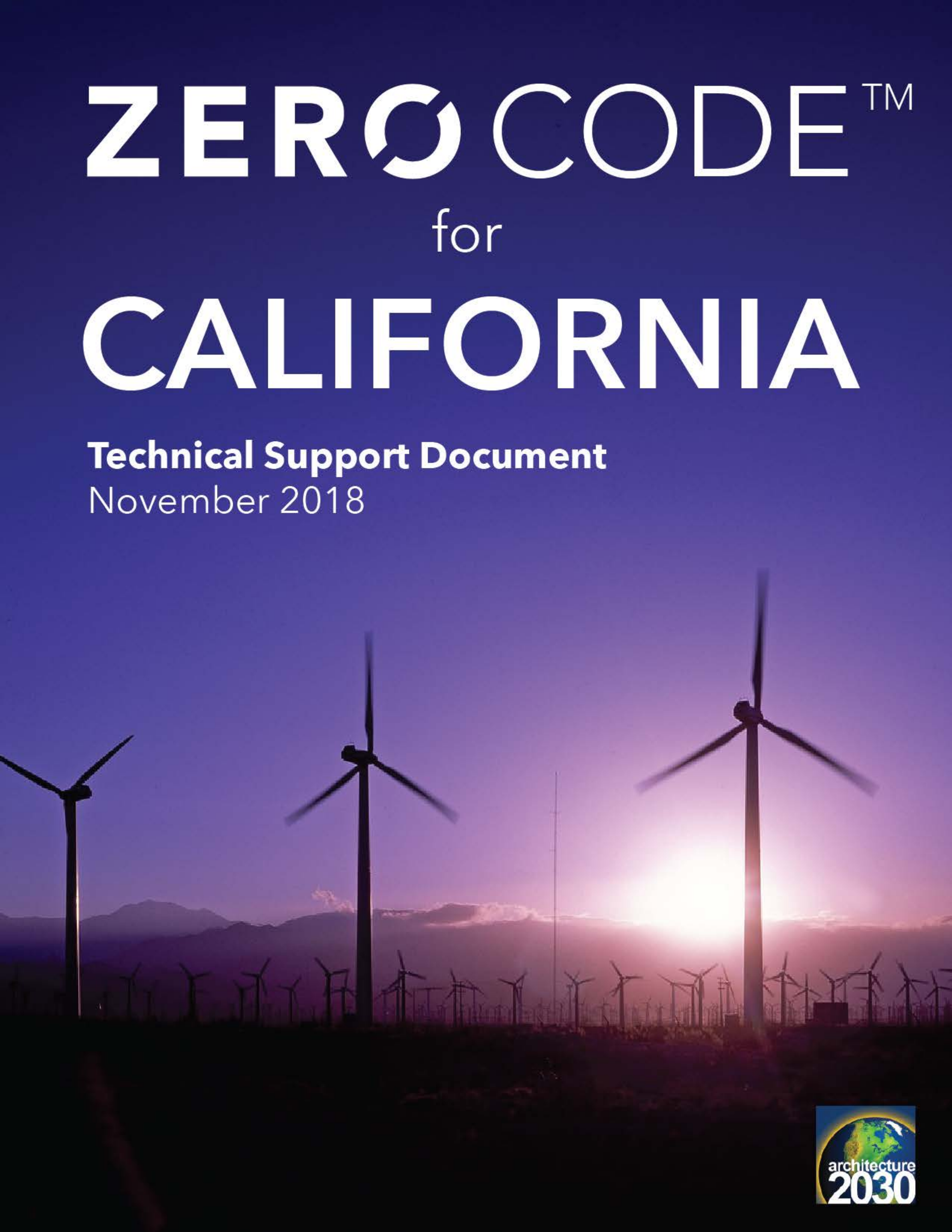
ZERO CODE™
for
CALIFORNIA

Technical Support Document
November 2018



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ZERO CODE™

Technical Support Document on the ZERO Code for California

This technical support document provides background and technical information in support of the ZERO Code for California (ZERO Code$_{ca}$) developed by Architecture 2030.

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The ZERO Code for California standard is presented solely as a guide, which may be modified and consequently adopted as such by appropriate legal jurisdictions. In utilizing the standard or Energy Calculator, practitioners must research and ensure compliance with ordinances and codes applicable in their jurisdictions.

Architecture 2030, November 26, 2018

architecture 2030 ZEROCODE™

Technical Support Document on the ZERO Code for California

Charles Eley, FAIA, PE, Architecture 2030 Senior Fellow

Revision 9, November 26, 2018 (incorporates revisions to the TDS data)

This technical support document provides background and technical information in support of the ZERO Code for California (ZERO Code$_{ca}$) developed by Architecture 2030.

