler efficiency from 0.89 to 0.97 (condensing boiler)=	-0.07	-0.02	26%
12	=Changed fan efficiency from 0.6045 to 0.7=	-0.53	-0.65	29%
13	=Reduced fan pressure drop by 46% (through use of low-pressure design)=	-0.89	-1.11	33%
14	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-9.44	-11.86	79%
	Ending EUI:	10.2	5.38	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$20.43
Incremental First Cost:	$21.54*
Net Life Cycle Cost:	$1.11*

High-Rise Residential Change Log

CZ15
Palm Springs

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	42.4	43.65	0%
1	=Use 100% LED lighting, reduced to 0.08 W/sf in apartments, 0.4W/sf in office, 0.36W/sf in corridors. Assumed 200 lumens/watt=	-2.23	-2.25	5%
2	=EnergyStar Appliances, including refrigerators and dishwashers=	-1.07	-0.91	7%
3	=Miscellaneous internal electric load reduction=	-2.10	-2.19	12%
4	=Low Flow showers and sinks=	-2.16	-0.75	14%
5	=Glazing improved U 0.25 / SHGC 0.2=	-0.51	-0.69	16%
6	=Added PV panel shading on roof=	-0.11	-0.14	16%
7	=3 ft overhang on all South-facing windows=	-0.34	-0.38	17%
8	=Added 4" of thermal mass to each zone=	0.20	0.15	16%
9	=Drain water heat recovery added=	-0.14	-0.04	16%
10	=Improved water heater thermal efficiency to 0.94 from 0.8 to reflect high efficiency technology currently on market=	-0.45	-0.13	17%
11	=Changed boiler efficiency from 0.89 to 0.97 (condensing boiler)=	0.00	0.00	17%
12	=Changed fan efficiency from 0.6045 to 0.7=	-1.99	-2.07	22%
13	=Reduced fan pressure drop by 46% (through use of low-pressure design)=	-3.49	-3.65	30%
14	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-10.00	-11.38	56%
	Ending EUI:	18.0	19.21	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$24.43
Incremental First Cost:	$21.78*
Net Life Cycle Cost:	-$2.65*

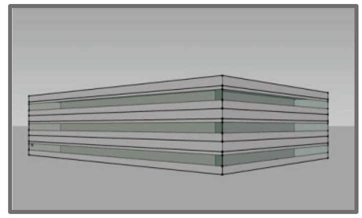
Building Performance Data

Multi-family High-rise

Square feet:	84,360	Climate Zones						
Avail. Roof:	6,749	15	13	12	10	7	3	16
Total Building Energy Metrics								
kWh/ft^2	Load	7.47	5.94	5.34	5.58	4.63	4.41	5.37
	Minimized Site-kBtu	4.90	3.54	2.94	3.07	2.12	1.99	2.82
	Minimized TDV	4.90	3.54	2.94	3.07	2.12	1.99	2.82
kW/bldg (250 hr method)	Load	141	114	99	108	59	49	78
	Minimized Site-kBtu	104	67	53	67	18	-1	29
	Minimized TDV	104	67	53	67	18	-1	29
Therms/ft^2	Load	0.03	0.05	0.05	0.04	0.03	0.05	0.07
Carbon								
CO_2e (lbs/ft^2)	Minimized Site-kBtu	3.20	2.66	2.32	2.26	1.70	1.77	2.62
	Minimized TDV	3.20	2.66	2.32	2.26	1.70	1.77	2.62
Solar Capacity								
Solar PV (kW)	Minimized Site-kBtu	129	129	129	129	129	129	129
	Minimized TDV	129	129	129	129	129	129	129
Peak Export (kW - bldg)	Minimized Site-kBtu	-67.1	-68.8	-69.0	-69.3	-70.9	-77.1	-69.2
	Minimized TDV	-67.1	-68.8	-69.0	-69.3	-70.9	-77.1	-69.2
% of Avail. Roof Used	Minimized Site-kBtu	100%	100%	100%	100%	100%	100%	100%
	Minimized TDV	100%	100%	100%	100%	100%	100%	100%
Building Height Analysis								
Max Floors at ZNE	w/ Site-kBtu Metric	3.6	3.8	4.1	4.4	5.1	4.8	3.9
	w/ TDV Metric	3.7	4.4	4.8	5.1	6.4	6.9	5.3
Max Floors with **Parking PV**	w/ Site-kBtu Metric	12.5	13.0	14.2	14.7	17.2	16.0	13.6
	w/ TDV Metric	13.1	15.2	16.6	17.1	21.5	22.8	18.8
	Park. PV Size (kW)	278	278	278	278	278	278	278

8.5 Medium Office

Medium Office



Size:	**53,600**	ft^2
Number of Floors:	**3**	floors

		Climate Zones						
		15	**13**	**12**	**10**	**7**	**3**	**16**
Site-kBtu $/ft^2$	**Load:**	20.6	19.7	19.0	18.0	15.9	17.2	21.5
	Solar:	-20.6	-19.7	-19.0	-18.0	-15.9	-17.2	-21.5
	Net:	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
TDV\$/ft² (30yr NPV)	**Load:**	23.56	20.06	18.75	19.55	16.65	15.90	17.71
	Solar:	-23.56	-20.06	-18.75	-19.55	-16.65	-15.90	-17.71
	Net:	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Description:

The Medium Office shows promise of being a ZNE building type in 2020. Due to its deep floor plate, the building's overall energy use is driven primarily by internal loads and not envelope loads.

A combination of lighting technology improvements, smart equipment specifications, and a robust use of demand-side controls to turn off unused devices can have a dramatic effect on overall internal gains within an office.

The New Buildings Institute (NBI) has found that office plug loads are often running at 50% of capacity through the middle of the night. These background loads, often serving no notable purpose, are a primary target for occupancy controls, timers, software for better computer system management, and offsite server virtualization.

Reduction in internal loads moves the building to a more "neutral" stance for California's climates, such that heating demand and cooling demand are much more evenly balanced. In that more neutral position, passive systems can be used to maintain occupant comfort.

Passive systems for offices include the use of natural ventilation, additional thermal mass, and passive solar design. Even during hours when passive ventilation was utilized, a modest number of fans were left running to ensure appropriate airflow given the sizable core zone of the building.

The HVAC system consists of packaged air conditioning units with a gas furnace inside the packaged DX air conditioning unit. The zone level distribution is variable air volume (VAV) with hot water reheat.

The Office models use morning warm-up much of the year, particularly when natural ventilation pre-cooling is implemented at night. This strategy creates a net reduction in TDV usage.

A radiant chilled ceiling system was developed and tested for the Medium Office, but it showed no benefit with the low internal loads as a result of the energy efficient lighting and controlled equipment loads. A high performance VAV system that utilizes an airside economizer and low-pressure drop design was found to be a better solution.

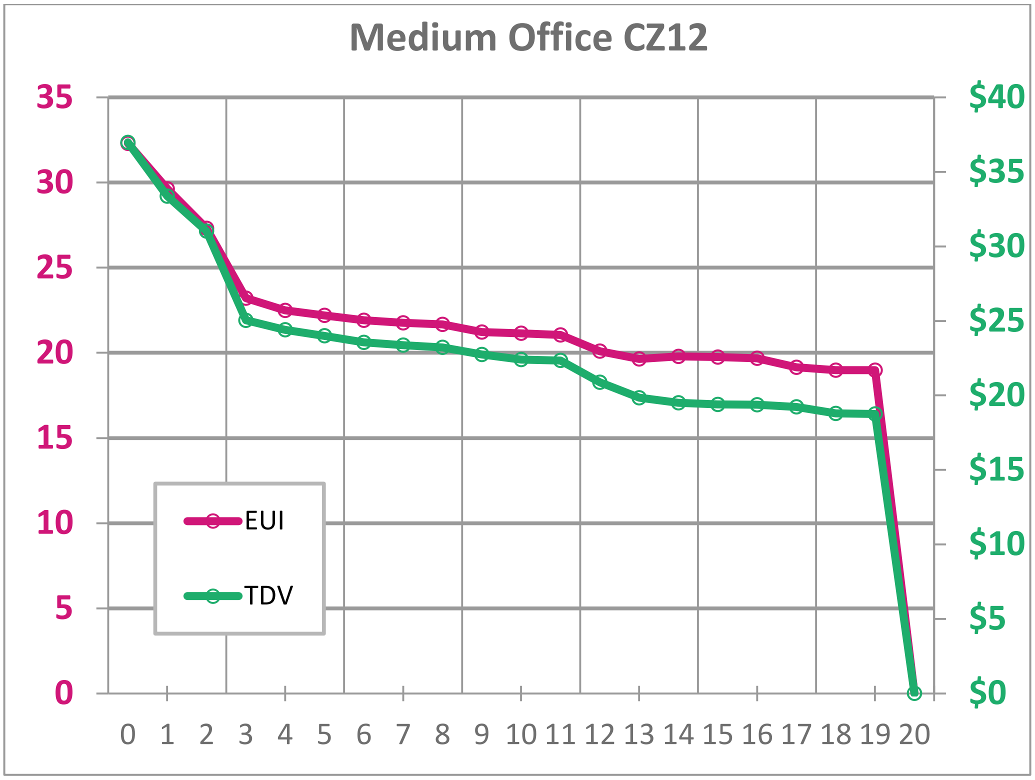
Medium Office Change Log

CZ12
Sacramento

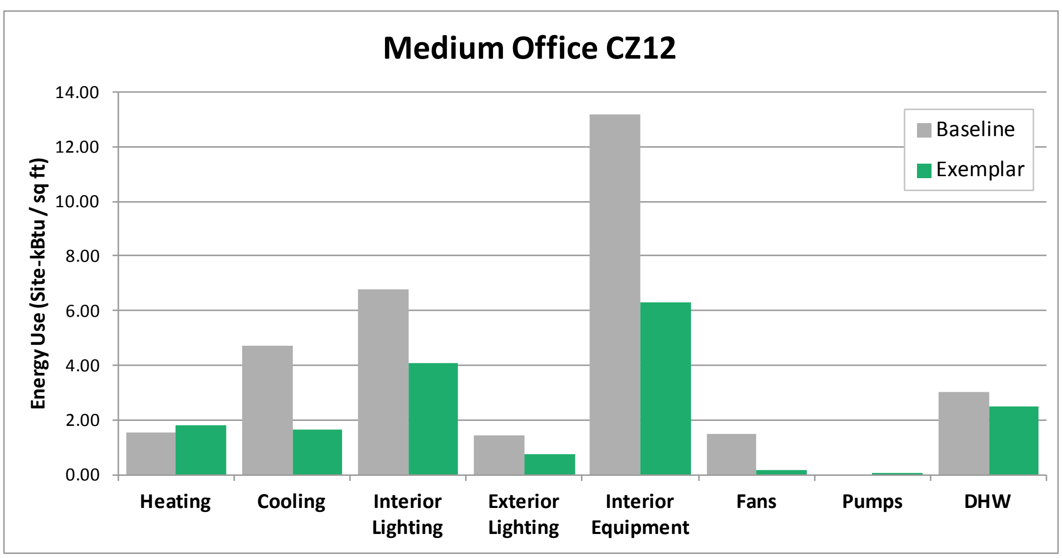
	Strategy *(Baseline is 90.1 2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	32.3	36.98	0%
1	Reduce Lighting Power Density (LPD) by 40%	-2.67	-3.61	10%
2	Reduce nighttime plug load schedule to 10%, with the use of a Night-Watchman type system on the computers	-2.32	-2.35	16%
3	Reduce design plug load level from 1.0 W/sf to 0.5 W/sf	-4.10	-5.99	32%
4	Reduced exterior lighting design wattage level by 50%	-0.72	-0.63	34%
5	Adjusted WWR from 33% to 30% by reducing the height of the windows	-0.29	-0.40	35%
6	Added 2 foot overhangs to all facades	-0.29	-0.45	36%
7	Changed exterior wall insulation from R-9.73 to R-12.16, 25% over 90.1	-0.15	-0.18	37%
8	Increased R-value of roof insulation from 19.7 to 24.6 (25% increase)	-0.09	-0.15	37%
9	Changed windows to U_0.43_SHGC_0.29	-0.45	-0.48	38%
10	Added PV panel shading on roof	-0.07	-0.34	39%
11	Created additional thermal mass (2 inches of concrete)	-0.10	-0.06	40%
12	Implemented natural ventilation	-0.95	-1.46	44%
13	Changed cooling setpoint from 75.2 F to 77 F during occupied hours	-0.46	-1.04	46%
14	Changed electric resistance reheat coils to hot water coils	0.15	-0.34	47%
15	Changed fan efficiency from 0.6045 to 0.7	-0.04	-0.11	48%
16	Changed boiler efficiency from 0.89 to 0.98 (condensing boiler)	-0.07	-0.02	48%
17	Improved water heater thermal efficiency to 0.97 from 0.8 to reflect high efficiency technology currently on market	-0.53	-0.14	48%
18	2.07 in wc, in order to represent low pressure drop design	-0.17	-0.44	49%
19	3.5 COP on DX coils (from 3.4)	0.00	-0.03	49%
20	Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)	-18.98	-18.75	100%
	Ending EUI:	0.0	0.00	

Total TDV$ Savings:	-$36.97
Incremental First Cost:	$41.26*
Net Life Cycle Cost:	$4.29*

Incremental Reduction by Measure



Subsystem Loads



Medium Office Change Log

CZ3
Oakland

	Strategy *(Baseline is 90.1 2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	29.2	31.63	0%
1	= Reduce Lighting Power Density (LPD) by 40% =	-2.72	-3.60	11%
2	= Reduce nighttime plug load schedule to 10%, with the use of a Night-Watchman type system on the computers =	-2.25	-2.19	18%
3	= Reduce design plug load level from 1.0 W/sf to 0.5 W/sf =	-4.13	-6.00	37%
4	= Reduced exterior lighting design wattage level by 50% =	-0.72	-0.63	39%
5	= Adjusted WWR from 33% to 30% by reducing the height of the windows =	-0.17	-0.22	40%
6	= Added 2 foot overhangs to all facades =	-0.15	-0.27	41%
7	= Changed exterior wall insulation from R-9.73 to R-12.16, 25% over 90.1 =	-0.09	-0.09	41%
8	= Increased R-value of roof insulation from 19.7 to 24.6 (25% increase) =	-0.08	-0.09	41%
9	= Changed windows to U_0.43_SHGC_0.29 =	-0.32	-0.24	42%
10	= Added PV panel shading on roof =	-0.05	-0.25	43%
11	= Created additional thermal mass (2 inches of concrete) =	-0.16	-0.15	43%
12	= Implemented natural ventilation =	-0.14	-0.75	46%
13	= Changed cooling setpoint from 75.2 F to 77 F during occupied hours =	-0.41	-0.69	48%
14	= Changed electric resistance reheat coils to hot water coils =	0.10	-0.20	49%
15	= Changed fan efficiency from 0.6045 to 0.7 =	-0.01	-0.03	49%
16	= Changed boiler efficiency from 0.89 to 0.98 (condensing boiler) =	-0.04	-0.01	49%
17	= Improved water heater thermal efficiency to 0.97 from 0.8 to reflect high efficiency technology currently on market =	-0.64	-0.17	49%
18	= 2.07 in wc, in order to represent low pressure drop design =	-0.04	-0.13	50%
19	= 3.5 COP on DX coils (from 3.4) =	0.00	-0.01	50%
20	= Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes) =	-17.22	-15.90	100%
	Ending EUI:	0.0	0.00	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$31.63
Incremental First Cost:	$38.65*
Net Life Cycle Cost:	$7.03*

Medium Office Change Log

CZ10
Riverside

	Strategy *(Baseline is 90.1 2010 Unless Noted Otherwise)*	kBtu/ft2 savings	TDV$/ft2 (30yr) savings	TDV$ reduction
	Starting EUI:	32.6	38.96	0%
1	= Reduce Lighting Power Density (LPD) by 40% =	-3.02	-3.91	10%
2	= Reduce nighttime plug load schedule to 10%, with the use of a Night-Watchman type system on the computers =	-2.58	-2.51	16%
3	= Reduce design plug load level from 1.0 W/sf to 0.5 W/sf =	-4.80	-6.54	33%
4	= Reduced exterior lighting design wattage level by 50% =	-0.73	-0.63	35%
5	= Adjusted WWR from 33% to 30% by reducing the height of the windows =	-0.25	-0.38	36%
6	= Added 2 foot overhangs to all facades =	-0.29	-0.46	37%
7	= Changed exterior wall insulation from R-9.73 to R-12.16, 25% over 90.1 =	-0.10	-0.14	37%
8	= Increased R-value of roof insulation from 19.7 to 24.6 (25% increase) =	-0.07	-0.12	38%
9	Changed windows to U_0.25_SHGC_0.40	-0.27	-0.31	39%
10	= Added PV panel shading on roof =	-0.14	-0.35	39%
11	= Created additional thermal mass (2 inches of concrete) =	-0.15	-0.15	40%
12	= Implemented natural ventilation =	-0.70	-1.80	44%
13	= Changed cooling setpoint from 75.2 F to 77 F during occupied hours =	-0.69	-1.10	47%
14	= Changed electric resistance reheat coils to hot water coils =	0.07	-0.06	47%
15	= Changed fan efficiency from 0.6045 to 0.7 =	-0.06	-0.15	48%
16	= Changed boiler efficiency from 0.89 to 0.98 (condensing boiler) =	-0.02	-0.01	48%
17	= Improved water heater thermal efficiency to 0.97 from 0.8 to reflect high efficiency technology currently on market =	-0.53	-0.14	48%
18	= 2.07 in wc, in order to represent low pressure drop design =	-0.23	-0.56	50%
19	= 3.5 COP on DX coils (from 3.4) =	-0.03	-0.07	50%
20	= Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes) =	-17.97	-19.55	100%
	Ending EUI:	0.0	0.00	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$38.96
Incremental First Cost:	$40.77*
Net Life Cycle Cost:	$1.81*

Medium Office Change Log

CZ15
Palm Springs

	Strategy *(Baseline is 90.1 2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	37.9	45.02	0%
1	=Reduce Lighting Power Density (LPD) by 40%=	-3.25	-4.00	9%
2	=Reduce nighttime plug load schedule to 10%, with the use of a Night-Watchman type system on the computers=	-2.82	-2.63	15%
3	=Reduce design plug load level from 1.0 W/sf to 0.5 W/sf=	-5.29	-6.64	29%
4	=Reduced exterior lighting design wattage level by 50%=	-0.72	-0.64	31%
5	=Adjusted WWR from 33% to 30% by reducing the height of the windows=	-0.39	-0.55	32%
6	Added 4 foot overhangs all facades	-0.59	-0.94	34%
7	=Changed exterior wall insulation from R-9.73 to R-12.16, 25% over 90.1=	-0.17	-0.24	35%
8	=Increased R-value of roof insulation from 19.7 to 24.6 (25% increase)=	-0.10	-0.16	35%
9	Changed windows to U_0.29_SHGC_0.17	-1.32	-1.90	39%
10	=Added PV panel shading on roof=	-0.20	-0.35	40%
11	Created additional thermal mass (4 inches of concrete)	-0.06	-0.06	40%
12	=Implemented natural ventilation=	-0.24	-0.24	41%
13	=Changed cooling setpoint from 75.2 F to 77 F during occupied hours=	-0.84	-1.45	44%
14	=Changed electric resistance reheat coils to hot water coils=	0.03	-0.03	44%
15	=Changed fan efficiency from 0.6045 to 0.7=	-0.15	-0.28	45%
16	=Changed boiler efficiency from 0.89 to 0.98 (condensing boiler)=	-0.01	0.00	45%
17	=Improved water heater thermal efficiency to 0.97 from 0.8 to reflect high efficiency technology currently on market=	-0.53	-0.14	45%
18	=2.07 in wc, in order to represent low pressure drop design=	-0.57	-1.05	47%
19	=3.5 COP on DX coils (from 3.4)=	-0.07	-0.16	48%
20	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-20.63	-23.56	100%
	Ending EUI:	0.0	0.00	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$45.01
Incremental First Cost:	$43.06*
Net Life Cycle Cost:	-$1.95*