BACKGROUND

Architecture 2030 released the national and international ZERO Code in April 2018. This code applies to commercial, institutional and mid- to high-rise residential buildings. It does not apply to low-rise residential buildings. Energy efficiency is achieved by referencing and requiring compliance with ASHRAE Standard 90.1-2016. Remaining building energy must be offset by either on-site or off-site renewable energy systems. See Figure 1.

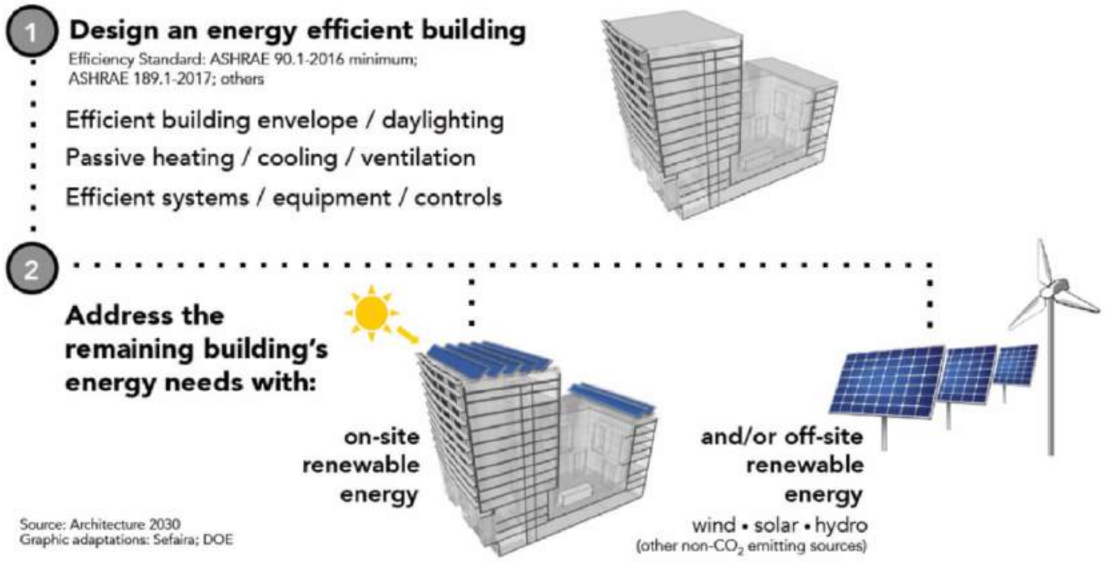

Figure 1 – ZERO Code Concept

The ZERO Code encourages but does not require on-site renewable energy. It recognizes various methods to procure off-site renewable energy, such as community solar and virtual power purchase agreements, but discounts these options to account for the added risk and uncertainty, compared to on-site systems.

The national and international ZERO Code and the technical support document for off-site procurement are available at www.zero-code.org. This site also has a *ZERO Code Energy Calculator* that estimates the roof-top renewable energy potential and compares this to the estimated building energy use to determine how much renewable energy must be procured in order to comply with the ZERO Code.

California is a leader in both energy efficiency and renewable energy. Opportunities exist in the state to both improve the energy efficiency of buildings and more directly address the emissions that cause climate change. California has been enforcing its own energy efficiency standards since the mid-1970's and these standards are well understood and supported. The California grid is cleaner than the United States average and already incorporates a significant amount of renewable energy. The state is on target to meet its 33% RPS (renewable portfolio standard) goal by 2020 and its 50% RPS goal by 2026.[1]

During the swing seasons when system loads are low and solar energy is abundant, California is already curtailing the output of utility scale solar systems. Matching renewable energy production with energy needs is a challenge and will become more important as additional renewable energy (especially solar) is added to the energy mix. The ZERO Code for California (ZERO Code$_{ca}$) directly focuses on the time pattern of energy use and carbon emissions and encourages buildings to better match renewable energy production with building loads.

MINIMUM ENERGY EFFICIENCY

The 2019 California Building Energy Efficiency Standards is established as the minimum building energy efficiency for the ZERO Code$_{ca}$. Some have suggested that the ZERO Code$_{ca}$ should require more efficiency than code minimum, but code minimum is recommended for several reasons:

- Both prescriptive and performance compliance paths are available. Were we to set the level of energy efficiency to be say 20% greater than code minimum,

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[1] These goals are established by Senate Bill 100 was signed by Governor Brown in September 2018.

then a performance analysis would always be necessary and the prescriptive approach would not be available.

- Using the prescriptive information found on Architecture 2030's ZERO Code website, designers, contractors and building owners can get a quick estimate of the source energy intensity and carbon footprint of their building and a good idea of the renewable energy needed to achieve zero energy/emissions using either the prescriptive or performance path.
- The process for local government adoption and enforcement is easier since no changes are being made to the California Building Energy Efficiency Standards. The ZERO Code$_{ca}$ simply adds a requirement for renewable energy.

The ZERO Code$_{ca}$ encourages building energy use and carbon emissions to be lower than code minimum when the performance approach is used. Designers and builders will seek the least expensive way to meet the code. The fundamental choices are to (1) reduce emissions by designing a more energy efficient building, (2) shift building loads to periods when solar is plentiful, (3) install on-site renewable energy systems, and/or (4) procure off-site renewable energy in addition to what is already being purchased by California electric utilities. Reducing building energy use (beyond code minimum) and shifting load are likely to be the least expensive and most effective options.

TIME-DEPENDENT SOURCE (TDS) ENERGY

The national and international ZERO Code uses site energy as the metric for determining if a building achieves zero. When buildings produce or procure as much site energy from renewable sources as the building uses, the assumption is that carbon neutrality is achieved, but this is an approximation at best. Compared to flat source energy factors in multi-fuel buildings, site energy results in more installation or procurement of renewable energy. Site energy is used at the national and international level out of necessity and for simplicity. However, the energy use and carbon intensity of electricity generation is not constant. It varies with season and especially time of day. In areas like California where the grid is supplied by a large share of solar energy, the differences over the course of the day can be dramatic. In solar-rich grids, energy use and carbon emissions are less on sunny afternoons than at night when natural gas generators come on line or ramp up to meet demand. In California, we have an opportunity to more accurately address the time dependency of energy use and carbon emissions, as discussed below.

Time-Dependent Valued (TDV) Energy

Since 2005, the California Energy Commission has been using time-dependent-valued (TDV) energy as the metric for new building energy performance. "The concept behind TDV is that energy efficiency measure savings should be valued differently depending on which hours of the year the savings occur, to better reflect the actual costs of energy to consumers, to the utility system, and to society."[2] TDV consists of an hourly time series of values for each climate zone and fuel type (electricity, natural gas and propane). Separate values are also provided for residential and nonresidential buildings. Building electricity use for each hour is multiplied times the TDV for that hour and TDV for the year is the sum of these products. TDV is used in California not only to evaluate building energy performance but to also establish the cost effectiveness of the standard.

TDV is expressed as kBtu/kWh for electricity and kBtu/therm for natural gas, but it is based on cost. The TDV cost components are listed in Table 1 and shown graphically in Figure 2. The TDV peak occurs in the early evening and is driven by two factors: the need to install new capacity to accommodate ramps in net load[3] and the costs of expanding transmission and distribution capacity to meet customer peak loads.

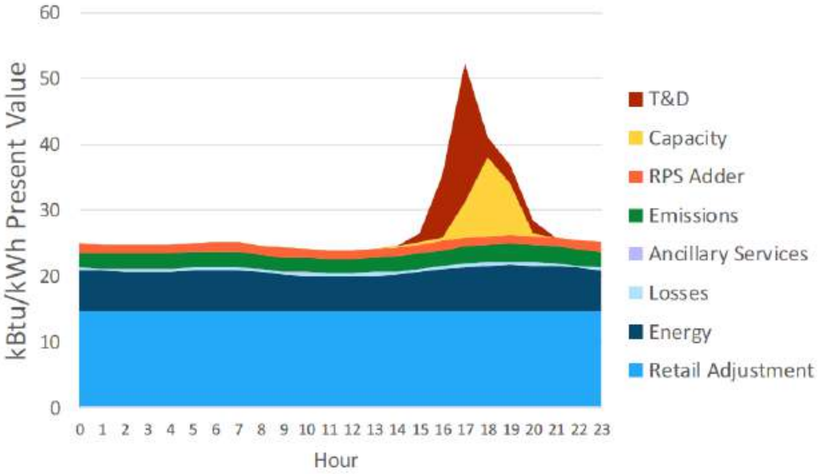

Figure 2 – Sample TDV shape by Component, Average Day, Levelized 30-Year Residential, CZ12

Source: Figure 4 from Energy Economics and Environment, Inc., Time Dependent Valuation of Energy for Developing Building Efficiency Standards, 2019 Time Dependent Valuation (TDV) Data Sources and Inputs, July 2016.