Medium Office Change Log

CZ16
Blue Canyon

	Strategy *(Baseline is 90.1 2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	33.1	34.89	0%
1	= Reduce Lighting Power Density (LPD) by 40% =	-2.22	-3.38	10%
2	= Reduce nighttime plug load schedule to 10%, with the use of a Night-Watchman type system on the computers =	-2.01	-2.03	16%
3	= Reduce design plug load level from 1.0 W/sf to 0.5 W/sf =	-3.11	-5.61	32%
4	= Reduced exterior lighting design wattage level by 50% =	-0.72	-0.62	33%
5	= Adjusted WWR from 33% to 30% by reducing the height of the windows =	-0.31	-0.34	34%
6	= Added 2 foot overhangs to all facades =	-0.33	-0.47	36%
7	= Changed exterior wall insulation from R-9.73 to R-12.16, 25% over 90.1 =	-0.25	-0.23	36%
8	= Increased R-value of roof insulation from 19.7 to 24.6 (25% increase) =	-0.20	-0.20	37%
9	Changed windows to U_0.25_SHGC_0.40	-1.49	-1.23	40%
10	= Added PV panel shading on roof =	0.15	-0.21	41%
11	= Created additional thermal mass (4 inches of concrete) =	-0.48	-0.25	42%
12	= Implemented natural ventilation =	-0.40	-0.72	44%
13	= Changed cooling setpoint from 75.2 F to 77 F during occupied hours =	0.32	-0.74	46%
14	= Changed electric resistance reheat coils to hot water coils =	0.21	-0.43	47%
15	= Changed fan efficiency from 0.6045 to 0.7 =	-0.03	-0.11	47%
16	= Changed boiler efficiency from 0.89 to 0.98 (condensing boiler) =	-0.08	-0.03	48%
17	= Improved water heater thermal efficiency to 0.97 from 0.8 to reflect high efficiency technology currently on market =	-0.54	-0.14	48%
18	= 2.07 in wc, in order to represent low pressure drop design =	-0.10	-0.42	49%
19	= 3.5 COP on DX coils (from 3.4) =	-0.01	-0.03	49%
20	= Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes) =	-21.48	-17.71	100%
	Ending EUI:	0.0	0.00	

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Total TDV$ Savings:	-$34.88
Incremental First Cost:	$34.33*
Net Life Cycle Cost:	-$0.56*

Building Performance Data

Medium Office

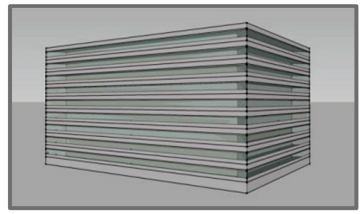
		Climate Zones						
Square feet:	53,600							
Avail. Roof:	14,293	15	13	12	10	7	3	16
Total Building Energy Metrics								
kWh/ft^2	Load	5.15	4.24	3.99	4.15	3.81	3.54	3.60
	Minimized Site-kBtu	-0.90	-1.53	-1.58	-1.11	-0.86	-1.51	-2.70
	Minimized TDV	-1.17	-0.94	-0.85	-0.80	-0.41	-0.32	-0.96
kW/bldg (250 hr method)	Load	91.6	74.5	66.6	70.4	50.3	44.8	52.5
	Minimized Site-kBtu	36.4	4.0	-1.4	15.3	1.5	-21.5	-23.9
	Minimized TDV	33.9	11.3	7.5	18.6	6.1	-5.9	-2.9
Therms/ft^2	Load	0.03	0.05	0.05	0.04	0.03	0.05	0.09
Carbon								
CO_2e (lbs/ft^2)	Minimized Site-kBtu	-0.12	-0.20	-0.21	-0.15	-0.11	-0.20	-0.36
	Minimized TDV	-0.28	0.14	0.21	0.03	0.15	0.49	0.65
Solar Capacity								
Solar PV (kW)	Minimized Site-kBtu	193	197	190	173	153	172	202
	Minimized TDV	202	177	165	162	138	131	147
Peak Export (kW - bldg)	Minimized Site-kBtu	-148	-153	-147	-133	-117	-136	-157
	Minimized TDV	-155	-137	-127	-125	-105	-102	-112
% of Avail. Roof Used	Minimized Site-kBtu	71%	72%	69%	63%	56%	63%	74%
	Minimized TDV	74%	65%	60%	59%	50%	48%	54%
Building Height Analysis								
Max Floors at ZNE	w/ Site-kBtu Metric	4.2	4.2	4.3	4.8	5.4	4.8	4.1
	w/ TDV Metric	4.1	4.6	5.0	5.1	5.9	6.3	5.6
Max Floors with **Parking PV**	w/ Site-kBtu Metric	12.8	12.4	12.8	13.9	15.7	13.8	12.3
	w/ TDV Metric	12.3	14.0	14.8	14.8	17.3	18.0	17.2
	Park. PV Size (kW)	416	416	416	416	416	416	416

8.6 Large Office

Large Office

Size: **498,600** ft^2

Number of Floors: **12** floors *+basement*



		Climate Zones						
		15	**13**	**12**	**10**	**7**	**3**	**16**
Site-kBtu /ft^2	**Load:**	19.2	16.7	16.2	15.2	14.1	14.6	18.9
	Solar:	-6.7	-6.3	-6.3	-6.5	-6.5	-6.3	-6.7
	Net:	**12.5**	**10.4**	**9.9**	**8.7**	**7.5**	**8.3**	**12.2**
TDV$/ft^2 (30yr NPV)	**Load:**	22.49	17.87	16.90	17.30	15.89	15.08	22.06
	Solar:	-7.32	-7.32	-7.14	-7.58	-7.56	-7.63	-7.84
	Net:	**15.17**	**10.55**	**9.76**	**9.72**	**8.33**	**7.45**	**14.22**

Description:

The Large Office is a 12-story 498,600 square foot building. The Large Office is quite similar to the Medium Office, with a deep floor plate and 15' deep perimeter zones.

Internal loads were reduced by the same amount as in the Medium Office with reductions in equipment and lighting loads.

Passive energy efficient measures such as natural ventilation (mixed mode), thermal mass, and passive solar design were utilized in the Large Office model as well. Using natural ventilation in a building of this height creates notable complications in simultaneously complying with the fire code, which can increase first costs.

The HVAC system consists of a gas-condensing boiler and two water-cooled centrifugal chillers. The zone level distribution is VAV with hot water reheat. As with the Medium Office, the Large Office exemplar model utilizes low turndown on the VAV distribution, which greatly reduces reheat as well as fan energy. A high performance VAV system with airside economizer and low-pressure drop design is a better option than a radiant system for the Large Office model as well.

The central chiller represented a significant operational change in the model, at COP=6.5.

While the Large Office does not meet the ZNE goal with rooftop solar, it can meet the goal with parking lot PV at standard densities where the resource is available.

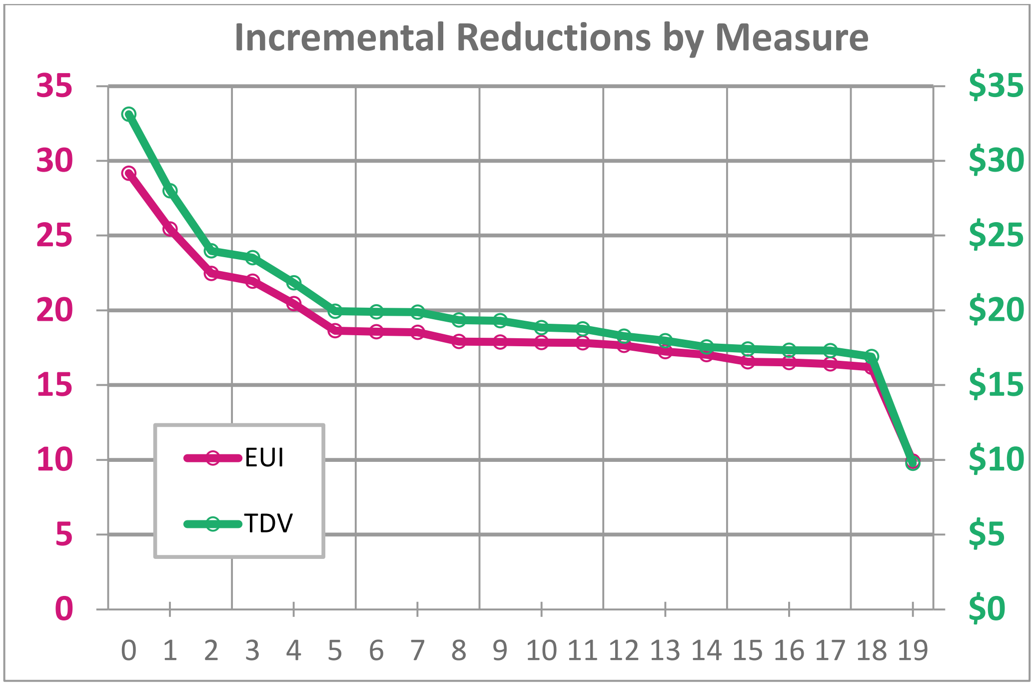
Large Office Change Log

CZ12
Sacramento

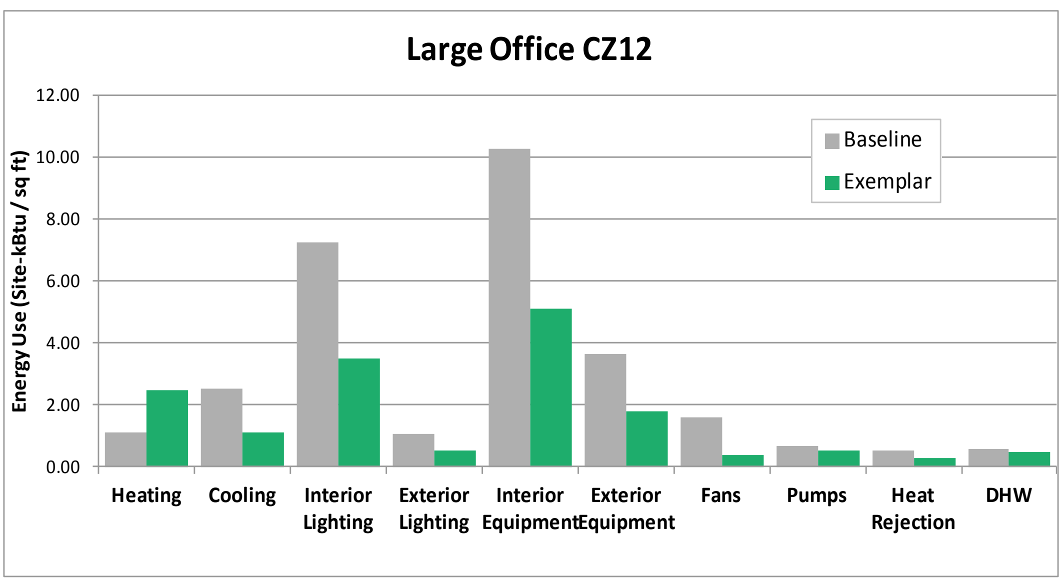
	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	29.2	33.12	0%
1	Reduce LPD to 0.4 W/sf	-3.73	-5.12	15%
2	Reduce EPD to 0.5 W/sf	-2.97	-4.01	28%
3	Reduce exterior lighting by 50%	-0.52	-0.46	29%
4	Reduced unoccupied plug load to 10% of design value	-1.50	-1.68	34%
5	Reduced elevator design load by 50% and reduced elev fan and lights by 60%	-1.81	-1.90	40%
6	Changed exterior wall insulation from R-6.33 to R-8, 25% over 90.1	-0.07	-0.04	40%
7	Increased R-value of roof insulation from 19.7 to 24.6 (25% increase)	-0.04	-0.02	40%
8	Changed windows to Window_U_0.35_SHGC_0.26	-0.61	-0.52	42%
9	Added PV panel shading on roof	-0.04	-0.05	42%
10	Added 2 foot overhangs to all facades	-0.03	-0.47	43%
11	Created additional thermal mass (4 inches of concrete) in all zones	-0.02	-0.08	43%
12	Implemented natural ventilation	-0.17	-0.49	45%
13	Changed cooling setpoint from 75.2 F to 76 F during occupied hours	-0.42	-0.30	46%
14	Reduced fan pressure drop from 5.58 in wc to 3.0 in wc (through use of low-pressure design, therma-fusers)	-0.20	-0.42	47%
15	Changed boiler efficiency from 0.89 to 0.97 (condensing boiler)	-0.48	-0.14	47%
16	Changed fan efficiency from 0.6045 to 0.7	-0.05	-0.08	48%
17	Improved water heater thermal efficiency to 0.97 from 0.8 to reflect high efficiency technology currently on market	-0.09	-0.03	48%
18	Improved COP of chillers from 5.5 to 6.5	-0.22	-0.39	49%
19	Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)	-6.29	-7.14	71%
	Ending EUI:	9.9	9.76	

Total TDV$ Savings:	-$23.35
Incremental First Cost:	$25.63*
Net Life Cycle Cost:	$2.28*

Incremental Reduction by Measure



Subsystem Loads



Large Office Change Log

CZ3
Oakland

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	26.8	26.29	0%
1	=Reduce LPD to 0.4 W/sf=	-2.59	-0.71	3%
2	=Reduce EPD to 0.5 W/sf=	-3.65	-4.33	19%
3	=Reduce exterior lighting by 50%=	-0.52	-0.45	21%
4	=Reduced unoccupied plug load to 10% of design value =	-1.56	-1.68	27%
5	=Reduced elevator design load by 50% and reduced elev fan and lights by 60%=	-1.81	-1.86	34%
6	=Changed exterior wall insulation from R-6.33 to R-8, 25% over 90.1=	-0.05	-0.01	34%
7	=Increased R-value of roof insulation from 19.7 to 24.6 (25% increase)=	-0.03	-0.01	34%
8	=Changed windows to Window_U_0.35_SHGC_0.26=	-0.49	-0.31	36%
9	=Added PV panel shading on roof=	-0.04	-0.05	36%
10	=Added 2 foot overhangs to all facades=	-0.35	-0.44	38%
11	=Created additional thermal mass (4 inches of concrete) in all zones=	0.01	-0.08	38%
12	=Implemented natural ventilation =	-0.14	-0.44	40%
13	=Changed cooling setpoint from 75.2 F to 76 F during occupied hours=	-0.36	-0.25	40%
14	=Reduced fan pressure drop from 5.58 in wc to 3.0 in wc (through use of low-pressure design, therma-fusers)=	-0.16	-0.27	41%
15	=Changed boiler efficiency from 0.89 to 0.97 (condensing boiler)=	-0.31	-0.09	42%
16	=Changed fan efficiency from 0.6045 to 0.7=	-0.04	-0.05	42%
17	=Improved water heater thermal efficiency to 0.97 from 0.8 to reflect high efficiency technology currently on market=	-0.11	-0.03	42%
18	=Improved COP of chillers from 5.5 to 6.5=	-0.07	-0.13	43%
19	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-6.32	-7.63	72%
	Ending EUI:	8.3	7.45	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$18.83
Incremental First Cost:	$25.39*
Net Life Cycle Cost:	$6.56*

Large Office Change Log

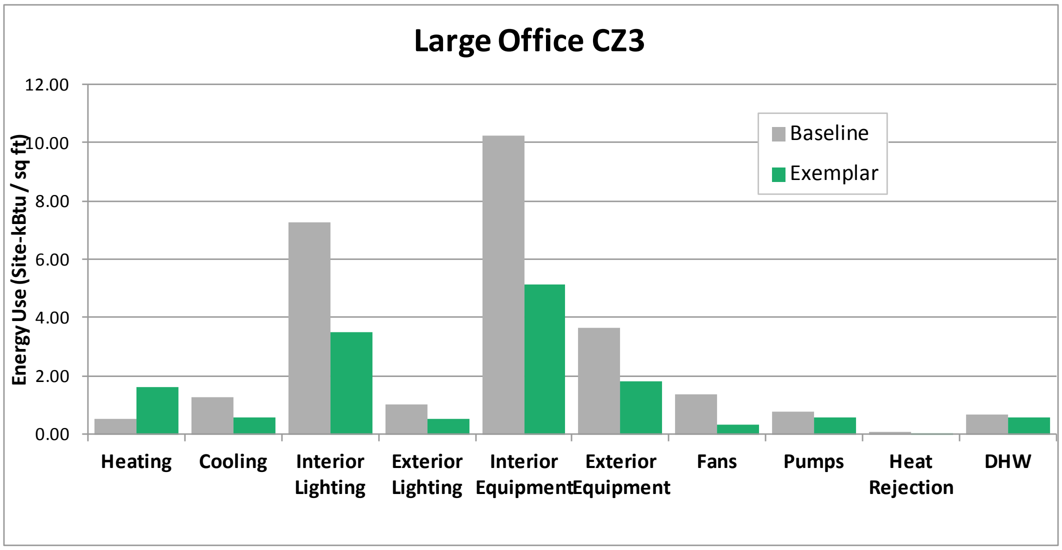
CZ15
Palm Springs

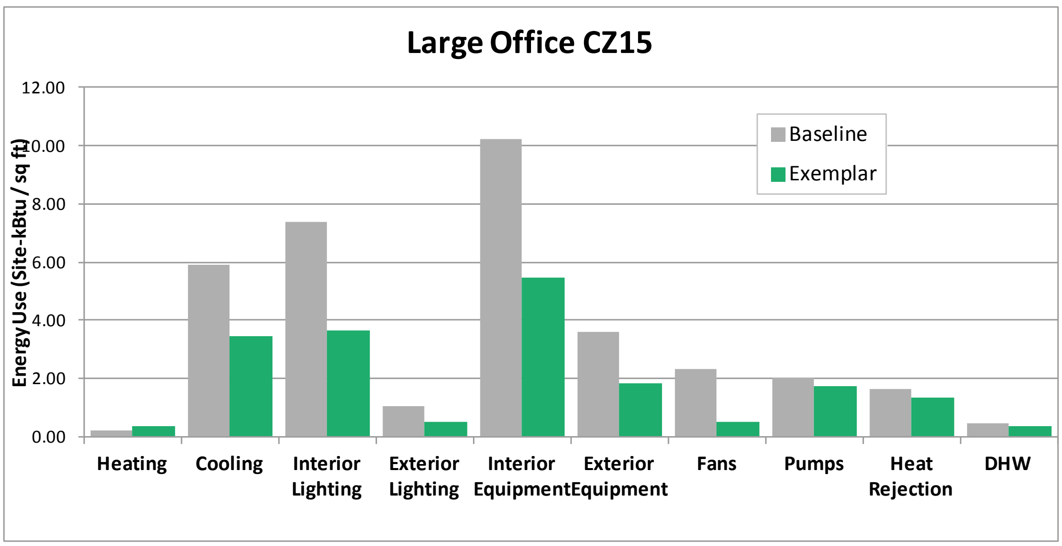
	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	kBtu/ft2 savings	TDV$/ft2 (30yr) savings	TDV$ reduction
	Starting EUI:	34.8	40.55	0%
1	=Reduce LPD to 0.4 W/sf=	-4.29	-5.20	13%
2	=Reduce EPD to 0.5 W/sf=	-3.35	-3.80	22%
3	=Reduce exterior lighting by 50%=	-0.52	-0.46	23%
4	=Reduced unoccupied plug load to 10% of design value =	-1.86	-1.82	28%
5	=Reduced elevator design load by 50% and reduced elev fan and lights by 60%=	-1.82	-1.87	32%
6	=Changed exterior wall insulation from R-6.33 to R-8, 25% over 90.1=	-0.10	-0.10	33%
7	=Increased R-value of roof insulation from 19.7 to 24.6 (25% increase)=	-0.03	-0.02	33%
8	Changed windows to Window_U_0.29_SHGC_0.17	-2.01	-2.52	39%
9	=Added PV panel shading on roof=	-0.04	-0.08	39%
10	=Added 2 foot overhangs to all facades=	-0.27	-0.41	40%
11	=Created additional thermal mass (4 inches of concrete) in all zones=	-0.21	-0.27	41%
12	Implemented natural ventilation	-0.32	-0.42	42%
13	=Changed cooling setpoint from 75.2 F to 76 F during occupied hours=	-0.05	-0.15	42%
14	=Reduced fan pressure drop from 5.58 in wc to 3.0 in wc (through use of low-pressure design, therma-fusers)=	-0.17	-0.28	43%
15	=Changed boiler efficiency from 0.89 to 0.97 (condensing boiler)=	-0.07	-0.02	43%
16	=Changed fan efficiency from 0.6045 to 0.7=	-0.05	-0.09	43%
17	=Improved water heater thermal efficiency to 0.97 from 0.8 to reflect high efficiency technology currently on market=	-0.08	-0.02	43%
18	=Improved COP of chillers from 5.5 to 6.5=	-0.40	-0.55	45%
19	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-6.69	-7.32	63%
	Ending EUI:	12.5	15.17	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$25.39
Incremental First Cost:	$26.69*
Net Life Cycle Cost:	$1.29*