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[2] Energy Economics and Environment, Inc., Time Dependent Valuation of Energy for Developing Building Efficiency Standards, 2019 Time Dependent Valuation (TDV) Data Sources and Inputs, July 2016.

[3] Net load is the demand for electricity after renewable energy sources have been subtracted.

Table 1 – Components of Time Dependent Valuation for Electricity

Source: Table 4 from Energy Economics and Environment, Inc., Time Dependent Valuation of Energy for Developing Building Efficiency Standards, 2019 Time Dependent Valuation (TDV) Data Sources and Inputs, July 2016.

	Component	*Description*
Marginal Energy Avoided Costs	Generation Energy	Estimate of hourly marginal wholesale value of energy adjusted for losses between the point of the wholesale transaction and the point of delivery
	System Capacity	The marginal cost of procuring Resource Adequacy resources in the near term. In the longer term, the additional payments (above energy and ancillary service market revenues) that a generation owner would require to build new generation capacity to meet system peak loads
	Ancillary Services	The marginal cost of providing system operations and reserves for electricity grid reliability
	System Losses	The costs associated with additional electricity generation to cover system losses
	T&D Capacity	The costs of expanding transmission and distribution capacity to meet customer peak loads
	CO2 Emissions	The cost of carbon dioxide emissions (CO2) associated with the marginal generating resource
	Avoided RPS	The cost reductions from being able to procure a lesser amount of renewable resources while meeting the Renewable Portfolio Standard (percentage of retail electricity usage).
Retail Rate Adder		The six components above are scaled to match the average retail rate through the retail rate adder.

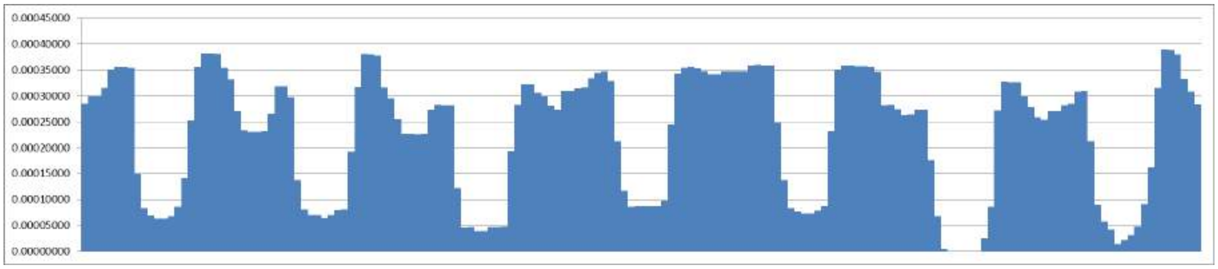
The peaks begin around 5 PM and extend through about 9 PM. For climate zone 12 (Sacramento), the peaks occur only in the summer months, but in climate zone 3 (Oakland), the principal peaks are also in the summer months, but minor peaks occur in the winter evening hours. For the majority of the year, the TDV multipliers are a fairly constant 24 to 25 kBtu/kWh.

Time-Dependent Source (TDS) Energy

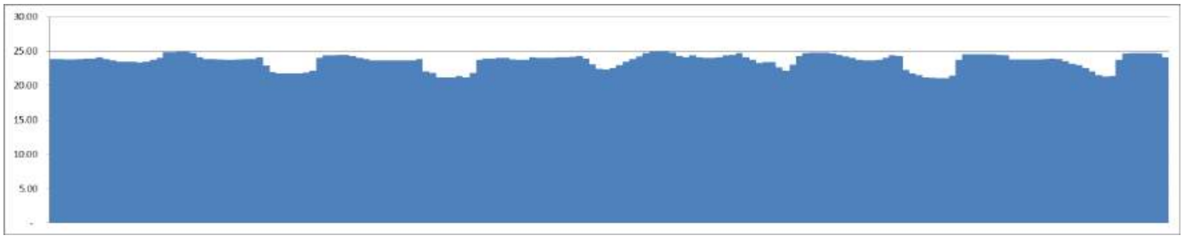
Using TDV as the metric to assess carbon neutrality would be an improvement over using site energy, but we have the opportunity in California to use a metric that better addresses the time pattern of both energy use and carbon emissions. Instead of TDV, the ZERO Code$_{ca}$ uses time dependent source (TDS) energy as the metric. TDS energy represents the amount of fossil fuel used per kWh of electricity generation. Except for a minor amount imported electricity from coal and a few biomass plants, natural gas represents virtually 100% of fossil fuels used in California to generate electricity. TDS values for gas are constant and do not change hourly.