Additional Subsystem Load Charts





Building Performance Data

Large Office

		Climate Zones						
Square feet:	498,600							
Avail. Roof:	30,683	15	13	12	10	7	3	16
Total Building Energy Metrics								
kWh/ft^2	Load	5.41	4.11	3.89	4.05	3.89	3.63	5.25
	Minimized Site-kBtu	3.43	2.26	2.04	2.12	1.96	1.77	3.28
	Minimized TDV	3.43	2.26	2.04	2.12	1.96	1.77	3.28
kW/bldg (250 hr method)	Load	719	564	516	533	436	400	703
	Minimized Site-kBtu	552	354	306	345	248	173	482
	Minimized TDV	552	354	306	345	248	173	482
Therms/ft^2	Load	0.01	0.03	0.03	0.01	0.01	0.02	0.01
Carbon								
CO_2e (lbs/ft^2)	Minimized Site-kBtu	2.10	1.68	1.58	1.43	1.25	1.32	2.05
	Minimized TDV	2.10	1.68	1.58	1.43	1.25	1.32	2.05
Solar Capacity								
Solar PV (kW)	Minimized Site-kBtu	588	588	588	588	588	588	588
	Minimized TDV	588	588	588	588	588	588	588
Peak Export (kW - bldg)	Minimized Site-kBtu	-404	-418	-418	-418	-418	-428	-385
	Minimized TDV	-404	-418	-418	-418	-418	-428	-385
% of Avail. Roof Used	Minimized Site-kBtu	100%	100%	100%	100%	100%	100%	100%
	Minimized TDV	100%	100%	100%	100%	100%	100%	100%
Building Height Analysis								
Max Floors at ZNE	w/ Site-kBtu Metric	4.6	4.9	5.1	5.6	6.1	5.7	4.6
	w/ TDV Metric	4.3	5.2	5.5	5.7	6.2	6.6	4.5
Max Floors with **Parking PV**	w/ Site-kBtu Metric	22.4	23.7	24.4	26.6	28.8	26.4	22.7
	w/ TDV Metric	21.0	25.6	26.7	27.0	29.4	30.6	22.6
	Park. PV Size (kW)	1,735	1,735	1,735	1,735	1,735	1,735	1,735

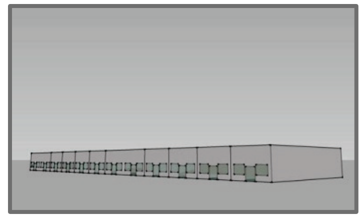
kWh by Bin			Climate Zones								
Large Office			15			12			3		
			Load	Solar	Net	Load	Solar	Net	Load	Solar	Net
May through October	Mon. - Fri.	21:00 - 6:00	164,551	-4,496	160,055	93,879	-4,384	89,495	91,637	-4,465	87,173
		6:00 - 9:00	211,957	-66,679	145,279	146,773	-59,828	86,945	139,575	-49,702	89,873
		9:00 - 12:00	260,492	-139,689	120,803	182,500	-144,511	37,990	169,437	-141,734	27,702
		12:00 - 15:00	283,210	-128,434	154,776	204,696	-141,410	63,287	181,341	-148,593	32,748
		15:00 - 18:00	240,885	-46,350	194,534	169,241	-61,155	108,087	142,081	-62,993	79,089
		18:00 - 21:00	166,853	296	167,150	104,372	-1,499	102,872	85,209	-1,854	83,356
	Sat. - Sun.	21:00 - 6:00	72,694	-5,758	66,936	40,901	-5,219	35,681	40,074	-4,253	35,821
		6:00 - 9:00	52,077	-37,264	14,813	30,236	-37,987	-7,751	27,038	-29,674	-2,636
		9:00 - 12:00	51,539	-56,734	-5,195	26,862	-61,997	-35,136	22,900	-59,099	-36,200
		12:00 - 15:00	55,662	-42,012	13,649	30,667	-48,100	-17,433	23,868	-49,554	-25,687
		15:00 - 18:00	47,823	-7,433	40,390	28,043	-12,025	16,018	19,085	-12,157	6,928
		18:00 - 21:00	38,434	-98	38,336	18,050	-60	17,990	17,286	48	17,334
	Gas Therms		686			1,810			2,462		
November through April	Mon. - Fri.	21:00 - 6:00	104,231	-1,500	102,731	92,805	72	92,877	92,662	-399	92,263
		6:00 - 9:00	116,373	-41,960	74,412	107,202	-23,031	84,171	106,539	-21,754	84,785
		9:00 - 12:00	182,758	-123,605	59,153	153,020	-89,667	63,353	150,956	-95,568	55,388
		12:00 - 15:00	193,046	-117,412	75,634	154,753	-95,613	59,140	152,858	-102,516	50,342
		15:00 - 18:00	179,589	-30,997	148,592	144,990	-31,199	113,791	142,270	-34,353	107,917
		18:00 - 21:00	101,079	292	101,371	74,448	314	74,762	70,216	314	70,529
	Sat. - Sun.	21:00 - 6:00	39,876	-2,963	36,913	36,985	-2,063	34,923	36,929	-2,106	34,823
		6:00 - 9:00	29,270	-30,798	-1,528	24,659	-20,062	4,597	24,312	-18,859	5,453
		9:00 - 12:00	29,104	-52,473	-23,368	19,273	-42,973	-23,699	18,971	-44,836	-25,865
		12:00 - 15:00	29,793	-38,831	-9,037	18,348	-32,856	-14,508	17,829	-35,117	-17,288
		15:00 - 18:00	27,137	-3,384	23,753	20,810	-4,206	16,604	20,145	-4,557	15,588
		18:00 - 21:00	19,045	77	19,121	17,617	140	17,757	17,617	140	17,757
	Gas Therms		2,920			12,754			8,442		

8.7 Strip Mall

Strip Mall

Size: **22,500** ft²

Number of Floors: **1** floor



		Climate Zones						
		15	**13**	**12**	**10**	**7**	**3**	**16**
Site-kBtu /ft²	**Load:**	26.0	27.4	27.0	25.5	24.0	25.6	28.5
	Solar:	-26.0	-27.4	-27.0	-25.5	-24.0	-25.6	-28.5
	Net:	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
TDV$/ft² (30yr NPV)	**Load:**	26.55	24.60	23.94	23.60	21.89	21.51	24.33
	Solar:	-26.55	-24.60	-23.94	-23.60	-21.89	-21.51	-24.33
	Net:	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Description:

The Strip Mall has 22,500 ft² of space on a single floor. There are eight stores within the Strip Mall of varying sizes.

In the Strip Mall, accent lighting drives much of the load. While fluorescent lighting is amongst the most efficient lighting sources at present, it is not well suited for accent purposes. LED lighting, in contrast, is ideal for directed applications. Consequently, retail will see significant gains from LED improvements. The lighting Site-kBtu reduction alone is 11 kBtu/ft²/yr.

Those gains are amplified by the extended retail schedules, running late into the night and through the weekend. Extended schedules are a primary driver of the higher EUIs seen in the retail prototypes as compared to the office prototypes.

The reduction in lighting power densities moved many of the Strip Mall prototypes from cooling dominated to heating dominated (dependent on climate zone). As the prototypes became more "neutral" in their HVAC needs, the TDV values declined while Site-kBtu sometimes increased. The more "neural" operations increased the ability to make use of natural ventilation to meet occupant comfort needs.

While moderate savings are produced by the implementation of a mixed mode natural ventilation system, even greater benefit was realized through the control of unwanted ventilation at the entry doors. A vestibule was added to the model to reduce door infiltration by 50%, resulting in a 2.2 kBtu/ft²/yr savings in CZ12.

One of the more radical shifts in the Strip Mall was to centralize the cooling, implementing a water-cooled chiller in the process. Window shading was tested on the Strip Mall but proved unbeneficial.

Strip Mall Change Log

CZ12
Sacramento

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	47.5	53.17	0%
1	Title 24 2013 Envelope Changes	0.64	1.23	-2%
2	LPD to 0.44 W/sf	-11.01	-17.48	31%
3	Exterior Lighting reduction (50%)	-1.16	-1.01	32%
4	Remove Floor Insulation	-2.63	-3.97	40%
5	Roof Reflectance to 0.9	0.15	-1.16	42%
6	Vestibules (50% reduction in door infiltration)	-2.27	-2.00	46%
7	Natural Ventilation (doors/windows open)	-0.27	-0.63	47%
8	VAV system with Water-cooled Chiller and Gas-fired Boiler	-2.18	-3.48	54%
9	Boiler Efficiency to 0.97 (Condensing Boiler)	-1.37	-0.39	54%
10	Fan Efficiency to 0.7	-0.22	-0.29	55%
11	Water Heater Thermal Efficiency to 0.97	-0.18	-0.05	55%
12	Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)	-27.01	-23.94	100%
	Ending EUI:	0.0	0.00	

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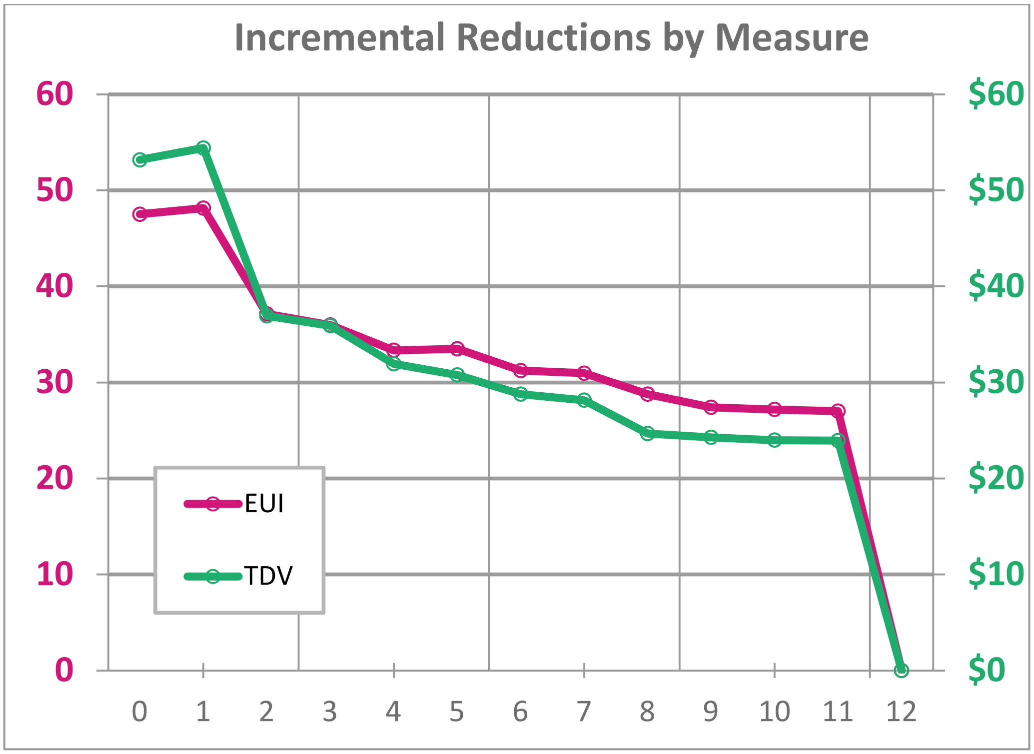
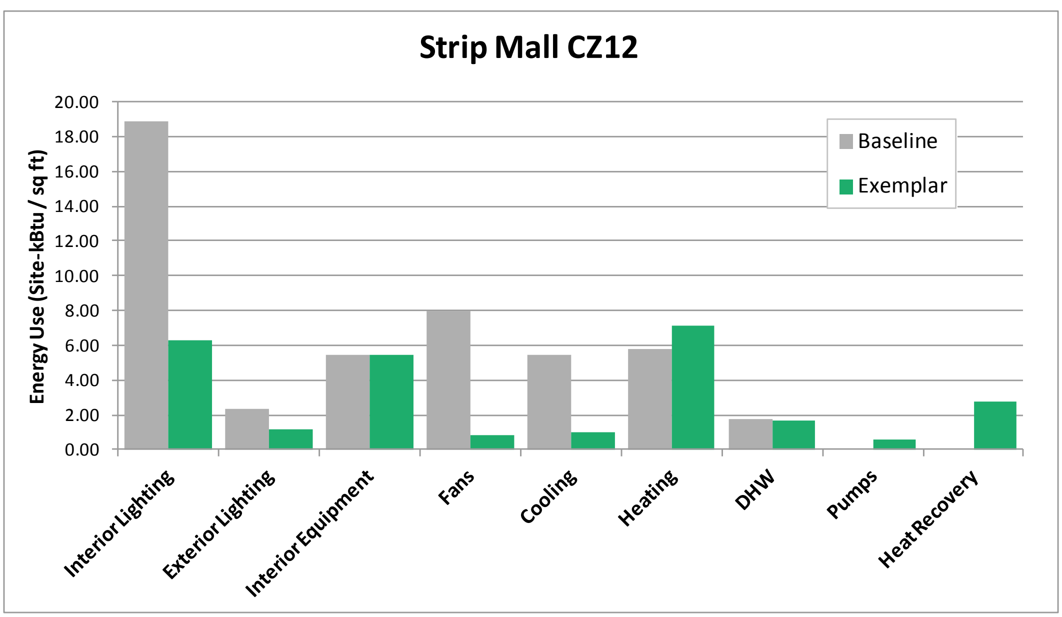
Total TDV$ Savings:	-$53.17
Incremental First Cost:	$26.76*
Net Life Cycle Cost:	-$26.41*

Incremental Reduction by Measure



Subsystem Loads



Strip Mall Change Log

CZ3
Oakland

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	kBtu/ft2 savings	TDV$/ft2 (30yr) savings	TDV$ reduction
	Starting EUI:	40.6	43.37	0%
1	=Title 24 2013 Envelope Changes=	0.33	0.09	0%
2	=LPD to 0.44 W/sf=	-10.07	-16.75	38%
3	=Exterior Lighting reduction (50%)=	-1.16	-1.01	41%
4	=Remove Floor Insulation=	-0.62	-1.74	45%
5	=Roof Reflectance to 0.9=	0.83	-0.72	46%
6	=Vestibules (50% reduction in door infiltration)=	-1.80	-0.62	48%
7	=Natural Ventilation (doors/windows open)=	-0.24	-0.61	49%
8	=VAV system with Water-cooled Chiller and Gas-fired Boiler=	-0.42	0.12	49%
9	=Boiler Efficiency to 0.97 (Condensing Boiler)=	-1.47	-0.41	50%
10	=Fan Efficiency to 0.7=	-0.10	-0.16	50%
11	=Water Heater Thermal Efficiency to 0.97=	-0.19	-0.05	50%
12	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-25.64	-21.51	100%
	Ending EUI:	0.0	0.00	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$43.37
Incremental First Cost:	$19.27*
Net Life Cycle Cost:	-$24.10*

Strip Mall Change Log

CZ10
Riverside

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	45.0	53.78	0%
1	=Title 24 2013 Envelope Changes=	-0.51	-0.83	2%
2	=LPD to 0.44 W/sf=	-13.66	-18.32	36%
3	=Exterior Lighting reduction (50%)=	-1.16	-1.01	37%
4	=Remove Floor Insulation=	-1.58	-2.65	42%
5	=Roof Reflectance to 0.9=	-0.27	-1.31	45%
6	=Vestibules (50% reduction in door infiltration)=	-1.57	-1.89	48%
7	=Natural Ventilation (doors/windows open)=	-0.43	-0.64	50%
8	=VAV system with Water-cooled Chiller and Gas-fired Boiler=	1.18	-2.88	55%
9	=Boiler Efficiency to 0.97 (Condensing Boiler)=	-1.04	-0.29	55%
10	=Fan Efficiency to 0.7=	-0.25	-0.32	56%
11	=Water Heater Thermal Efficiency to 0.97=	-0.18	-0.05	56%
12	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-25.48	-23.60	100%
	Ending EUI:	0.0	0.00	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$53.78
Incremental First Cost:	$23.54*
Net Life Cycle Cost:	-$30.24*

Strip Mall Change Log

CZ15
Palm Springs

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	55.4	70.03	0%
1	=Title 24 2013 Envelope Changes=	1.98	2.53	-4%
2	=LPD to 0.44 W/sf=	-15.57	-19.43	24%
3	=Exterior Lighting reduction (50%)=	-1.16	-1.02	26%
4	=Remove Floor Insulation=	-5.06	-6.77	35%
5	=Roof Reflectance to 0.9=	-1.11	-1.82	38%
6	=Vestibules (50% reduction in door infiltration)=	-3.77	-5.41	46%
7	=Natural Ventilation (doors/windows open)=	-1.28	-1.52	48%
8	=VAV system with Water-cooled Chiller and Gas-fired Boiler=	-2.25	-9.26	61%
9	=Boiler Efficiency to 0.97 (Condensing Boiler)=	-0.53	-0.15	61%
10	=Fan Efficiency to 0.7=	-0.47	-0.59	62%
11	=Water Heater Thermal Efficiency to 0.97=	-0.17	-0.04	62%
12	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-25.97	-26.55	100%
	Ending EUI:	0.0	0.00	

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Total TDV$ Savings:	-$70.02
Incremental First Cost:	$36.71*
Net Life Cycle Cost:	-$33.31*

Strip Mall Change Log

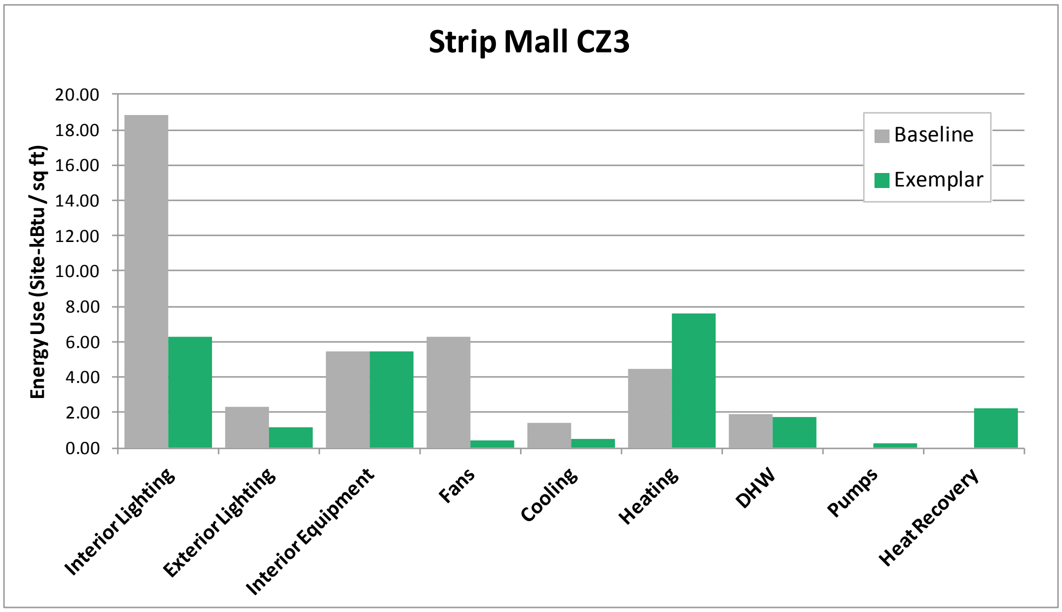
CZ16
Blue Canyon

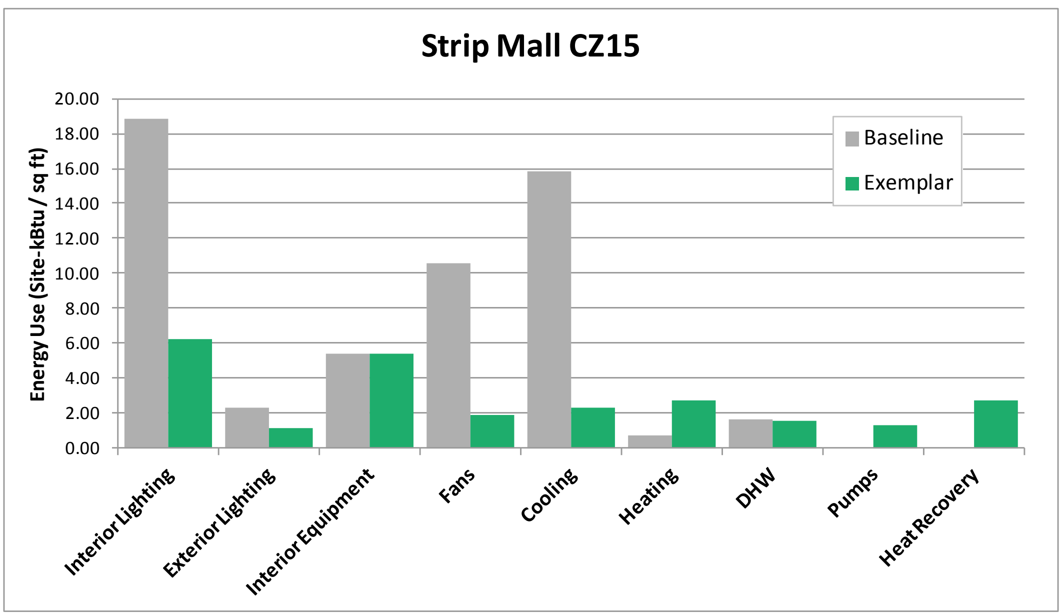
	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	52.1	50.75	0%
1	=Title 24 2013 Envelope Changes=	1.49	3.68	-7%
2	=LPD to 0.44 W/sf=	-9.43	-17.48	27%
3	=Exterior Lighting reduction (50%)=	-1.16	-1.00	29%
4	=Remove Floor Insulation=	-2.27	-4.97	39%
5	=Roof Reflectance to 0.9=	1.67	-1.16	41%
6	=Vestibules (50% reduction in door infiltration)=	-3.60	-2.24	46%
7	=Natural Ventilation (doors/windows open)=	-0.40	-0.94	48%
8	=VAV system with Water-cooled Chiller and Gas-fired Boiler=	-7.82	-1.51	50%
9	=Boiler Efficiency to 0.97 (Condensing Boiler)=	-1.70	-0.48	51%
10	=Fan Efficiency to 0.7=	-0.14	-0.27	52%
11	=Water Heater Thermal Efficiency to 0.97=	-0.20	-0.05	52%
12	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-28.54	-24.33	100%
	Ending EUI:	0.0	0.00	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$50.76
Incremental First Cost:	$25.77*
Net Life Cycle Cost:	-$24.99*

Additional Subsystem Load Charts





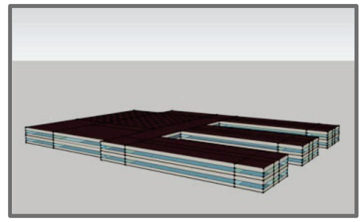
Building Performance Data

Strip Mall

		Climate Zones						
Square feet:	22,500							
Avail. Roof:	18,000	**15**	**13**	**12**	**10**	**7**	**3**	**16**
Total Building Energy Metrics								
kWh/ft^2	Load	6.37	5.54	5.34	5.41	4.86	4.77	5.24
	Minimized Site-kBtu	-1.25	-2.50	-2.58	-2.06	-2.17	-2.75	-3.13
	Minimized TDV	-0.75	-0.81	-0.84	-0.58	-0.69	-0.45	-1.03
kW/bldg (250 hr method)	Load	32.1	28.3	27.6	27.8	24.4	22.5	29.1
	Minimized Site-kBtu	3.0	-12.9	-13.0	-5.0	-6.5	-18.9	-13.5
	Minimized TDV	4.9	-4.3	-4.1	1.5	0.0	-6.2	-2.8
Therms/ft^2	Load	0.04	0.09	0.09	0.07	0.07	0.09	0.11
Carbon								
CO_2e (lbs/ft^2)	Minimized Site-kBtu	-0.17	-0.33	-0.34	-0.28	-0.29	-0.37	-0.42
	Minimized TDV	0.12	0.65	0.67	0.59	0.57	0.97	0.81
Solar Capacity								
Solar PV (kW)	Minimized Site-kBtu	102	115	114	103	97	107	113
	Minimized TDV	96	91	89	82	76	75	85
Peak Export (kW - bldg)	Minimized Site-kBtu	-74.6	-83.5	-81.8	-78.1	-73.4	-86.0	-90.8
	Minimized TDV	-69.7	-65.4	-63.6	-62.3	-57.7	-59.2	-67.8
% of Avail. Roof Used	Minimized Site-kBtu	30%	33%	33%	30%	28%	31%	33%
	Minimized TDV	28%	26%	26%	24%	22%	22%	25%
Building Height Analysis								
Max Floors at ZNE	w/ Site-kBtu Metric	3.4	3.0	3.0	3.4	3.6	3.2	3.1
	w/ TDV Metric	3.6	3.8	3.9	4.2	4.5	4.6	4.1
Max Floors with **Parking PV**	w/ Site-kBtu Metric	7.0	6.1	6.2	6.8	7.2	6.4	6.3
	w/ TDV Metric	7.5	7.8	8.0	8.5	9.1	9.2	8.5
	Park. PV Size (kW)	278	278	278	278	278	278	278

8.8 Secondary School

Secondary School



Size:	**210,900**	ft^2
Number of Floors:	**2**	floors

		Climate Zones						
		15	**13**	**12**	**10**	**7**	**3**	**16**
Site-kBtu $/ft^2$	**Load:**	28.9	26.1	26.3	24.9	22.7	22.0	28.4
	Solar:	-28.9	-26.1	-26.3	-24.9	-22.7	-22.0	-28.4
	Net:	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
TDV$/ft² (30yr NPV)	**Load:**	31.66	26.88	26.88	26.40	23.73	22.30	24.46
	Solar:	-31.66	-26.88	-26.88	-26.40	-23.73	-22.30	-24.46
	Net:	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Description:

The Secondary School is a two-story structure with classrooms, two gyms, a library, an auditorium, a kitchen, a cafeteria, and offices.

Similar to the office models, the School's overall energy consumption is driven primarily by internal loads, such as lighting, equipment, and people. This leads to high cooling energy consumption in all climate zones, except climate zone 16.

Initial envelope improvements were based on the Title 24 2013 Standard, creating modest gains from the ASHRAE 90.1-2010 baseline, although the changes slightly increased energy use in climate zone 16 (the mountains).

The equipment loads were not changed because, while computers are becoming more efficient, there is also likely to be an increase in computer use in the classroom. Lighting power was reduced 60% due to the use of more efficient LED lights that are expected to be commercially available by 2020.

The effect of pop-up skylights was tested, instead of the original horizontal skylights that were in the gyms. These pop-up skylights had minimal benefits for TDV and EUI. Two overhang depths were tested: half the height of the window and the full height of the window. Both overhangs had little effect on the overall Site-kBtu and TDV.

A mixed mode natural ventilation scheme was implemented in the School. The biggest reduction in energy was due to a reduction in fan energy use. For all climate zones, natural ventilation showed an improvement in both Site-kBtu and TDV. The original School model had an air-cooled chiller. Substituting a water-cooled chiller resulted in some of the biggest savings in TDV for all climate zones.

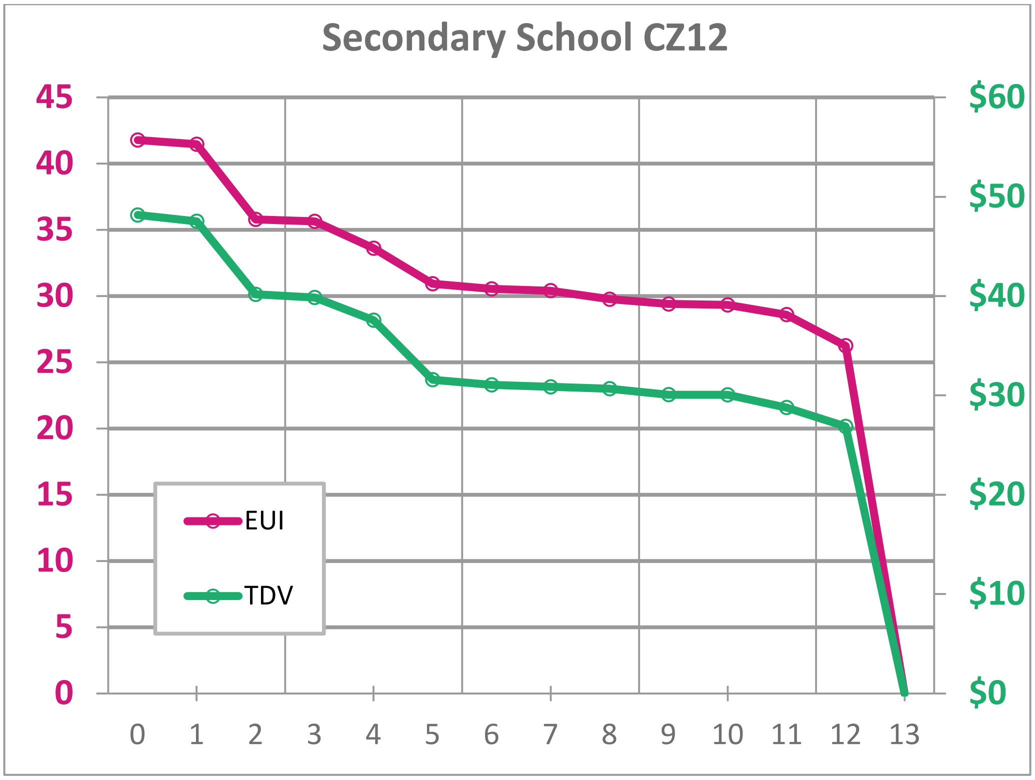
Secondary School Change Log

CZ12
Sacramento

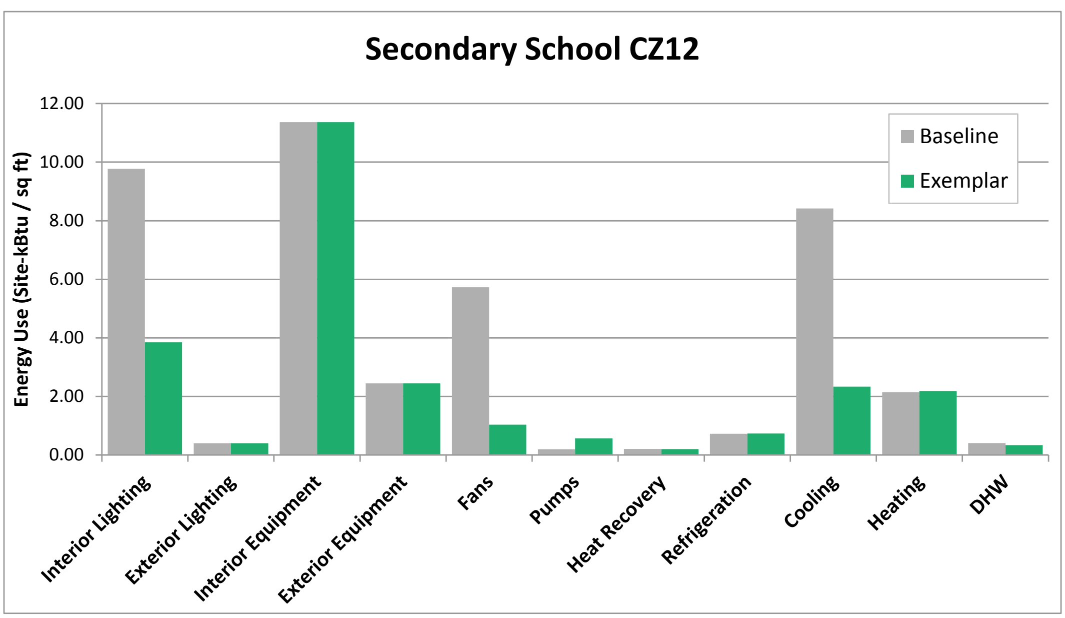
	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	41.8	48.16	0%
1	Title 24 2013: Envelope & Glazing Improvements	-0.32	-0.63	1%
2	60% Reduction in LPD due to 220 LM/W LED	-5.67	-7.36	17%
3	Pop-up skylights	-0.15	-0.31	17%
4	Natural Ventilation in all zones	-2.03	-2.29	22%
5	Water Cooled Chiller (replaced Air-cooled)	-2.68	-5.98	34%
6	Replaced Gas Furnaces in PTAC units to Hot Water Coils	-0.39	-0.52	35%
7	Increased COP of chiller to 6.5 from 5.5	-0.13	-0.20	36%
8	Increased Boiler efficiency to 0.97 (Condensing Boiler)	-0.65	-0.19	36%
9	Increased Fan efficiency to 0.7	-0.36	-0.60	38%
10	Increased Water Heater Thermal efficiency to 0.97	-0.07	-0.02	38%
11	Reduced Fan pressure drop to 3 in wc (therma-fusers)	-0.73	-1.28	40%
12	Changed Setpoints: Gym= 78-65˚F and all other rooms= 78-68˚F	-2.35	-1.90	44%
13	Rooftop PV (see "Solar PV (kW)" in "Building Performance Data" table for PV system sizes)	-26.25	-26.88	100%
	Ending EUI:	0.0	0.00	

Total TDV$ Savings:	-$48.16
Incremental First Cost:	$36.21*
Net Life Cycle Cost:	-$11.95*

Incremental Reduction by Measure



Subsystem Loads



Secondary School Change Log

CZ3
Oakland

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	35.9	39.16	0%
1	=Title 24 2013: Envelope & Glazing Improvements=	-1.01	-1.43	4%
2	=60% Reduction in LPD due to 220 LM/W LED=	-5.78	-7.06	22%
3	=Pop-up skylights=	-0.07	-0.19	22%
4	=Natural Ventilation in all zones=	-3.00	-3.50	31%
5	=Water Cooled Chiller (replaced Air-cooled)=	-0.74	-1.58	35%
6	=Replaced Gas Furnaces in PTAC units to Hot Water Coils=	-0.28	-0.28	36%
7	=Increased COP of chiller to 6.5 from 5.5=	-0.06	-0.10	36%
8	=Increased Boiler efficiency to 0.97 (Condensing Boiler)=	-0.30	-0.08	36%
9	=Increased Fan efficiency to 0.7=	-0.21	-0.36	37%
10	=Increased Water Heater Thermal efficiency to 0.97=	-0.09	-0.02	37%
11	=Reduced Fan pressure drop to 3 in wc (therma-fusers)=	-0.37	-0.71	39%
12	=Changed Setpoints: Gym= 78-65˚F and all other rooms= 78-68˚F=	-1.96	-1.56	43%
13	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-22.02	-22.30	100%
	Ending EUI:	0.0	0.00	

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Total TDV$ Savings:	-$39.17
Incremental First Cost:	$29.06*
Net Life Cycle Cost:	-$10.11*

Secondary School Change Log

CZ10
Riverside

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	**42.6**	**50.52**	0%
1	=Title 24 2013: Envelope & Glazing Improvements=	-1.69	-2.27	4%
2	=60% Reduction in LPD due to 220 LM/W LED=	-6.20	-7.49	19%
3	=Pop-up skylights=	-0.14	-0.28	20%
4	=Natural Ventilation in all zones=	-2.42	-2.35	25%
5	=Water Cooled Chiller (replaced Air-cooled)=	-3.26	-7.03	38%
6	=Replaced Gas Furnaces in PTAC units to Hot Water Coils=	-0.26	-0.41	39%
7	=Increased COP of chiller to 6.5 from 5.5=	-0.15	-0.21	40%
8	=Increased Boiler efficiency to 0.97 (Condensing Boiler)=	-0.30	-0.08	40%
9	=Increased Fan efficiency to 0.7=	-0.37	-0.59	41%
10	=Increased Water Heater Thermal efficiency to 0.97=	0.00	0.00	41%
11	=Reduced Fan pressure drop to 3 in wc (therma-fusers)=	-0.78	-1.31	44%
12	=Changed Setpoints: Gym= 78-65˚F and all other rooms= 78-68˚F=	-2.11	-2.08	48%
13	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-24.87	-26.40	100%
	Ending EUI:	**0.0**	**0.00**	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$50.51
Incremental First Cost:	$35.26*
Net Life Cycle Cost:	-$15.26*

Secondary School Change Log

CZ15
Palm Springs

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	52.5	62.51	0%
1	=Title 24 2013: Envelope & Glazing Improvements=	-3.08	-3.73	6%
2	=60% Reduction in LPD due to 220 LM/W LED=	-7.10	-8.24	19%
3	=Pop-up skylights=	-0.27	-0.44	20%
4	=Natural Ventilation in all zones=	-1.98	-1.81	23%
5	=Water Cooled Chiller (replaced Air-cooled)=	-6.49	-10.90	40%
6	=Replaced Gas Furnaces in PTAC units to Hot Water Coils=	-0.38	-0.54	41%
7	=Increased COP of chiller to 6.5 from 5.5=	-0.26	-0.32	42%
8	=Increased Boiler efficiency to 0.97 (Condensing Boiler)=	-0.15	-0.05	42%
9	=Increased Fan efficiency to 0.7=	-0.63	-0.87	43%
10	=Increased Water Heater Thermal efficiency to 0.97=	-0.05	-0.02	43%
11	=Reduced Fan pressure drop to 3 in wc (therma-fusers)=	-1.40	-1.97	46%
12	=Changed Setpoints: Gym= 78-65˚F and all other rooms= 78-68˚F=	-1.89	-1.97	49%
13	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-28.86	-31.66	100%
	Ending EUI:	0.0	0.00	

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Total TDV$ Savings:	-$62.52
Incremental First Cost:	$42.25*
Net Life Cycle Cost:	-$20.27*

Secondary School Change Log

CZ16
Blue Canyon

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	41.6	42.97	0%
1	=Title 24 2013: Envelope & Glazing Improvements=	0.88	0.03	0%
2	=60% Reduction in LPD due to 220 LM/W LED=	-4.64	-6.75	16%
3	=Pop-up skylights=	-0.07	-0.28	16%
4	=Natural Ventilation in all zones=	-2.32	-3.20	24%
5	=Water Cooled Chiller (replaced Air-cooled)=	-1.38	-3.15	31%
6	=Replaced Gas Furnaces in PTAC units to Hot Water Coils=	-0.60	-0.67	33%
7	=Increased COP of chiller to 6.5 from 5.5=	-0.07	-0.12	33%
8	=Increased Boiler efficiency to 0.97 (Condensing Boiler)=	-1.41	-0.40	34%
9	=Increased Fan efficiency to 0.7=	-0.36	-0.64	35%
10	=Increased Water Heater Thermal efficiency to 0.97=	-0.10	-0.03	35%
11	=Reduced Fan pressure drop to 3 in wc (therma-fusers)=	-0.65	-1.36	39%
12	=Changed Setpoints: Gym= 78-65˚F and all other rooms= 78-68˚F=	-2.42	-1.94	43%
13	=Rooftop PV (see "Solar PV (kW)" in "Building Performance Data" table for PV system sizes)=	-28.44	-24.46	100%
	Ending EUI:	0.0	0.00	

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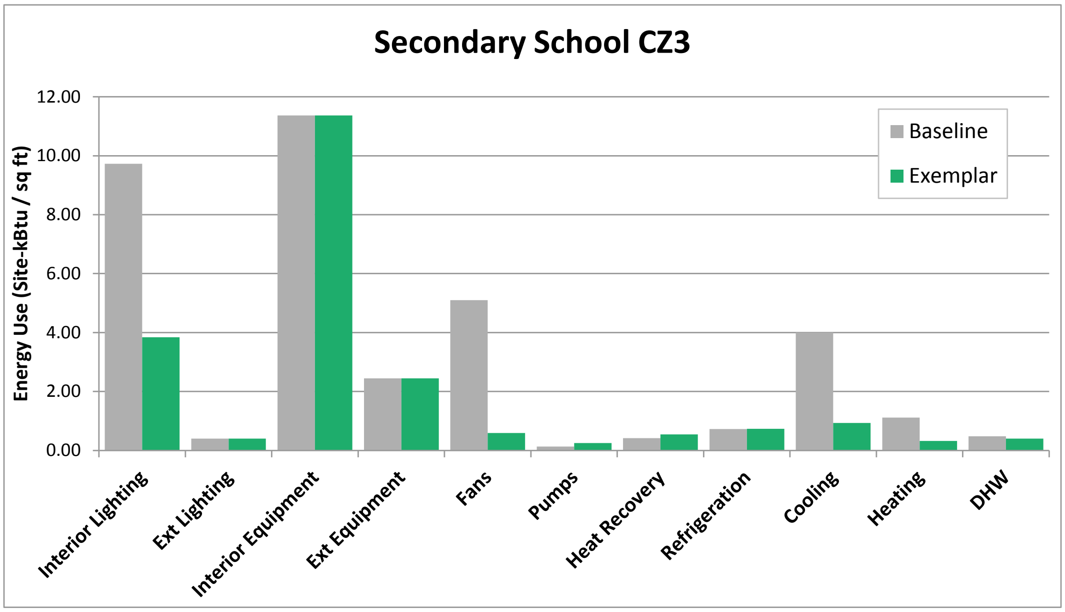
Total TDV$ Savings:	-$42.97
Incremental First Cost:	$31.48*
Net Life Cycle Cost:	-$11.49*