Both TDV and TDS are based on the same consistent procedures and are aligned with the official California Energy Commission weather files used for building analysis. This enables us to look at specific hours during the year and compare the metrics for specific system loading and weather conditions. Figure 3 shows the TDS metric, hourly carbon emissions and TDV energy for climate zone 3 for the week of March 23 (beginning on a Monday). This sunny, swing season week was chosen to compare the metrics because it represents conditions when grid-level solar generators would likely be curtailed. In viewing the figure, you will note that TDS energy and carbon emissions track each other very closely. The major difference is the scale.

Long-Run Marginal TDS Energy (kBtu/kWh)



Long-Run Marginal Hourly CO2e Emissions (tons/kWh)



TDV Energy (kBtu/kWh)

Figure 3 – Comparison of Metrics – Climate Zone 3

These images shows the long-term marginal, 15-year time dependent source energy (TDS), hourly carbon emissions, and TDV for the week of March 23, beginning on a Monday. These values are synchronized with the official California weather files used for building performance analysis.

On Saturday, grid-level solar energy is being curtailed and marginal source energy is zero. During these hours, if you increase load, the curtailed solar (reserve) would be brought on-line and the marginal source energy and emissions would be zero. For this same week, the TDV curve is much flatter, providing less incentive for load shifting. The vertical axis of all three curves extends to zero to make the comparisons easier to visualize.

The objective of the ZERO Code$_{ca}$ is to get to zero source/emissions, but to do so in a way that does not create undue stress on the electric grid. With either the TDS or emissions metrics, a building would receive no credit for generating electricity and dumping it into the grid during hours of zero source energy.[4] Producing electricity during these hours would not help in complying with the ZERO Code$_{ca}$. TDS provides a very positive incentive for the building to incorporate battery or thermal storage in addition to on-site PV, as will be discussed later. Using hourly source/emissions as the metric would help to achieve grid harmonization between ZNE buildings and the electric grid. In reference to the infamous "duck curve", the belly would be raised and the neck shortened as more buildings are designed to meet the ZERO Code$_{ca}$.[5]

Site energy as a metric would be perfectly flat for all hours of the year (a constant 3,412 Btu/kWh) and would provide no incentive for grid harmonization. On-site PV production would be credited even during periods when the grid was saturated with solar energy and being curtailed at the system level. The over-generation problem is compounded by site energy, and grid harmonization would worse. The TDV metric is better than site but does not provide nearly as much incentive as either the TDS or emissions metrics.

Figure 4, Figure 5, and Figure 6 show in a different way how TDS promotes grid harmonization. The vertical axis in these graphs is the average TDS or TDV value for an average hour in each month. TDV is flat for the majority of the year with sharp peaks in the summer, driven by the cost to procure additional capacity and expand transmission and distribution networks. These peaks occur in the summer months after about 4:00 to 5:00 PM. The TDS curves more directly acknowledge the time variation of source energy use (and carbon emissions), thus providing convincing motivation to building designers and operators to be good neighbors in the grid.