Additional Subsystem Load Charts



Building Performance Data

Secondary School

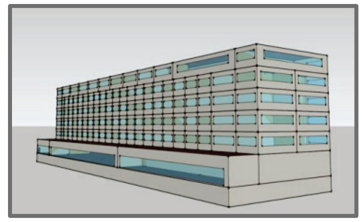
Square feet:	210,900	**Climate Zones**						
Avail. Roof:	73,815	**15**	**13**	**12**	**10**	**7**	**3**	**16**
Total Building Energy Metrics								
kWh/ft^2	Load	7.62	6.36	6.24	6.24	5.80	5.53	5.72
	Minimized Site-kBtu	-0.84	-1.30	-1.46	-1.05	-0.86	-0.93	-2.62
	Minimized TDV	-0.87	-0.58	-0.70	-0.45	-0.22	0.12	-0.58
kW/bldg (250 hr method)	Load	406	335	342	332	248	218	255
	Minimized Site-kBtu	102	-33	-28	32	-26	-116	-143
	Minimized TDV	101	2	9	57	1	-62	-46
Therms/ft^2	Load	0.03	0.04	0.05	0.04	0.03	0.03	0.09
Carbon								
CO_2e (lbs/ft^2)	Minimized Site-kBtu	-0.11	-0.17	-0.19	-0.14	-0.12	-0.12	-0.35
	Minimized TDV	-0.13	0.25	0.25	0.21	0.26	0.49	0.84
Solar Capacity								
Solar PV (kW)	Minimized Site-kBtu	1065	1030	1035	940	859	864	1054
	Minimized TDV	1068	933	933	863	775	724	797
Peak Export (kW - bldg)	Minimized Site-kBtu	-781	-758	-771	-709	-642	-648	-785
	Minimized TDV	-784	-680	-688	-645	-572	-533	-578
% of Avail. Roof Used	Minimized Site-kBtu	75%	73%	73%	66%	61%	61%	75%
	Minimized TDV	76%	66%	66%	61%	55%	51%	56%
Building Height Analysis								
Max Floors at ZNE	w/ Site-kBtu Metric	2.7	2.7	2.7	3.0	3.3	3.3	2.7
	w/ TDV Metric	2.6	3.0	3.0	3.3	3.6	3.9	3.5
Max Floors with **Parking PV**	w/ Site-kBtu Metric	4.3	4.4	4.4	4.8	5.2	5.1	4.3
	w/ TDV Metric	4.3	4.9	4.8	5.2	5.8	6.1	5.8
	Park. PV Size (kW)	648	648	648	648	648	648	648

kWh by Bin			Climate Zones								
Secondary School			15			12			3		
			Load	Solar	Net	Load	Solar	Net	Load	Solar	Net
May through October	Mon. - Fri.	21:00 - 6:00	99,021	-8,174	90,847	89,438	-6,961	82,477	89,322	-5,503	83,819
		6:00 - 9:00	114,330	-121,222	-6,892	76,982	-95,001	-18,019	72,429	-61,266	11,163
		9:00 - 12:00	156,158	-253,954	-97,796	112,487	-229,470	-116,982	90,327	-174,710	-84,382
		12:00 - 15:00	164,283	-233,493	-69,210	130,557	-224,545	-93,988	92,142	-183,165	-91,022
		15:00 - 18:00	151,849	-84,265	67,584	121,389	-97,108	24,281	76,036	-77,648	-1,612
		18:00 - 21:00	101,480	539	102,019	79,780	-2,381	77,399	53,661	-2,285	51,376
	Sat. - Sun.	21:00 - 6:00	41,253	-10,469	30,785	35,629	-8,288	27,341	35,540	-5,242	30,297
		6:00 - 9:00	16,802	-67,746	-50,944	11,229	-60,320	-49,090	10,839	-36,578	-25,739
		9:00 - 12:00	23,138	-103,143	-80,005	12,907	-98,446	-85,539	10,869	-72,849	-61,980
		12:00 - 15:00	26,925	-76,379	-49,453	16,522	-76,378	-59,857	11,025	-61,084	-50,059
		15:00 - 18:00	25,505	-13,513	11,992	16,097	-19,095	-2,997	11,350	-14,985	-3,635
		18:00 - 21:00	20,921	-179	20,742	13,399	-96	13,303	12,762	59	12,821
	Gas Therms		2,784			3,061			3,030		
November through April	Mon. - Fri.	21:00 - 6:00	94,755	-2,727	92,028	94,962	114	95,076	94,749	-492	94,258
		6:00 - 9:00	70,741	-76,284	-5,543	67,053	-36,571	30,482	68,632	-26,815	41,817
		9:00 - 12:00	106,760	-224,713	-117,953	94,659	-142,382	-47,723	96,226	-117,803	-21,576
		12:00 - 15:00	112,873	-213,454	-100,581	96,179	-151,825	-55,646	95,245	-126,367	-31,122
		15:00 - 18:00	103,180	-56,353	46,827	86,044	-49,541	36,503	83,487	-42,345	41,142
		18:00 - 21:00	75,583	532	76,114	64,604	498	65,102	65,289	387	65,675
	Sat. - Sun.	21:00 - 6:00	36,862	-5,386	31,476	37,115	-3,276	33,839	36,943	-2,596	34,347
		6:00 - 9:00	11,469	-55,990	-44,522	11,443	-31,857	-20,414	11,379	-23,246	-11,868
		9:00 - 12:00	12,471	-95,395	-82,924	11,338	-68,236	-56,898	11,181	-55,267	-44,087
		12:00 - 15:00	13,597	-70,594	-56,997	11,502	-52,172	-40,670	11,207	-43,287	-32,080
		15:00 - 18:00	13,295	-6,152	7,144	12,461	-6,679	5,782	12,250	-5,618	6,633
		18:00 - 21:00	13,281	139	13,421	13,107	222	13,329	13,067	172	13,240
	Gas Therms		3,290			7,404			3,655		

8.9 Large Hotel

Large Hotel

Size:	**122,132**	ft^2
Number of Floors:	**6**	floors *+basement*



		Climate Zones						
		15	**13**	**12**	**10**	**7**	**3**	**16**
Site-kBtu /ft^2	**Load:**	73.4	79.4	75.1	77.3	74.6	82.2	94.8
	Solar:	-12.4	-11.7	-11.7	-12.2	-12.2	-11.7	-12.5
	Net:	**61.0**	**67.7**	**63.5**	**65.2**	**62.4**	**70.5**	**82.4**
TDV$/ft^2 (30yr NPV)	**Load:**	46.72	44.52	41.41	43.39	42.55	41.28	45.84
	Solar:	-13.60	-13.59	-13.26	-14.08	-14.04	-14.17	-14.56
	Net:	**33.12**	**30.93**	**28.15**	**29.31**	**28.52**	**27.11**	**31.28**

Description:

The Large Hotel model is 122,132 ft^2, with six floors and a basement. Combining commercial and residential functions, and having a high overall EUI, the Hotel prototype presents a host of energy efficiency opportunities.

Lighting and elevator improvements reduce the internal loads, along with better control systems in each guest room to shut down systems during non-occupancy.

Hotel water heating is significant. This is minimized through the use of ozone laundry systems that can oxidize and remove dirt with much lower temperature water. The boiler was also improved via a condensing system.

As with a number of the exemplar buildings, shifting to a water-cooled chiller from an air-cooled system results in significant savings. While ground source heat pumps were not modeled in this study, they can often be used to drive the same efficiency improvements as a water-cooled chiller in the heat rejection process. Ground source heat pumps are employed in many current ZNE structures.

Heat gain was reduced through a combination of high performance windows and overhangs. Additional wall insulation could have created even greater savings, but the assumed construction in the energy model is a masonry wall and there are potential constructability issues in moving beyond the modeled R-10 insulation.

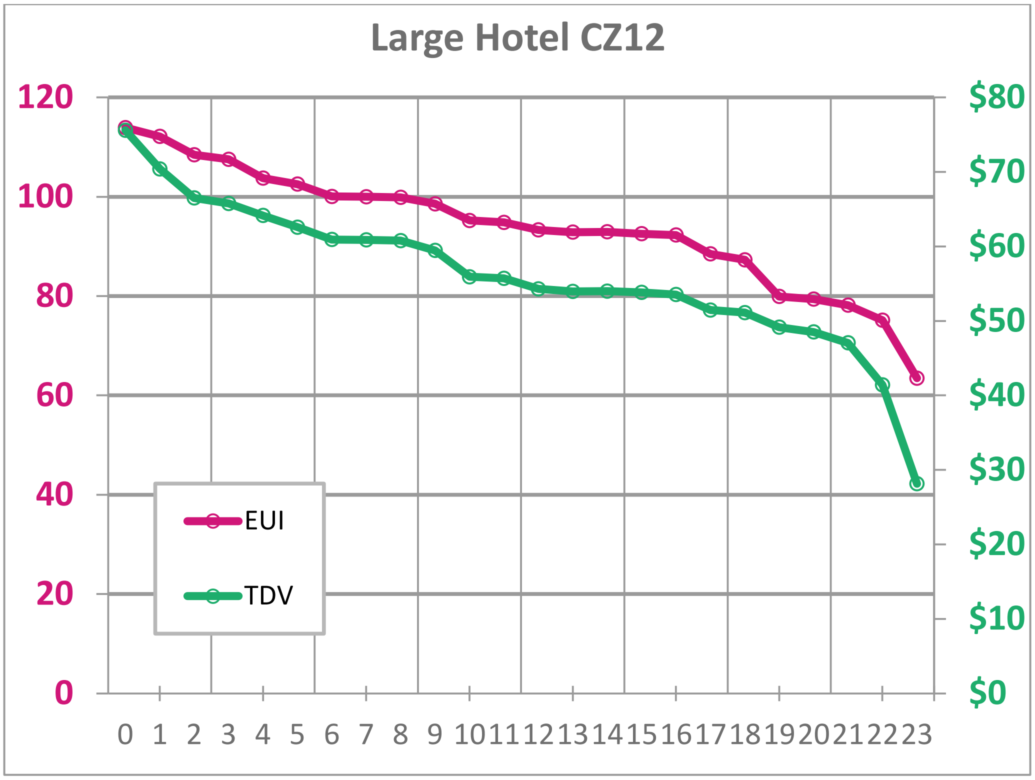
A combination of parking lot PV and a combined heat and power system can likely move the exemplar Hotel to ZNE using the TDV metric. The Site-kBtu EUI of such an on-site generation strategy would still be quite high due to the natural gas consumption of the combined heat and power unit. The CHP natural gas consumption offsets any Site-kBtu gains provided by a 180 kW tracker PV system.

Hotel Change Log

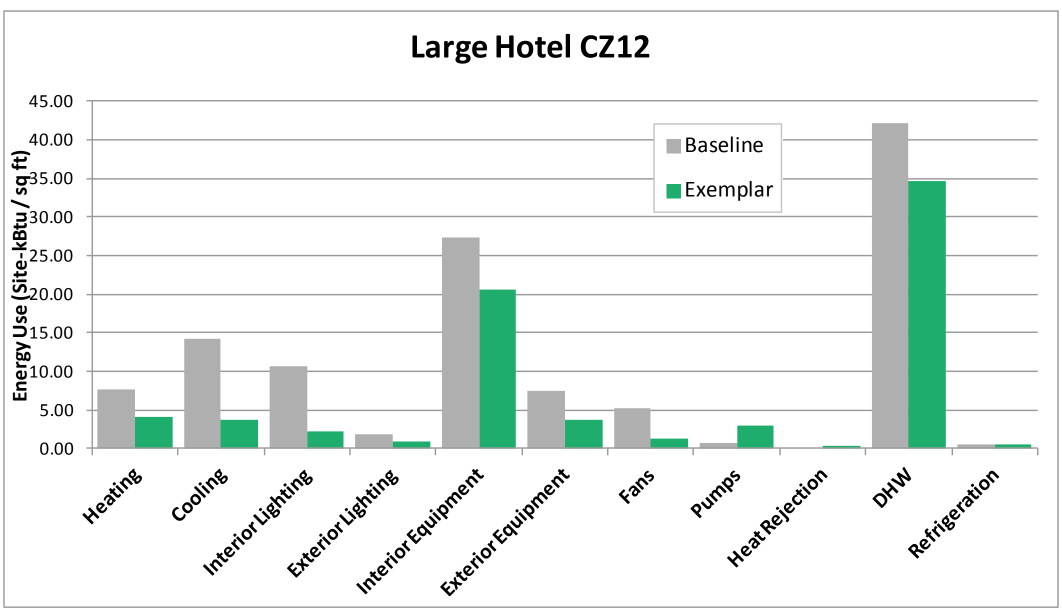
CZ12 Sacramento

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	113.9	75.59	0%
1	Use 100% LED lighting, reduced to 0.4 W/sf in public spaces, 0.1 W/sf in rooms, 0.13 in corridors	-1.76	-5.19	7%
2	Reduced elevator design load by 50% and reduced elev fan and lights by 60%	-3.70	-3.89	12%
3	Reduce exterior lighting by 50%	-0.92	-0.75	13%
4	Reduce laundry gas consumption by 60% due to ozone laundry equipment	-3.78	-1.60	15%
5	Reduced lighting and plug load to 0.05 W/sf during unoccupied times for guest rooms through the use of guest room master switching	-1.20	-1.58	17%
6	Reduce kitchen electric and gas plug loads by 30%	-2.50	-1.64	19%
7	Reduce retail space electric plug load from 1.0 to 0.75 W/sf	-0.06	-0.05	19%
8	Reduced laundry dryer load by 30%	-0.11	-0.10	20%
9	Added 2' south facing overhangs	-1.32	-1.31	21%
10	Changed exterior wall insulation from R-6.33 to R-10	-3.35	-3.55	26%
11	Increased R-value of roof insulation from 19.7 to 24.6 (25% increase)	-0.38	-0.20	26%
12	Changed windows to U 0.25 / SHGC 0.2	-1.50	-1.42	28%
13	Added PV panel shading on roof	-0.45	-0.34	29%
14	Created additional thermal mass (4 inches of concrete) in all zones	0.07	0.03	29%
15	Reduce infiltration by 50%, tight building construction	-0.39	-0.16	29%
16	Implemented natural ventilation in guest rooms	-0.26	-0.29	29%
17	Allow for unoccupied setback temperatures in hotel rooms, 77 F for cooling, 67 F for heating	-3.80	-2.09	32%
18	Changed boiler efficiency from 0.89 to 0.97 (condensing boiler)	-1.21	-0.34	32%
19	Improved water heater thermal efficiency to 0.97 from 0.8 to reflect high efficiency technology currently on market	-7.36	-1.95	35%
20	Changed fan efficiency from 0.6045 to 0.7	-0.54	-0.64	36%
21	Reduced fan pressure drop by 46% (through use of low-pressure design)	-1.22	-1.46	38%
22	Replaced air cooled chiller with water cooled chiller, COP of 6.5	-3.03	-5.65	45%
23	Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)	-11.68	-13.26	63%
	Ending EUI:	63.5	28.15	
		Total TDV$ Savings:	-$47.43	
		Incremental First Cost:	$13.59*	
		Net Life Cycle Cost:	-$33.84*	

Incremental Reduction by Measure



Subsystem Loads



Hotel Change Log

CZ3
Oakland

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	116.8	69.03	0%
1	=Use 100% LED lighting, reduced to 0.4 W/sf in public spaces, 0.1 W/sf in rooms, 0.13 in corridors=	-4.15	-8.26	12%
2	=Reduced elevator design load by 50% and reduced elev fan and lights by 60%=	-3.70	-3.82	17%
3	=Reduce exterior lighting by 50%=	-0.91	-0.75	19%
4	=Reduce laundry gas consumption by 60% due to ozone laundry equipment=	-3.50	-1.19	20%
5	=Reduced lighting and plug load to 0.05 W/sf during unoccupied times for guest rooms through the use of guest room master switching=	-0.97	-1.24	22%
6	=Reduce kitchen electric and gas plug loads by 30%=	-4.63	-2.77	26%
7	=Reduce retail space electric plug load from 1.0 to 0.75 W/sf=	1.30	0.28	26%
8	=Reduced laundry dryer load by 30%=	-0.20	-0.18	26%
9	=Added 2' south facing overhangs=	-1.21	-1.07	28%
10	=Changed exterior wall insulation from R-6.33 to R-10=	-0.18	-0.02	28%
11	=Increased R-value of roof insulation from 19.7 to 24.6 (25% increase)=	-0.23	-0.09	28%
12	=Changed windows to U 0.25 / SHGC 0.2=	-1.00	-0.68	29%
13	=Added PV panel shading on roof=	-0.23	-0.15	29%
14	=Created additional thermal mass (4 inches of concrete) in all zones=	0.05	0.10	29%
15	=Reduce infiltration by 50%, tight building construction=	-0.14	0.03	29%
16	=Implemented natural ventilation in guest rooms=	-0.31	-0.38	29%
17	=Allow for unoccupied setback temperatures in hotel rooms, 77 F for cooling, 67 F for heating=	-2.30	-0.95	31%
18	=Changed boiler efficiency from 0.89 to 0.97 (condensing boiler)=	-0.98	-0.27	31%
19	=Improved water heater thermal efficiency to 0.97 from 0.8 to reflect high efficiency technology currently on market=	-5.85	-2.30	34%
20	=Changed fan efficiency from 0.6045 to 0.7=	-3.52	-0.61	35%
21	=Reduced fan pressure drop by 46% (through use of low-pressure design)=	-1.22	-1.56	38%
22	=Replaced air cooled chiller with water cooled chiller, COP of 6.5=	-0.73	-1.86	40%
23	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-11.73	-14.17	61%
	"=Text=" means same attributes as CZ12 **Ending EUI:**	70.5	27.11	
	Total TDV$ Savings:		-$41.92	
	Incremental First Cost:		$12.48*	
	Net Life Cycle Cost:		-$29.44*	

Building Performance Data

Large Hotel

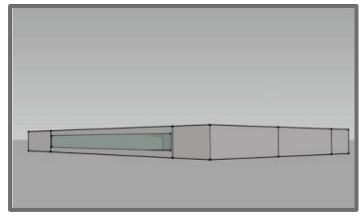
Square feet:	122,132	Climate Zones						
Avail. Roof:	13,958	**15**	**13**	**12**	**10**	**7**	**3**	**16**
Total Building Energy Metrics								
kWh/ft²	Load	10.0	8.5	7.8	8.5	8.3	7.4	7.8
	Minimized Site-kBtu	6.3	5.0	4.4	4.9	4.8	3.9	4.1
	Minimized TDV	6.3	5.0	4.4	4.9	4.8	3.9	4.1
kW/bldg (250 hr method)	Load	205	177	157	173	155	136	146
	Minimized Site-kBtu	129	81	62	87	70	33	45
	Minimized TDV	129	81	62	87	70	33	45
Therms/ft²	Load	0.39	0.51	0.49	0.48	0.46	0.57	0.68
Carbon								
CO_2e (lbs/ft²)	Minimized Site-kBtu	8.88	9.60	8.95	9.25	8.87	9.82	11.43
	Minimized TDV	8.88	9.60	8.95	9.25	8.87	9.82	11.43
Solar Capacity								
Solar PV (kW)	Minimized Site-kBtu	267	267	267	267	267	267	267
	Minimized TDV	267	267	267	267	267	267	267
Peak Export (kW - bldg)	Minimized Site-kBtu	-148	-165	-167	-166	-164	-166	-161
	Minimized TDV	-148	-165	-167	-166	-164	-166	-161
% of Avail. Roof Used	Minimized Site-kBtu	100%	100%	100%	100%	100%	100%	100%
	Minimized TDV	100%	100%	100%	100%	100%	100%	100%
Building Height Analysis								
Max Floors at ZNE	w/ Site-kBtu Metric	1.2	1.0	1.1	1.1	1.1	1.0	0.9
	w/ TDV Metric	2.0	2.1	2.2	2.3	2.3	2.4	2.2
Max Floors with **Parking PV**	w/ Site-kBtu Metric	2.3	2.0	2.1	2.1	2.2	1.9	1.8
	w/ TDV Metric	3.9	4.0	4.3	4.3	4.4	4.5	4.2
	Park. PV Size (kW)	185	185	185	185	185	185	185

CHP w/ Parking PV	**15**	**13**	**12**	**10**	**7**	**3**	**16**
CHP system size (kW)	146	127	107	114	105	94	119
Site-kBtu/ft²	62.3	68.9	62.9	65.1	61.5	69.2	82.1
TDV/ft² (30yr NPV)	0.03	0.00	0.00	0.00	0.00	0.53	0.07

CHP sized at minimum threshold to reach TDV$ ZNE. CHP tracks the thermal load to maximize efficiency.

8.10 Grocery

Grocery



Size:	**45,000**	ft^2
Number of Floors:	**1**	floor

		Climate Zones						
		15	**13**	**12**	**10**	**7**	**3**	**16**
Site-kBtu $/ft^2$	**Load:**	66.4	77.1	77.4	70.1	67.0	73.3	90.5
	Solar:	-66.4	-66.4	-66.4	-69.1	-67.0	-66.7	-70.9
	Net:	**0.0**	**10.7**	**11.0**	**1.0**	**0.0**	**6.6**	**19.6**
TDV$/ft^2$ (30yr NPV)	**Load:**	68.84	68.85	67.78	65.90	64.52	63.87	66.58
	Solar:	-68.84	-68.85	-67.78	-65.90	-64.52	-63.87	-66.58
	Net:	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Description:

The Grocery store model is 45,000 ft^2 on one floor. The high EUI of a grocery store presents significant opportunities for efficiency improvements, particularly in the refrigeration systems.

Switching the heat rejection to a water-based system created notable savings. Improvements were made to the Grocery model where possible to simulate better system performance using strategies such as hot gas defrost, but EnergyPlus is not well suited to doing complete refrigeration system modeling. Accordingly, the model was in part calibrated to reference high performance benchmarks for the refrigeration system. That calibration was implemented in the model through a reduction in peak loads on the cooling system. However, the associated energy reductions would be implemented in a real store, for instance, through the installation of more refrigerator cases with doors.

Waste heat from the near constant refrigeration cycle was used both for space heating and defrost. HVAC air delivery systems were tuned to minimize delivery losses, including aggressive reductions in pressure drop.

The kitchen is a notable energy intensive area as well, and measures similar to those used in the Sit-down Restaurant prototype were applied in the Grocery kitchen area.

While the exemplar Grocery models are still quite energy intensive, the Grocery can likely meet the ZNE goals because it is only one story. Tapping into the typically ubiquitous parking areas associated with grocery stores should also greatly enhance the ability to move groceries towards ZNE goals.

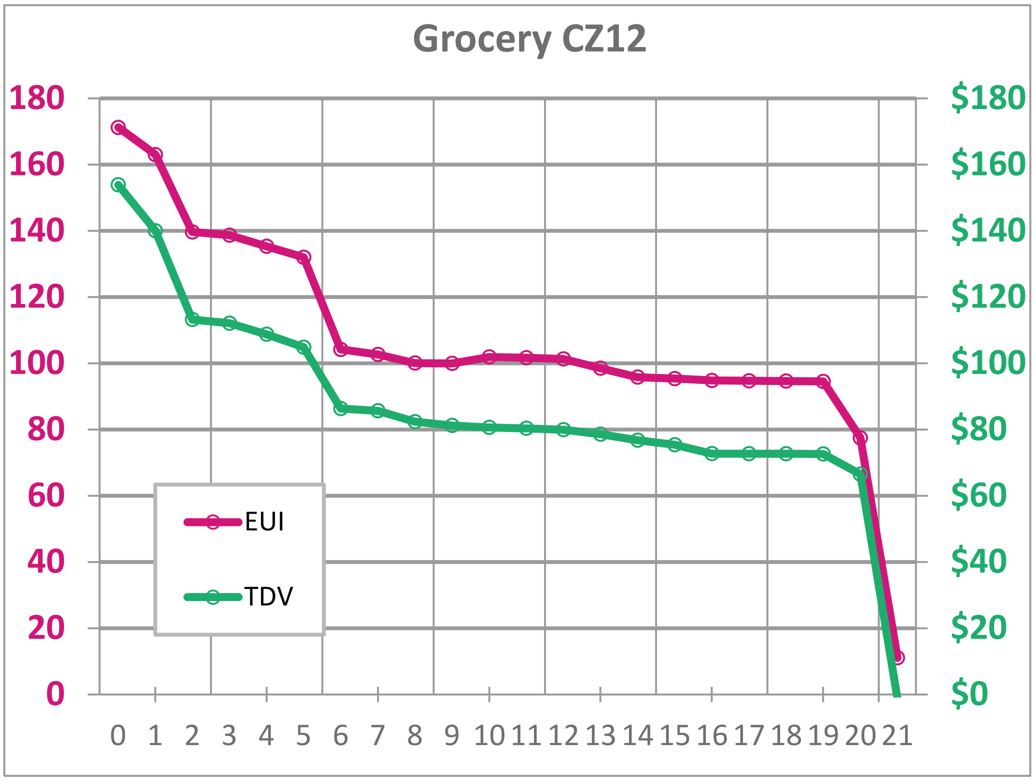
Grocery Change Log

CZ12
Sacramento

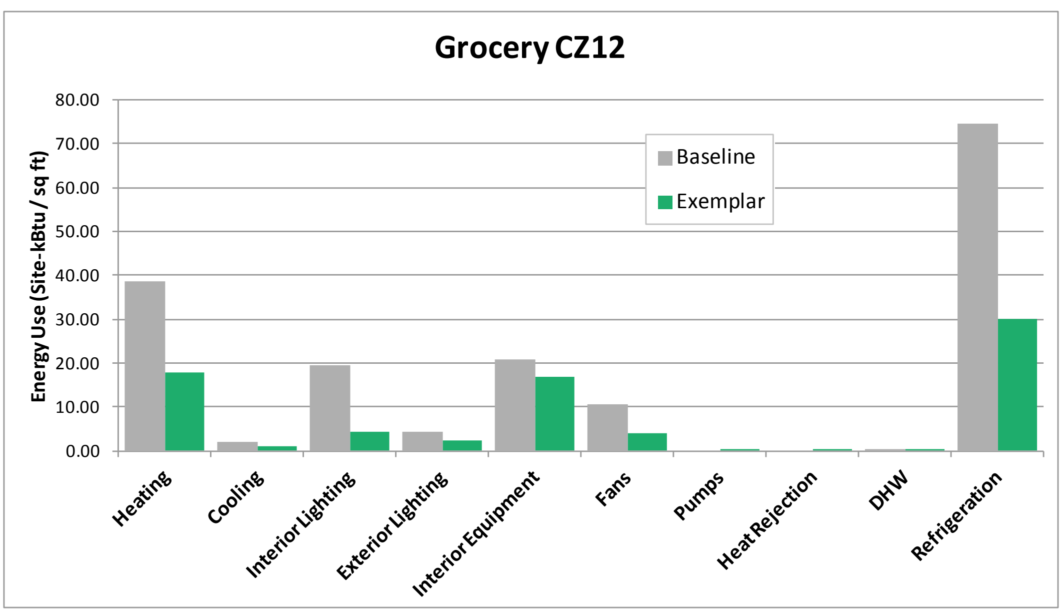
	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	171.2	155.20	0%
1	Reduced LPD by 60%	-8.21	-13.89	9%
2	Water Cooled Condensers on refrigeration equipment	-23.36	-26.79	26%
3	Lighting occupancy sensors in freezers and refrigerators	-0.97	-1.14	27%
4	Refrigeration cases with hot gas defrost (not electric)	-3.35	-3.31	29%
5	Reduce exterior lighting by 50%	-3.33	-3.94	32%
6	40% reduction in total medium and low temp refrigeration through improved insulation, compressor technology, LED lighting in cases, more efficient fans, etc.	-27.83	-18.51	44%
7	Reduce gas appliances by 35%	-1.51	-0.66	44%
8	Reduce electric appliance load by 30% in bakery and deli	-2.58	-3.31	46%
9	Skylights	-0.11	-1.13	47%
10	PV shading, represented with 100% reflective roof	1.95	-0.57	47%
11	Changed windows to 'Window_U_0.43_SHGC_0.29'	-0.24	-0.28	47%
12	Increased thickness of board insulation from 1.4 inch to 3 inch	-0.37	-0.43	48%
13	Increased thickness of board insulation from 5 inch to 10.2 inch (R-30)	-2.80	-1.36	49%
14	Decreased infiltration by 50%	-2.68	-1.81	50%
15	Increased fan efficiency to 0.7	-0.47	-1.37	51%
16	Reduced fan pressure drop to 2.07 on rooftop units (low pressure design)	-0.56	-2.67	52%
17	Reduced exhaust fan cfm by 50% to represent low flow exhaust hoods	-0.10	-0.04	52%
18	Improved water heater thermal efficiency to 0.95 from 0.8 to reflect high efficiency condensing technology	-0.07	-0.02	52%
19	Reduced hot water consumption by 40% through use of low flow fixtures in bathrooms and low flow dishwasher	-0.13	-0.06	52%
20	Heat recovery from refrigeration to space heat	-17.03	-6.13	56%
21	Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)	-66.41	-67.78	100%
	Ending EUI:	11.0	0.00	

Total TDV$ Savings:	-$155.20
Incremental First Cost:	$72.73*
Net Life Cycle Cost:	-$82.47*

Incremental Reduction by Measure



Subsystem Loads



Grocery Change Log

CZ3
Oakland

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	169.1	144.55	0%
1	=Reduced LPD by 60%=	-6.55	-12.93	9%
2	=Water Cooled Condensers on refrigeration equipment=	-20.88	-23.13	25%
3	=Lighting occupancy sensors in freezers and refrigerators=	-0.97	-1.15	26%
4	=Refrigeration cases with hot gas defrost (not electric)=	-3.35	-3.28	28%
5	=Reduce exterior lighting by 50%=	-2.94	-3.57	30%
6	=40% reduction in total medium and low temp refrigeration through improved insulation, compressor technology, LED lighting in cases, more efficient fans, etc.=	-31.80	-20.73	45%
7	=Reduce gas appliances by 35%=	-1.48	-0.57	45%
8	=Reduce electric appliance load by 30% in bakery and deli=	-2.39	-3.07	47%
9	=Skylights=	-0.41	-1.57	48%
10	=PV shading, represented with 100% reflective roof=	3.53	0.66	48%
11	=Changed windows to 'Window_U_0.43_SHGC_0.29'=	-0.05	-0.38	48%
12	=Increased thickness of board insulation from 1.4 inch to 3 inch=	-0.20	-0.27	48%
13	=Increased thickness of board insulation from 5 inch to 10.2 inch (R-30)=	-2.67	-1.10	49%
14	=Decreased infiltration by 50%=	-2.51	-1.64	50%
15	=Increased fan efficiency to 0.7=	-0.10	-0.98	51%
16	=Reduced fan pressure drop to 2.07 on rooftop units (low pressure design)=	0.26	-1.86	52%
17	=Reduced exhaust fan cfm by 50% to represent low flow exhaust hoods=	-0.14	-0.05	52%
18	=Improved water heater thermal efficiency to 0.95 from 0.8 to reflect high efficiency condensing technology =	-0.07	-0.02	52%
19	=Reduced hot water consumption by 40% through use of low flow fixtures in bathrooms and low flow dishwasher=	-0.11	-0.03	52%
20	=Heat recovery from refrigeration to space heat=	-22.95	-5.00	56%
21	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-66.72	-63.87	100%
	Ending EUI:	6.6	0.00	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$144.55
Incremental First Cost:	$70.14*
Net Life Cycle Cost:	-$74.41*

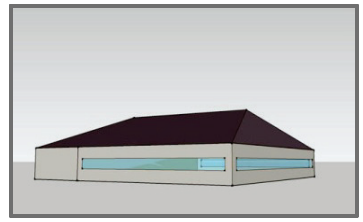
Building Performance Data

Grocery

Square feet:	45,000	Climate Zones						
Avail. Roof:	29,250	15	13	12	10	7	3	16
Total Building Energy Metrics								
kWh/ft^2	Load	17.4	16.7	16.6	16.7	16.8	16.3	15.4
	Minimized Site-kBtu	-2.1	-2.8	-3.0	-3.7	-2.9	-3.3	-5.4
	Minimized TDV	-1.1	-1.0	-0.9	0.0	0.4	0.8	-1.8
kW/bldg (250 hr method)	Load	166	144	133	137	120	115	112
	Minimized Site-kBtu	17	-57	-67	-42	-53	-101	-99
	Minimized TDV	24	-39	-46	-9	-24	-56	-62
Therms/ft^2	Load	0.07	0.20	0.21	0.13	0.10	0.18	0.38
Carbon								
CO_2e (lbs/ft^2)	Minimized Site-kBtu	-0.28	1.02	1.04	-0.41	-0.38	0.40	1.88
	Minimized TDV	0.31	2.04	2.22	1.73	1.55	2.80	3.98
Solar Capacity								
Solar PV (kW)	Minimized Site-kBtu	523	560	560	560	541	560	560
	Minimized TDV	496	510	502	459	450	443	463
Peak Export (kW - bldg)	Minimized Site-kBtu	-352	-363	-362	-390	-367	-404	-401
	Minimized TDV	-331	-324	-317	-313	-298	-308	-323
% of Avail. Roof Used	Minimized Site-kBtu	93%	100%	100%	100%	97%	100%	100%
	Minimized TDV	88%	91%	90%	82%	80%	79%	83%
Building Height Analysis								
Max Floors at ZNE	w/ Site-kBtu Metric	1.1	0.9	0.9	1.0	1.0	0.9	0.8
	w/ TDV Metric	1.1	1.1	1.1	1.2	1.2	1.3	1.2
Max Floors with **Parking PV**	w/ Site-kBtu Metric	2.1	1.7	1.7	1.9	2.0	1.8	1.6
	w/ TDV Metric	2.2	2.2	2.2	2.4	2.4	2.4	2.4
	Park. PV Size (kW)	416	416	416	416	416	416	416

8.11 Sit Down Restaurant

Sit Down Restaurant



Size:	**5,502**	ft^2
Number of Floors:	**1**	floor

		Climate Zones						
		15	**13**	**12**	**10**	**7**	**3**	**16**
Site-kBtu $/ft^2$	**Load:**	183	194	191	178	158	178	225
	Solar:	-87	-82	-82	-85	-85	-82	-87
	Net:	**96**	**113**	**109**	**92**	**73**	**96**	**137**
TDV$/ft^2$ (30yr NPV)	**Load:**	151	138	131	130	112	114	130
	Solar:	-95	-95	-93	-99	-98	-99	-102
	Net:	**55**	**43**	**39**	**31**	**14**	**15**	**28**

Description:

The Sit Down Restaurant model is 5,502 ft^2 on a single floor. A key aspect of this model is that the air change rate in a restaurant is both significant and persistent. Improvements to the HVAC system can accordingly deliver notable energy savings.

The Restaurant model was optimized by reducing duct static pressure, improving stove hood designs to reduce ventilation needs, and confirming that the kitchen was taking supply air from the dining area within the EnergyPlus model.

Since there is also significant refrigeration in a restaurant, many of the same measures were employed as were used in the Grocery, including hot gas defrost and improvements to the walk-in refrigerator insulation. With smart purchasing decisions and appropriate controls, it was assumed that general equipment loads in the kitchen and dining room could be reduced by 30%.

A restaurant is similar to other retail establishments in having notable levels of display lighting that are presently operating at lower efficiency levels, so restaurants are likely to see some of the biggest energy reductions from the further development and installation of high performance LED fixtures. As with retail, the persistent operating hours of a restaurant accentuate the energy benefits of lighting improvements.

A restaurant is also similar to retail in that it often has a steady stream of customers entering and exiting. Consequently, a vestibule can create a notable drop in the entryway infiltration rate. That drop in infiltration resulted in significant energy savings in some of the warmer climates.

Finally, the Restaurant model assumed modest reductions in hot water use through high efficiency fixtures and a high efficiency dishwasher. The savings from these measures were fairly robust given the steady stream of hot water use. As would be expected, the biggest reductions were in Site-kBtu rather than TDV.

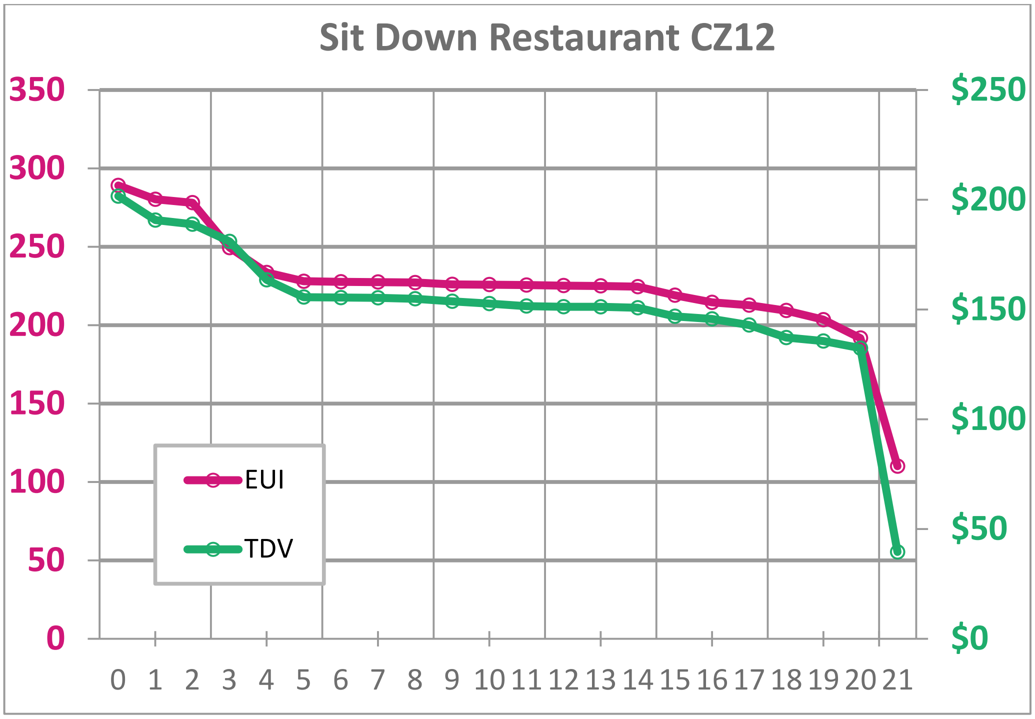
Restaurant Change Log

CZ12
Sacramento

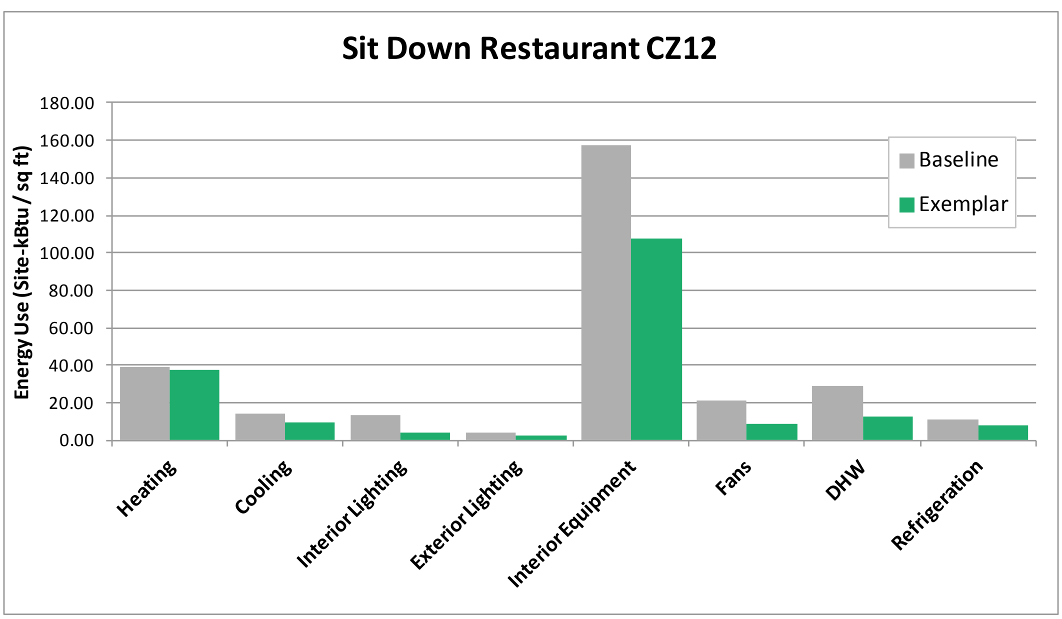
	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	kBtu/ft2 savings	TDV$/ft2 (30yr) savings	TDV$ reduction
	Starting EUI:	287.9	200.69	0%
1	Use 100% LED lighting, results in 73% reduction in dining area and 60% reduction in kitchen	-8.83	-10.91	5%
2	Reduce exterior lighting by 50%	-2.14	-1.86	6%
3	Reduce kitchen gas appliance loads by 35%	-28.70	-7.85	10%
4	Reduce kitchen electric appliance loads by 30%	-15.86	-17.49	19%
5	Reduce dining room electric appliance loads by 30%	-5.60	-7.85	23%
6	Changed defrost type on walk in freezer from electric to hot gas	-0.30	-0.27	23%
7	Used smart defrost system, which results in 35% energy consumption on defrost cycle for walk-in freezer	-0.14	-0.09	23%
8	60% reduction on lighting in walk in freezer and fridge	-0.38	-0.43	23%
9	Increased insulation of walk-in freezer and fridge which results in lower cooling capacity	-1.13	-1.15	24%
10	Added 2'overhangs	-0.13	-1.06	24%
11	Added PV panel shading on roof	-0.32	-1.10	25%
12	Changed exterior wall insulation from R-9 to R-15	-0.31	-0.32	25%
13	Increased R-value of roof insulation from 35.4 to 44.3 (25% increase)	-0.19	-0.04	25%
14	Changed windows to 'Window_U_0.43_SHGC_0.29'	-0.53	-0.43	25%
15	Reduce infiltration by 50%, tight building construction, and vestibule	-5.44	-3.87	27%
16	Improved water heater thermal efficiency to 0.95 from 0.8 to reflect high efficiency condensing technology	-4.56	-1.21	28%
17	Changed fan efficiency from 0.6045 to 0.7	-1.78	-2.78	29%
18	Reduced fan pressure drop to 2.07 (low pressure design)	-3.40	-5.72	32%
19	Reduced exhaust fan cfm by 50% to represent low flow exhaust hoods	-5.88	-1.58	33%
20	Reduced hot water consumption by 40% through use of low flow fixtures in bathrooms and low flow dishwasher	-11.68	-3.26	35%
21	Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)	-81.74	-92.82	81%
	Ending EUI:	108.9	38.60	