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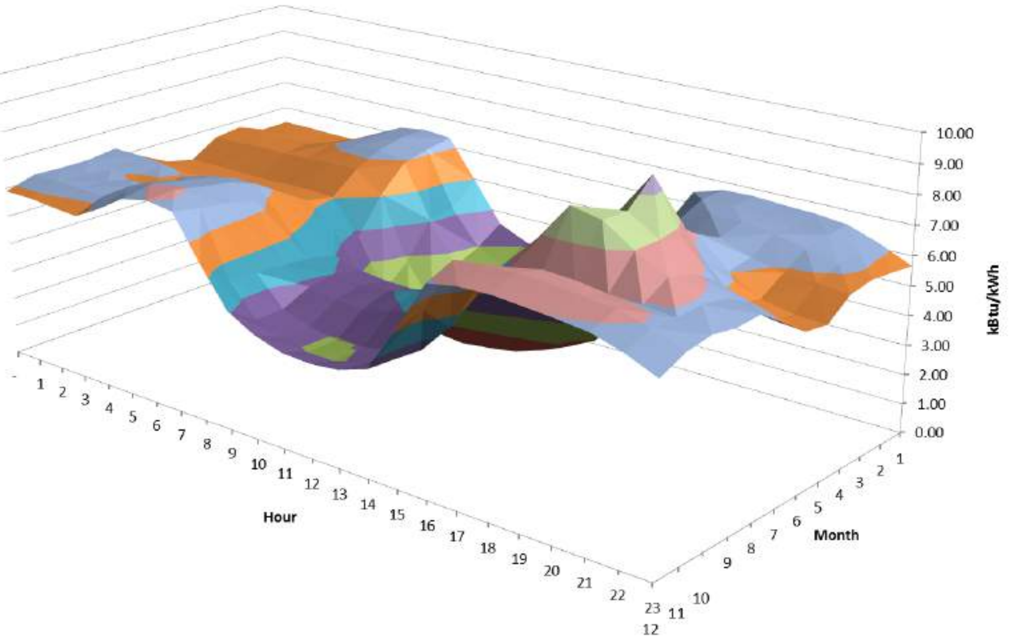
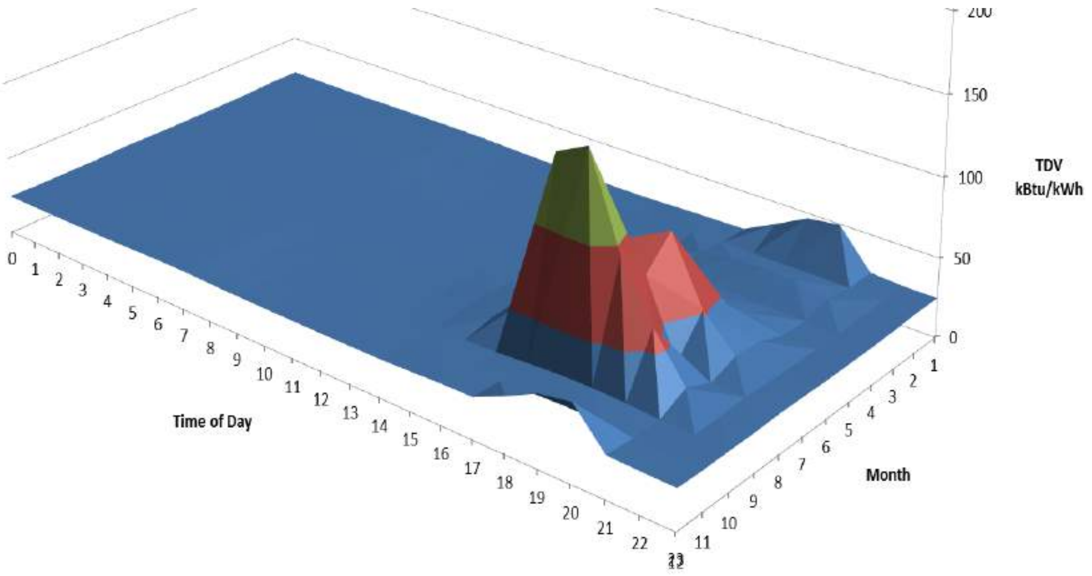
[4] Smart inverters would allow roof-top or on-site systems to shut down during these hours to avoid the penalty.

[5] See https://www.caiso.com/documents/flexibleresourceshelprenewables_fastfacts.pdf for information on the duck curve.