Total TDV$ Savings:	-$162.08
Incremental First Cost:	$92.31*
Net Life Cycle Cost:	-$69.78*

Incremental Reduction by Measure



Subsystem Loads



Restaurant Change Log

CZ3
Oakland

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	270.4	173.06	0%
1	=Use 100% LED lighting, results in 73% reduction in dining area and 60% reduction in kitchen=	-8.02	-10.42	6%
2	=Reduce exterior lighting by 50%=	-2.14	-1.86	7%
3	=Reduce kitchen gas appliance loads by 35%=	-28.42	-7.62	11%
4	=Reduce kitchen electric appliance loads by 30%=	-15.33	-17.03	21%
5	=Reduce dining room electric appliance loads by 30%=	-4.78	-7.24	26%
6	=Changed defrost type on walk in freezer from electric to hot gas=	-0.30	-0.28	26%
7	=Used smart defrost system, which results in 35% energy consumption on defrost cycle for walk-in freezer=	-0.16	-0.09	26%
8	=60% reduction on lighting in walk in freezer and fridge=	-0.36	-0.42	26%
9	=Increased insulation of walk-in freezer and fridge which results in lower cooling capacity=	-1.02	-1.05	27%
10	=Added 2'overhangs=	0.60	-0.45	27%
11	=Added PV panel shading on roof=	0.33	-0.43	27%
12	=Changed exterior wall insulation from R-9 to R-15=	-0.17	-0.14	27%
13	=Increased R-value of roof insulation from 35.4 to 44.3 (25% increase)=	-0.23	-0.03	27%
14	=Changed windows to 'Window_U_0.43_SHGC_0.29'=	-0.47	-0.29	27%
15	=Reduce infiltration by 50%, tight building construction, and vestibule=	-4.30	-1.29	28%
16	=Improved water heater thermal efficiency to 0.95 from 0.8 to reflect high efficiency condensing technology =	-5.49	-1.43	29%
17	=Changed fan efficiency from 0.6045 to 0.7=	-1.48	-2.34	30%
18	=Reduced fan pressure drop to 2.07 (low pressure design)=	-0.98	-1.62	31%
19	=Reduced exhaust fan cfm by 50% to represent low flow exhaust hoods=	-5.38	-1.42	32%
20	=Reduced hot water consumption by 40% through use of low flow fixtures in bathrooms and low flow dishwasher=	-14.03	-3.72	34%
21	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-82.12	-99.19	92%
	Ending EUI:	96.1	14.70	

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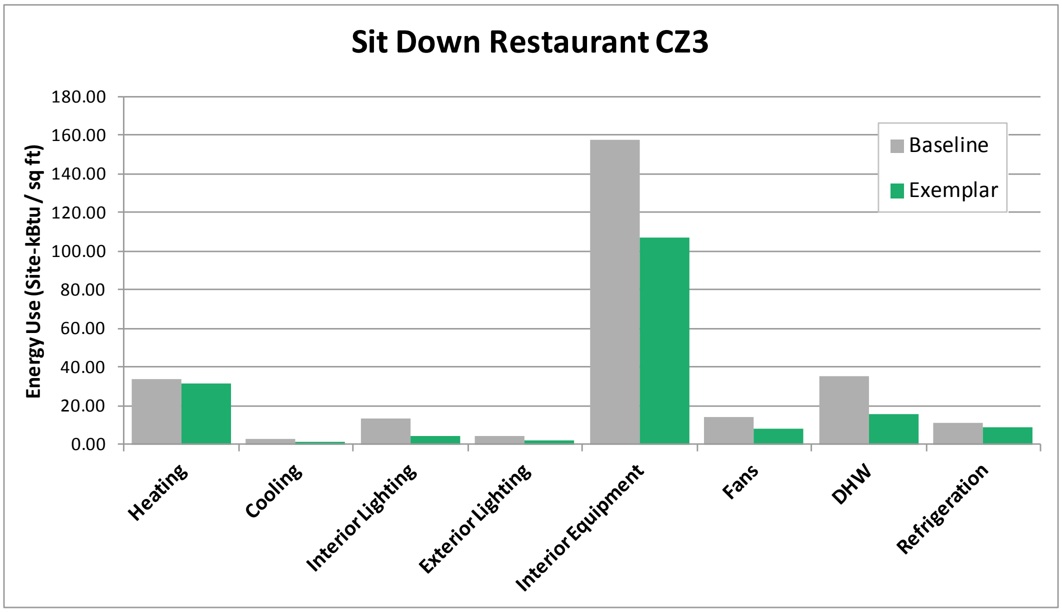
Total TDV$ Savings:	-$158.37
Incremental First Cost:	$88.95*
Net Life Cycle Cost:	-$69.41*

Additional Subsystem Load Charts



Building Performance Data

Sit Down Restaurant

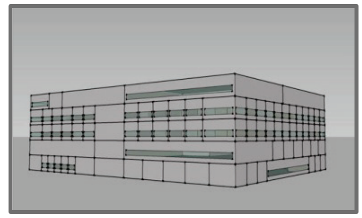
Square feet:	5,502	Climate Zones						
Avail. Roof:	4,402	**15**	**13**	**12**	**10**	**7**	**3**	**16**
Total Building Energy Metrics								
kWh/ft^2	Load	32.2	27.4	25.6	26.5	23.9	23.2	24.1
	Minimized Site-kBtu	6.5	3.3	1.6	1.4	-1.2	-0.9	-1.5
	Minimized TDV	6.5	3.3	1.6	1.4	-1.2	-0.9	-1.5
kW/bldg (250 hr method)	Load	45.4	37.4	34.3	35.3	23.9	22.8	25.6
	Minimized Site-kBtu	21.3	7.3	4.2	8.4	-3.1	-9.8	-6.2
	Minimized TDV	21.3	7.3	4.2	8.4	-3.1	-9.8	-6.2
Therms/ft^2	Load	0.73	1.01	1.03	0.87	0.76	0.99	1.42
Carbon								
CO_2e (lbs/ft^2)	Minimized Site-kBtu	13.44	15.28	14.56	12.34	9.39	12.53	17.93
	Minimized TDV	13.44	15.28	14.56	12.34	9.39	12.53	17.93
Solar Capacity								
Solar PV (kW)	Minimized Site-kBtu	84.3	84.3	84.3	84.3	84.3	84.3	84.3
	Minimized TDV	84.3	84.3	84.3	84.3	84.3	84.3	84.3
Peak Export (kW - bldg)	Minimized Site-kBtu	-59.1	-58.1	-58.3	-60.7	-60.6	-65.5	-64.3
	Minimized TDV	-59.1	-58.1	-58.3	-60.7	-60.6	-65.5	-64.3
% of Avail. Roof Used	Minimized Site-kBtu	100%	100%	100%	100%	100%	100%	100%
	Minimized TDV	100%	100%	100%	100%	100%	100%	100%
Building Height Analysis								
Max Floors at ZNE	w/ Site-kBtu Metric	0.5	0.4	0.4	0.5	0.5	0.5	0.4
	w/ TDV Metric	0.6	0.7	0.7	0.8	0.9	0.9	0.8
Max Floors with **Parking PV**	w/ Site-kBtu Metric	1.7	1.5	1.5	1.7	1.9	1.6	1.4
	w/ TDV Metric	2.3	2.4	2.5	2.6	3.0	2.9	2.8
	Park. PV Size (kW)	162	162	162	162	162	162	162

8.12 Hospital

Hospital

Size: **241,410** ft^2

Number of Floors: **5** floors *+basement*



		Climate Zones						
		15	**13**	**12**	**10**	**7**	**3**	**16**
Site-kBtu /ft^2	**Load:**	70.1	69.3	68.4	68.6	68.8	67.6	67.6
	Solar:	-14.5	-13.6	-13.6	-14.2	-14.2	-13.7	-14.5
	Net:	**55.7**	**55.7**	**54.8**	**54.4**	**54.6**	**53.9**	**53.1**
TDV$/ft^2 (30yr NPV)	**Load:**	63.37	61.93	60.98	61.70	62.88	60.28	59.52
	Solar:	-15.86	-15.86	-15.47	-16.43	-16.38	-16.53	-16.99
	Net:	**47.51**	**46.07**	**45.51**	**45.27**	**46.50**	**43.75**	**42.53**

Description:

The Hospital is a 5-story 241,400 square foot building. The space types include Emergency Room, Office, Lobby, Nurse Station, Operating Room, Patient Room, Physical Therapy, Lab, Radiology, Dining, Kitchen, and Corridors.

The Hospital has high equipment loads due to the specialized equipment required to operate a healthcare facility. Due to the complexity of this equipment and the fact that by 2020 this equipment will be more sophisticated and is ever-changing, the starting equipment loads have not been altered in the model.

Energy efficient LED lighting was modeled as well as occupancy sensors to control lighting during unoccupied hours. Some envelope/passive improvements were implemented but with very minimal effect due to the fact that the Hospital model is internal load driven.

The greatest improvement in energy usage was achieved through changes in the HVAC system. The exemplar model utilizes an active chilled beam system with a dedicated outside air system (DOAS) that includes air-to-air heat recovery.

The role of the DOAS is to supply the minimum required ventilation air to the building. The chilled beams more efficiently handle the high sensible cooling load in the Hospital than the VAV reheat system. The main energy improvement with this system is that natural gas consumption for heating is almost completely negated by eliminating reheat at the zone level and greatly reducing heating at the air handling unit (AHU) through the use of heat recovery.

Adjustments for other climate zones are largely identical to climate zone 12 due to the dominance of internal loads in the Hospital.

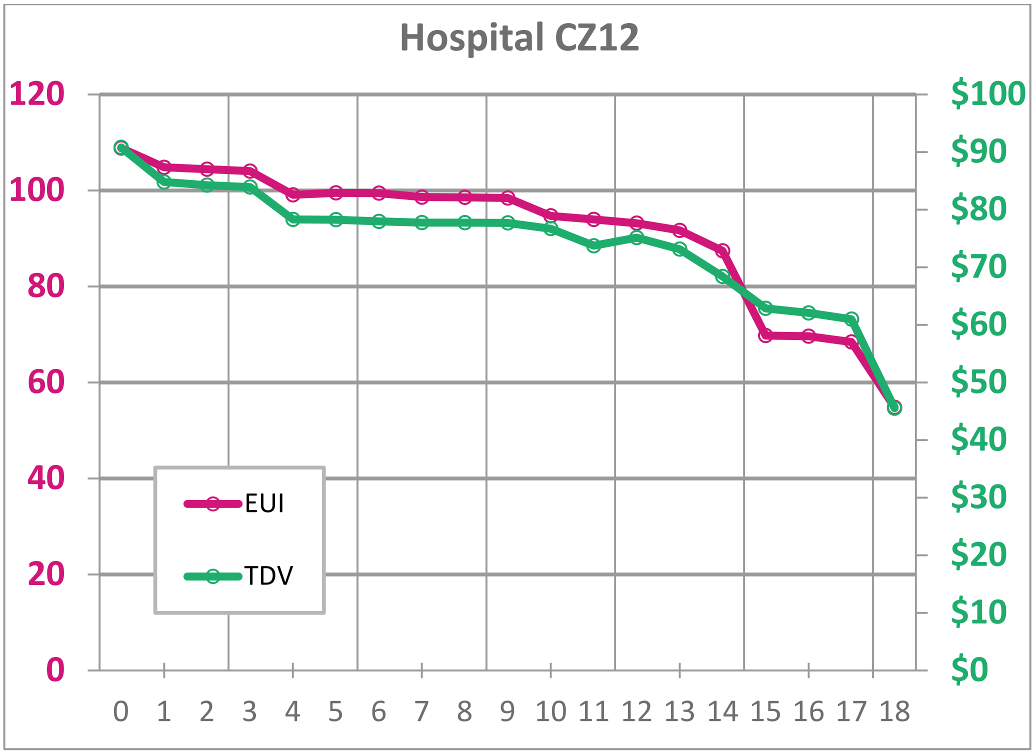
Hospital Change Log

CZ12
Sacramento

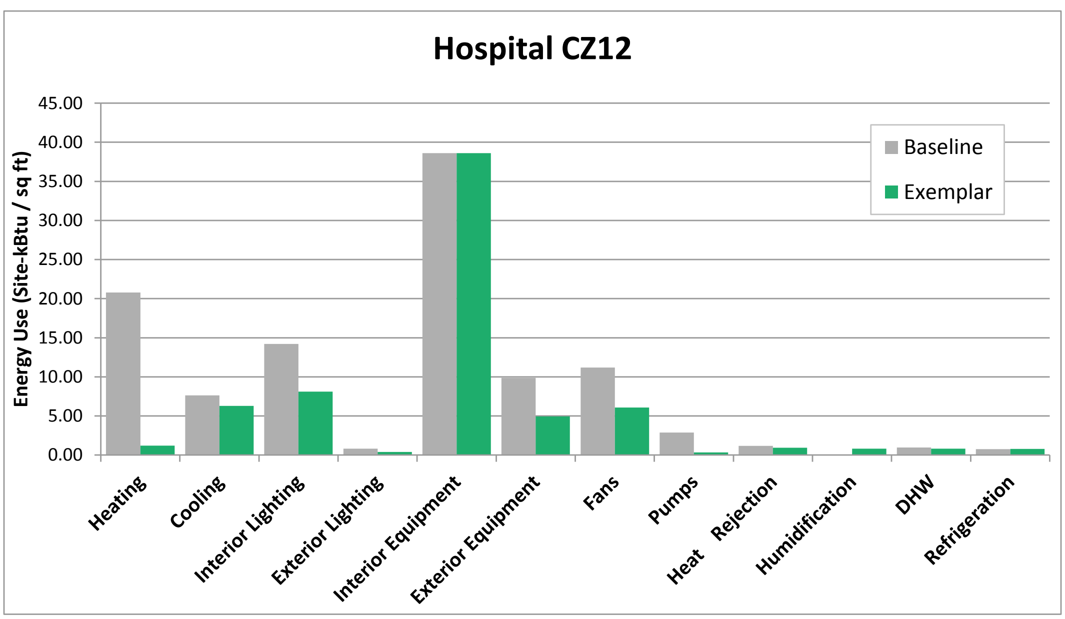
	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	108.8	90.80	0%
1	Use 100% LED lighting at 220 LM/W, 60% reduction	-4.02	-6.01	7%
2	Use occ sensors in Office, Lobby, Clinic, OR	-0.39	-0.55	7%
3	Reduce exterior lights by 50% to represent all LED lighting	-0.40	-0.33	8%
4	Reduced elevator design load by 50% and reduced elev fan and lights by 60%	-4.94	-5.62	14%
5	Window shades on all facades, 2'	0.42	-0.04	14%
6	Added PV shading on roof	-0.06	-0.31	14%
7	Changed windows from 'Window_U_0.62_SHGC_0.25' to 'Window_U_0.35_SHGC_0.35'	-0.84	-0.20	14%
8	Reduced infiltration rate by 40%	-0.04	-0.01	14%
9	Increased wall insulation by 25%	-0.14	-0.04	14%
10	Changed boiler efficiency from 0.81 to 0.97 (condensing boiler)	-3.70	-0.99	16%
11	Changed fan efficiency from 0.6045 to 0.7	-0.76	-2.99	19%
12	Improved water heater thermal efficiency to 0.97 from 0.8 to reflect high efficiency technology currently on market	-0.77	1.42	17%
13	Improved COP of chillers from 5.17 to 6.5	-1.52	-2.00	19%
14	Reduced fan pressure drop from 5.58 in wc to 3.0 in wc (through use of low-pressure design)	-4.25	-4.76	25%
15	Created new HVAC system: chilled beams, DOAS with heat recovery, 55 F supply air temp	-17.64	-5.52	31%
16	Fixed the chilled water temperature to be 59 F	-0.14	-0.80	32%
17	Right sized chilled water plant (0.5 sizing on each chiller, optimum part load is at 0.5)	-1.19	-1.07	33%
18	Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)	-13.62	-15.47	50%
	Ending EUI:	54.8	45.51	

Total TDV$ Savings:	-$45.29
Incremental First Cost:	$35.93*
Net Life Cycle Cost:	-$9.35*

Incremental Reduction by Measure



Subsystem Loads



Hospital Change Log

CZ3
Oakland

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	107.2	87.34	0%
1	=Use 100% LED lighting at 220 LM/W, 60% reduction=	-4.06	-5.33	6%
2	=Use occ sensors in Office, Lobby, Clinic, OR=	-0.38	-0.54	7%
3	=Reduce exterior lights by 50% to represent all LED lighting=	-0.40	-0.33	7%
4	=Reduced elevator design load by 50% and reduced elev fan and lights by 60%=	-4.94	-5.61	14%
5	=Window shades on all facades, 2'=	0.52	0.05	13%
6	=Added PV shading on roof=	0.11	-0.14	14%
7	=Changed windows from 'Window_U_0.62_SHGC_0.25' to 'Window_U_0.35_SHGC_0.35'=	-0.96	-0.21	14%
8	=Reduced infiltration rate by 40%=	-0.10	-0.02	14%
9	=Increased wall insulation by 25%=	-0.01	-0.01	14%
10	=Changed boiler efficiency from 0.81 to 0.97 (condensing boiler)=	-3.59	-0.95	15%
11	=Changed fan efficiency from 0.6045 to 0.7=	-1.26	-1.47	17%
12	=Improved water heater thermal efficiency to 0.97 from 0.8 to reflect high efficiency technology currently on market=	-0.21	-0.05	17%
13	=Improved COP of chillers from 5.17 to 6.5=	-0.41	-0.47	17%
14	=Reduced fan pressure drop from 5.58 in wc to 3.0 in wc (through use of low-pressure design)=	-4.18	-4.72	23%
15	=Created new HVAC system: chilled beams, DOAS with heat recovery, 55 F supply air temp=	-18.96	-6.57	30%
16	=Fixed the chilled water temperature to be 59 F=	-0.81	-0.71	31%
17	=Right sized chilled water plant (0.5 sizing on each chiller, optimum part load is at 0.5)=	0.01	0.02	31%
18	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-13.69	-16.53	50%
	Ending EUI:	53.9	43.75	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$43.59
Incremental First Cost:	$34.00*
Net Life Cycle Cost:	-$9.58*

Hospital Change Log

CZ15
Sacramento

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	112.7	99.68	0%
1	=Use 100% LED lighting at 220 LM/W, 60% reduction=	-5.09	-6.36	6%
2	=Use occ sensors in Office, Lobby, Clinic, OR=	-0.44	-0.57	7%
3	=Reduce exterior lights by 50% to represent all LED lighting=	-0.40	-0.33	7%
4	=Reduced elevator design load by 50% and reduced elev fan and lights by 60%=	-4.94	-5.61	13%
5	=Window shades on all facades, 2'=	-0.24	-0.42	13%
6	=Added PV shading on roof=	-0.30	-0.35	14%
7	=Changed windows from 'Window_U_0.62_SHGC_0.25' to 'Window_U_0.35_SHGC_0.35'=	-0.59	-0.34	14%
8	=Reduced infiltration rate by 40%=	-0.02	-0.02	14%
9	=Increased wall insulation by 25%=	-0.04	-0.10	14%
10	=Changed boiler efficiency from 0.81 to 0.97 (condensing boiler)=	-2.52	-0.68	15%
11	=Changed fan efficiency from 0.6045 to 0.7=	-1.31	-1.56	16%
12	=Improved water heater thermal efficiency to 0.97 from 0.8 to reflect high efficiency technology currently on market=	-0.14	-0.04	16%
13	=Improved COP of chillers from 5.17 to 6.5=	-0.81	-0.94	17%
14	=Reduced fan pressure drop from 5.58 in wc to 3.0 in wc (through use of low-pressure design)=	-4.34	-4.97	22%
15	=Created new HVAC system: chilled beams, DOAS with heat recovery, 55 F supply air temp=	-19.22	-11.73	34%
16	=Fixed the chilled water temperature to be 59 F=	-0.70	-1.04	35%
17	=Right sized chilled water plant (0.5 sizing on each chiller, optimum part load is at 0.5)=	-1.46	-1.26	36%
18	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-14.50	-15.86	52%
	Ending EUI:	55.7	47.51	

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Total TDV$ Savings:	-$52.17
Incremental First Cost:	$35.28*
Net Life Cycle Cost:	-$16.90*

Building Performance Data

Hospital

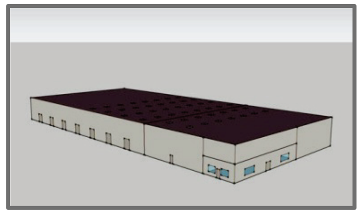
Square feet:	241,410	Climate Zones						
Avail. Roof:	32,188	15	13	12	10	7	3	16
Total Building Energy Metrics								
kWh/ft^2	Load	17.0	16.5	16.3	16.5	16.6	16.0	15.9
	Minimized Site-kBtu	12.8	12.5	12.3	12.3	12.4	12.0	11.7
	Minimized TDV	12.8	12.5	12.3	12.3	12.4	12.0	11.7
kW/bldg (250 hr method)	Load	604	583	570	575	570	547	551
	Minimized Site-kBtu	428	362	349	378	374	309	318
	Minimized TDV	428	362	349	378	374	309	318
Therms/ft^2	Load	0.12	0.13	0.13	0.12	0.12	0.13	0.13
Carbon								
CO_2e (lbs/ft^2)	Minimized Site-kBtu	9.03	9.01	8.86	8.82	8.85	8.71	8.56
	Minimized TDV	9.03	9.01	8.86	8.82	8.85	8.71	8.56
Solar Capacity								
Solar PV (kW)	Minimized Site-kBtu	617	617	617	617	617	617	617
	Minimized TDV	617	617	617	617	617	617	617
Peak Export (kW - bldg)	Minimized Site-kBtu	-146	-113	-118	-163	-165	-182	-165
	Minimized TDV	-146	-113	-118	-163	-165	-182	-165
% of Avail. Roof Used	Minimized Site-kBtu	100%	100%	100%	100%	100%	100%	100%
	Minimized TDV	100%	100%	100%	100%	100%	100%	100%
Building Height Analysis								
Max Floors at ZNE	w/ Site-kBtu Metric	1.2	1.2	1.2	1.2	1.2	1.2	1.3
	w/ TDV Metric	1.5	1.5	1.5	1.6	1.6	1.6	1.7
Max Floors with **Parking PV**	w/ Site-kBtu Metric	2.5	2.3	2.4	2.4	2.4	2.4	2.6
	w/ TDV Metric	3.0	3.0	3.0	3.1	3.1	3.2	3.4
	Park. PV Size (kW)	463	463	463	463	463	463	463

CHP w/ Parking PV	**15**	**13**	**12**	**10**	**7**	**3**	**16**
CHP system size (kW)	153	192	187	168	170	202	140
Site-kBtu/ft^2	47.1	49.3	48.4	47.2	47.3	48.0	44.7
TDV$/ft^2 (30yr NPV)	22.4	20.6	20.0	19.9	20.8	17.9	16.3

CHP sized to meet 30th percentile electric load after PV. CHP tracks the thermal load to maximize efficiency.

8.13 Warehouse

Warehouse



Size:	**49,495**	ft^2
Number of Floors:	**1**	floor

		Climate Zones						
		15	**13**	**12**	**10**	**7**	**3**	**16**
Site-kBtu $/ft^2$	**Load:**	8.2	9.8	9.4	8.1	6.4	8.7	13.1
	Solar:	-8.2	-9.8	-9.4	-8.1	-6.4	-8.7	-13.1
	Net:	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
TDV\$/ft^2 (30yr NPV)	**Load:**	8.70	7.81	7.08	6.90	6.05	6.58	8.30
	Solar:	-8.70	-7.81	-7.08	-6.90	-6.05	-6.58	-8.30
	Net:	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Description:

The non-refrigerated Warehouse model has 3 zones: 1) Small office, 2) Bulk storage, and 3) Fine storage. All 3 zones are heated and only the fine storage and office zones are cooled. The original model includes 46 skylights (1.5% glazing area) and there are only 4 windows in the office.

The non-refrigerated Warehouse can achieve ZNE with the help of PV panels. The Warehouse model has 7 energy end uses. Depending on the climate zone, the largest energy end uses vary. But interior lighting is a significant part of the total energy across all climate zones.

By 2020, LEDs will be widely used in commercial buildings and could likely provide 220 lumens/watt. Based on this assumption, interior lighting energy use was reduced by 60%. This resulted in about 15% reduction in Site-kBtu and about 20% reduction in TDV for all climate zones.

To further reduce internal loads, the plug loads in the office area of the Warehouse were reduced to 0.5 W/ft^2 and a nighttime plug load management system was implemented. The interior equipment in the storage areas was left unchanged due to uncertainty in potential improvements.

An analysis was completed on the tradeoffs between PV and skylights for the use of roof space. A few dyamic “forces” are at play: 1) rapidly improving LED efficiency diminishes the energy “value” of skylights, and 2) improving PV efficiency increases the energy “value” of empty roof space. The analysis showed that installing PV in the space that would otherwise be used for skylights would produce three times as much renewable energy as the energy that would be saved by installing skylights. Although the skylights remained in the prototype, this will be an important design consideration in some buildings with restricted roof areas.

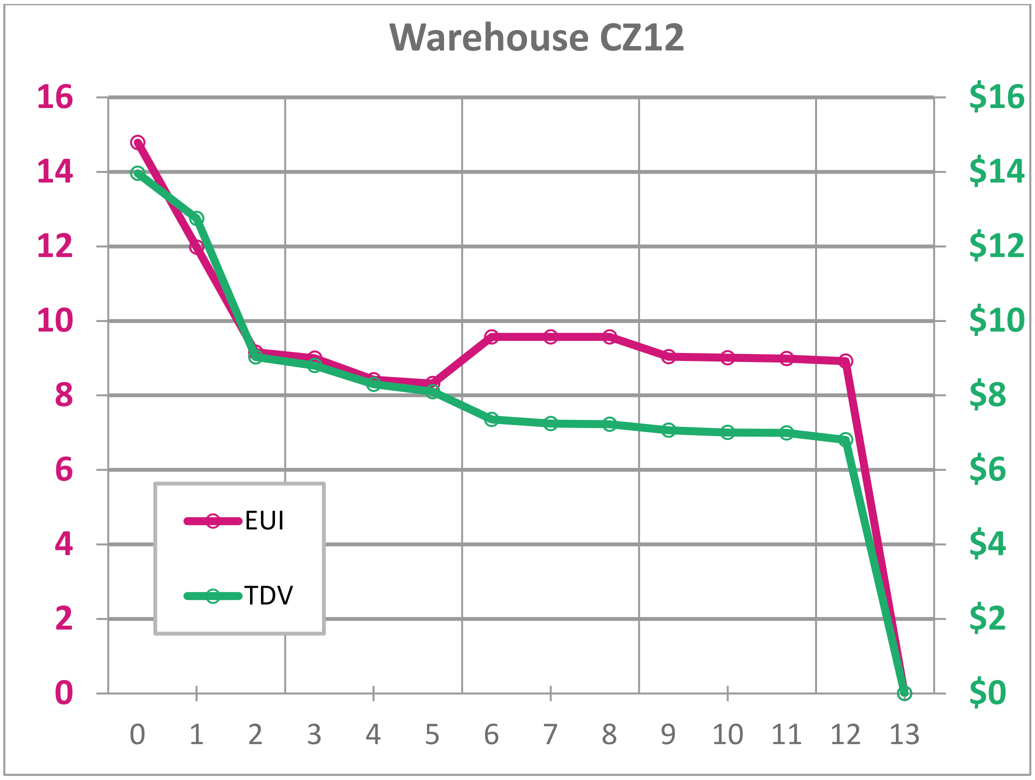
Warehouse Change Log

CZ12
Sacramento

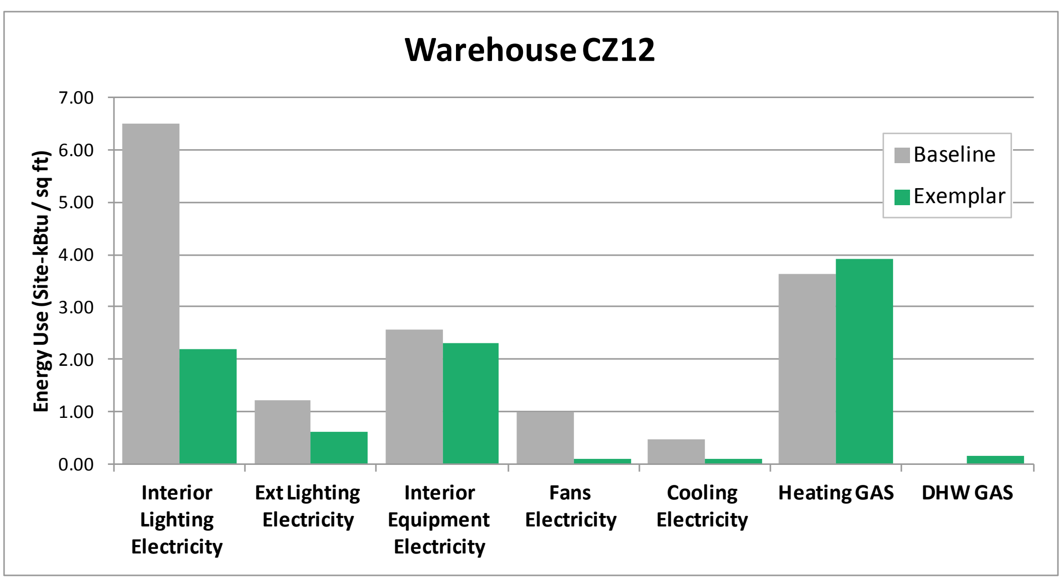
	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	15.3	14.23	0%
1	Title 24 2013 Envelope Changes	-2.81	-1.21	9%
2	60% Reduction in LPD	-2.82	-3.72	35%
3	Lighting Sensor Schedule for Storage (F&B)	-0.16	-0.23	36%
4	50% Reduction in Exterior Lighting	-0.58	-0.51	40%
5	Reduced Office Plug Load to 0.5 W/sf	-0.10	-0.20	41%
6	Roof Reflectance to 0.9	1.25	-0.74	46%
7	DHW electricity to gas (0.97 efficiency)	0.00	-0.11	47%
8	DX Coil COP to 4	0.00	-0.02	47%
9	Gas Furnace Efficiency to 0.92	-0.53	-0.16	48%
10	Fan Efficiency to 0.7	-0.03	-0.06	49%
11	Economizer in Office	-0.02	-0.01	49%
12	Natural Ventilation	-0.07	-0.18	50%
13	Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)	-9.42	-7.08	100%
	Ending EUI:	0.0	0.00	

Total 30 yr TDV$ Savings:	-$14.23
Incremental First Cost:	$5.66*
Net Life Cycle Cost:	-$8.58*

Incremental Reduction by Measure



Subsystem Loads



Warehouse Change Log

CZ3
Oakland

	Strategy	kBtu/ft2 savings	TDV$/ft2 (30yr) savings	TDV$ reduction
	Starting EUI:	16.1	12.83	0%
1	=Title 24 2013 Envelope Changes=	-3.51	-1.50	12%
2	= 60% Reduction in LPD=	-2.47	-3.40	38%
3	=Lighting Sensor Schedule for Storage (F&B)=	-0.15	-0.22	40%
4	=50% Reduction in Exterior Lighting=	-0.58	-0.50	44%
5	=Reduced Office Plug Load to 0.5 W/sf=	-0.01	-0.14	45%
6	N/A	0.00	0.00	46%
7	=DHW electricity to gas (0.97 efficiency)=	0.01	-0.14	46%
8	=DX Coil COP to 4=	0.00	0.00	46%
9	=Gas Furnace Efficiency to 0.92=	-0.47	-0.13	47%
10	=Fan Efficiency to 0.7=	-0.02	-0.05	47%
11	=Economizer in Office=	-0.16	-0.05	48%
12	=Natural Ventilation=	-0.05	-0.11	49%
13	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-8.69	-6.58	100%
	Ending EUI:	0.0	0.00	

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Total TDV$ Savings:	-$12.83
Incremental First Cost:	$5.80
Net Life Cycle Cost:	-$7.03

Warehouse Change Log

CZ10 Riverside

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	14.2	13.96	0%
1	=Title 24 2013 Envelope Changes=	-2.20	-1.12	8%
2	= 60% Reduction in LPD=	-2.99	-3.74	35%
3	=Lighting Sensor Schedule for Storage (F&B)=	-0.18	-0.24	37%
4	=50% Reduction in Exterior Lighting=	-0.58	-0.50	40%
5	=Reduced Office Plug Load to 0.5 W/sf=	-0.10	-0.20	42%
6	=Roof Reflectance to 0.9=	0.38	-0.76	47%
7	=DHW electricity to gas (0.97 efficiency)=	0.00	-0.12	48%
8	=DX Coil COP to 4=	-0.01	-0.03	48%
9	=Gas Furnace Efficiency to 0.92=	-0.34	-0.10	49%
10	=Fan Efficiency to 0.7=	-0.02	-0.06	49%
11	=Economizer in Office=	-0.03	-0.01	49%
12	=Natural Ventilation=	-0.07	-0.17	51%
13	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-8.10	-6.90	100%
	Ending EUI:	0.0	0.00	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$13.96
Incremental First Cost:	$6.53*
Net Life Cycle Cost:	-$7.43*

Warehouse Change Log

CZ15
Palm Springs

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	17.0	19.07	0%
1	=Title 24 2013 Envelope Changes=	-2.83	-2.80	15%
2	= 60% Reduction in LPD=	-3.68	-4.20	37%
3	=Lighting Sensor Schedule for Storage (F&B)=	-0.22	-0.27	38%
4	=50% Reduction in Exterior Lighting=	-0.58	-0.51	41%
5	=Reduced Office Plug Load to 0.5 W/sf=	-0.18	-0.23	42%
6	=Roof Reflectance to 0.9=	-0.69	-1.40	49%
7	=DHW electricity to gas (0.97 efficiency)=	0.01	-0.09	50%
8	=DX Coil COP to 4=	-0.17	-0.27	51%
9	=Gas Furnace Efficiency to 0.92=	-0.09	-0.03	51%
10	=Fan Efficiency to 0.7=	-0.13	-0.17	52%
11	=Economizer in Office=	-0.01	-0.01	52%
12	=Natural Ventilation=	-0.28	-0.39	54%
13	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-8.16	-8.70	100%
	Ending EUI:	0.0	0.00	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$19.07
Incremental First Cost:	$5.73*
Net Life Cycle Cost:	-$13.35*

Warehouse Change Log

CZ16
Blue Canyon

	Strategy *(Baseline is 90.1-2010 Unless Noted Otherwise)*	**kBtu**/ft2 savings	**TDV$**/ft2 (30yr) savings	**TDV$** reduction
	Starting EUI:	19.4	13.98	0%
1	=Title 24 2013 Envelope Changes=	-2.42	-0.44	3%
2	= 60% Reduction in LPD=	-1.92	-3.58	29%
3	=Lighting Sensor Schedule for Storage (F&B)=	-0.12	-0.23	30%
4	=50% Reduction in Exterior Lighting=	-0.58	-0.50	34%
5	=Reduced Office Plug Load to 0.5 W/sf=	-0.06	-0.19	35%
6	N/A	0.00	0.00	35%
7	=DHW electricity to gas (0.97 efficiency)=	0.01	-0.02	35%
8	=DX Coil COP to 4=	-0.01	-0.02	36%
9	=Gas Furnace Efficiency to 0.92=	-1.03	-0.31	38%
10	=Fan Efficiency to 0.7=	-0.05	-0.12	39%
11	=Economizer in Office=	-0.02	-0.02	39%
12	=Natural Ventilation=	-0.12	-0.28	41%
13	=Rooftop PV (see “Solar PV (kW)” in “Building Performance Data” table for PV system sizes)=	-13.05	-8.30	100%
	Ending EUI:	0.0	0.00	

"=Text=" means same attributes as CZ12

Total TDV$ Savings:	-$13.99
Incremental First Cost:	$5.83
Net Life Cycle Cost:	-$8.16

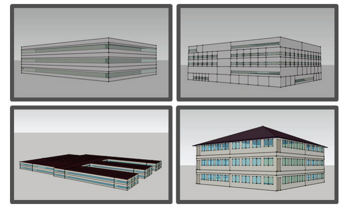
Building Performance Data

Warehouse

		Climate Zones						
Square feet:	**49,495**							
Avail. Roof:	**34,647**	**15**	**13**	**12**	**10**	**7**	**3**	**16**
Total Building Energy Metrics								
kWh/ft^2	Load	2.1	1.7	1.6	1.6	1.5	1.5	1.6
	Minimized Site-kBtu	-0.3	-1.2	-1.2	-0.8	-0.3	-1.0	-2.2
	Minimized TDV	-0.2	-0.3	-0.2	-0.1	0.0	-0.1	-0.5
kW/bldg (250 hr method)	Load	25.3	18.4	14.1	15.3	11.8	11.2	14.6
	Minimized Site-kBtu	5.2	-14.1	-17.1	-7.6	-6.4	-19.7	-28.2
	Minimized TDV	5.6	-4.4	-6.5	-1.6	-3.0	-8.1	-9.3
Therms/ft^2	Load	0.01	0.04	0.04	0.03	0.01	0.03	0.08
Carbon								
CO_2e (lbs/ft^2)	Minimized Site-kBtu	-0.04	-0.16	-0.16	-0.10	-0.05	-0.13	-0.30
	Minimized TDV	0.00	0.35	0.39	0.26	0.16	0.42	0.69
Solar Capacity								
Solar PV (kW)	Minimized Site-kBtu	71	91	87	72	57	80	114
	Minimized TDV	69	64	58	53	46	50	63
Peak Export (kW - bldg)	Minimized Site-kBtu	-55.5	-73.0	-69.9	-57.5	-45.5	-65.6	-91.1
	Minimized TDV	-54.1	-50.7	-45.9	-42.1	-36.8	-40.7	-50.4
% of Avail. Roof Used	Minimized Site-kBtu	11%	14%	13%	11%	9%	12%	17%
	Minimized TDV	10%	10%	9%	8%	7%	8%	10%
Building Height Analysis								
Max Floors at ZNE	w/ Site-kBtu Metric	9.4	7.3	7.6	9.2	11.6	8.3	5.8
	w/ TDV Metric	9.6	10.4	11.5	12.5	14.3	13.2	10.5
Max Floors with **Parking PV**	w/ Site-kBtu Metric	11.6	8.9	9.3	11.3	14.2	10.1	7.2
	w/ TDV Metric	11.9	12.8	14.1	15.3	17.4	16.1	12.9
	Park. PV Size (kW)	116	116	116	116	116	116	116

8.14 College

College



Size:	**N/A**	ft^2
Number of Floors:	**N/A**	floor

Climate Zones

		15	13	12	10	7	3	16
Site-kBtu $/ft^2$	**Load:**	44	43	43	41	37	40	47
	Solar:	-29	-27	-26	-26	-25	-25	-28
	Net:	**15**	**17**	**16**	**15**	**13**	**15**	**19**
TDV\$/ft² (30yr NPV)	**Load:**	41	37	36	35	32	31	34
	Solar:	-31	-28	-27	-28	-26	-26	-27
	Net:	**10**	**9**	**8**	**8**	**6**	**6**	**7**

Description:

In general, a college is a miniature village unto itself, consisting of multiple building types including school, office, residential, restaurant, and medical services. Consequently, the College results are a weighted average of other prototypes.

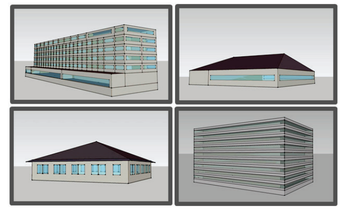
Although not analyzed in this research, colleges are an ideal platform to implement wider building-to-building energy sharing strategies, such as aggregated solar installations, community ground source heat pump loops, and combined heat and power systems.

The College energy data is used to complete the statewide energy use analyses discussed in Chapter 6.

College Source Prototype Distribution	
Secondary School	30%
Medium Office	20%
Multi-family Low-rise	30%
Sit-down Restaurant	10%
Hospital	10%

8.15 Other Commercial

Other Commercial



Size:	**N/A** ft^2
Number of Floors:	**N/A** floor

Climate Zones

		15	13	12	10	7	3	16
Site-kBtu /ft^2	**Load:**	33	34	34	32	30	32	38
	Solar:	-21	-21	-21	-20	-19	-20	-23
	Net:	**12**	**13**	**13**	**12**	**10**	**12**	**16**
TDV/ft^2 (30yr NPV)	**Load:**	32	29	28	28	26	25	29
	Solar:	-22	-21	-20	-21	-19	-19	-21
	Net:	**10**	**8**	**8**	**7**	**7**	**6**	**8**

Description:

The Other Commercial EUI estimates are a weighted average, on a construction volume basis, of the other commercial building EUIs. Other Commercial energy data is used to complete the statewide energy use analyses.

Other Commercial Source Prototype Distribution	
Large Office	22%
Strip Mall	21%
Warehouse	21%
Secondary School	9%
Medium Office	7%
Hospital	6%
Grocery	6%
Hotel	5%
Restaurant	3%

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