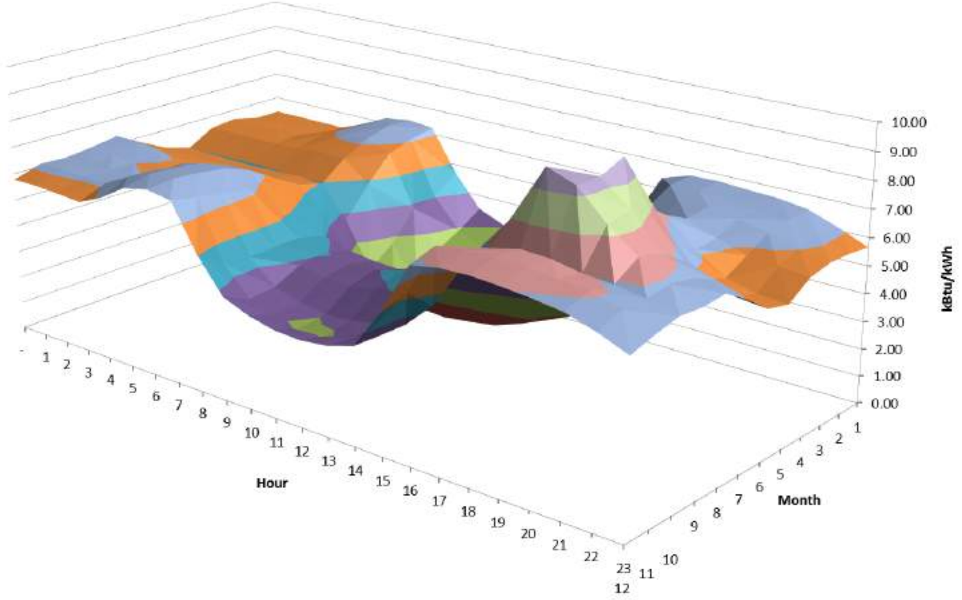
TDS Metric



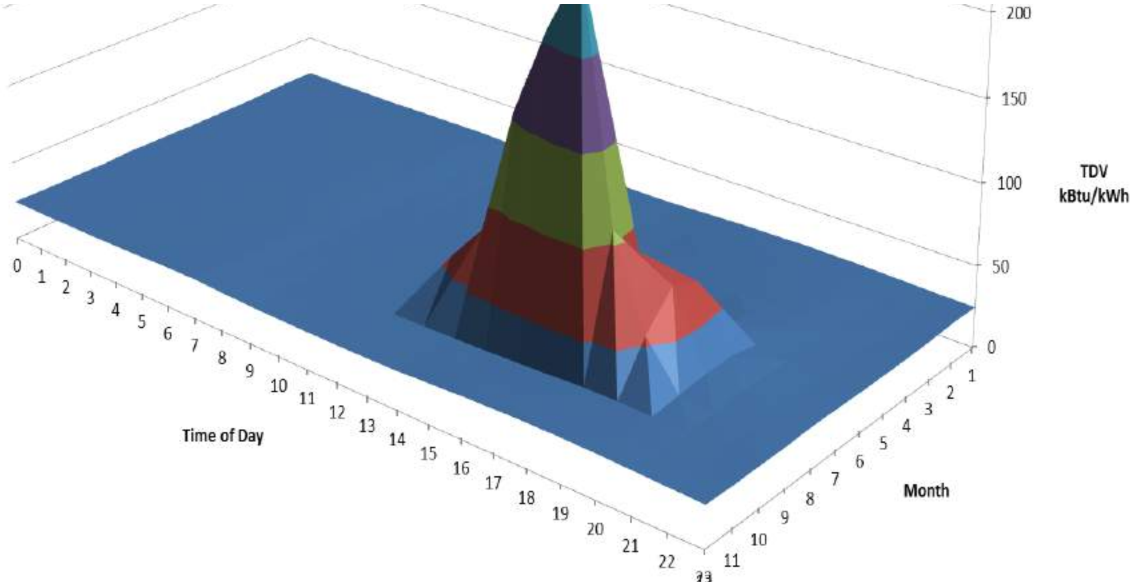
TDV Metric

Figure 4 – TDS vs. TDV Metrics – CZ03

This visualization shows the average TDS and TDV multipliers for electricity for each hour of the day and each month of the year. For TDV, averages are calculated from the 15-year 2019 TDV values for nonresidential buildings. For TDS, averages are calculated based on the 2022 15-year long run marginal source energy factors. This graph is an approximation. The average for each hour of the month is plotted and there will be variation throughout the month which is triggered by climate conditions and other factors such as curtailment.



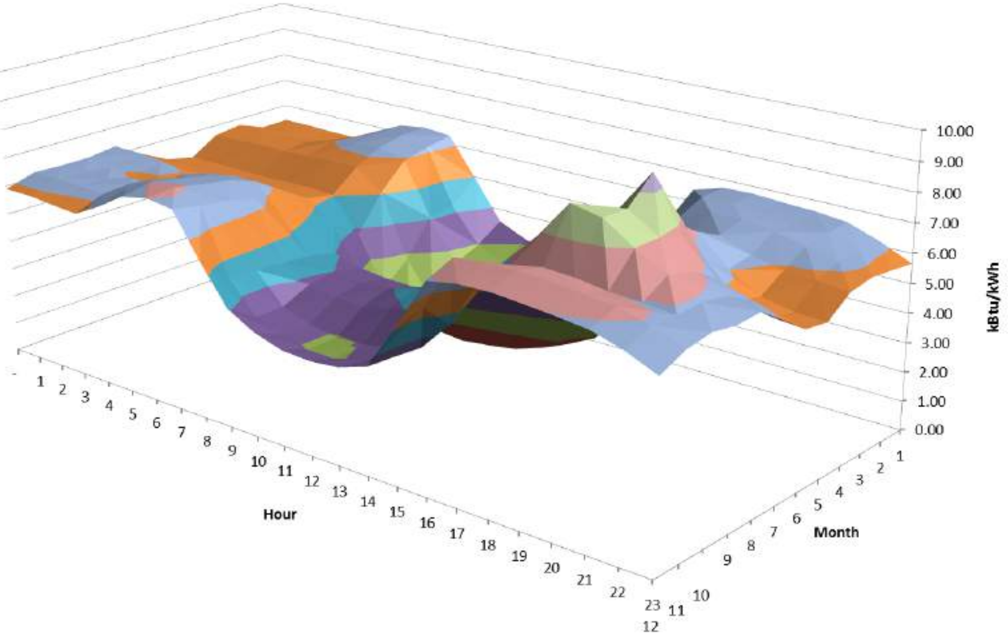
TDS Metric



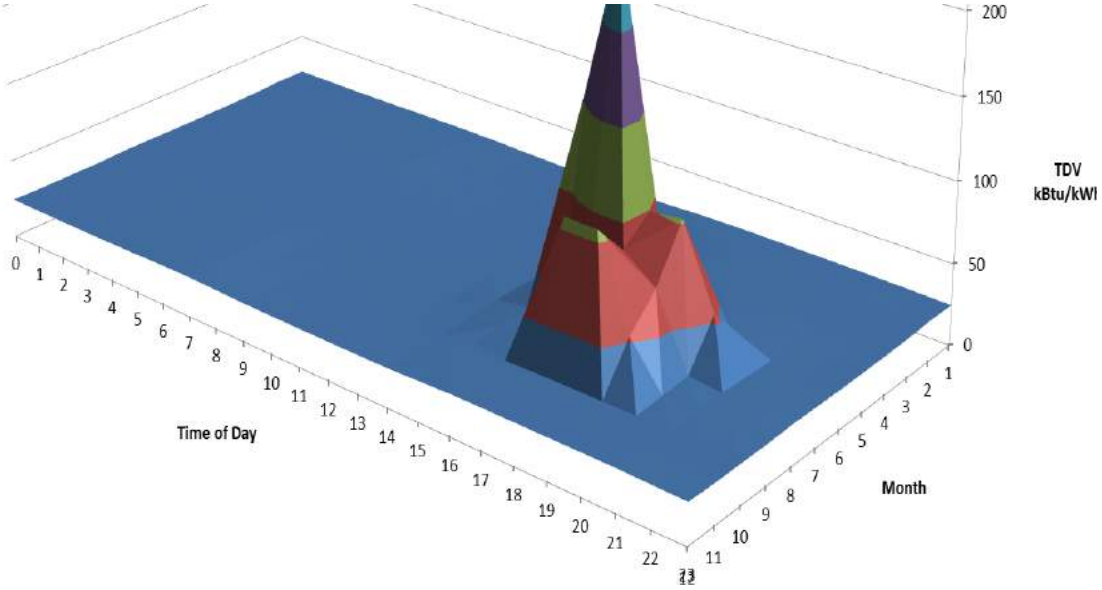
TDV Metric

Figure 5 – TDS vs. TDV Metrics – CZ10

This visualization shows the average TDS and TDV multipliers for electricity for each hour of the day and each month of the year. For TDV, averages are calculated from the 15-year 2019 TDV values for nonresidential buildings. For TDS, averages are calculated based on the 2022 15-year long run marginal source energy factors. This graph is an approximation. The average for each hour of the month is plotted and there will be variation throughout the month which is triggered by climate conditions and other factors such as curtailment.



TDS Metric



TDV Metric

Figure 6 –TDS vs. TDV Metrics – CZ12

This visualization shows the average TDS and TDV multipliers for electricity for each hour of the day and each month of the year. For TDV, averages are calculated from the 15-year 2019 TDV values for nonresidential buildings. For TDS, averages are calculated based on the 2022 15-year long run marginal source energy factors. This graph is an approximation. The average for each hour of the month is plotted and there will be variation throughout the month which is triggered by climate conditions and other factors such as curtailment.

Source Energy Calculation Procedures

Different procedures are used to calculate source energy. All of the procedures use a similar accounting method for fossil fuel generators. The differences come down to how non-combustible renewable energy generators are treated. The USDOE and the EPA have traditionally used the "fossil fuel equivalency" method, where energy inputs for hydro, solar and wind generators are assumed to be the same as fossil fuel generators. For 2016, the average heat rate for fossil fuel plants was 10,459 Btu/kWh and solar, wind and hydro plants are all assumed to use this amount of energy per unit of output. The fossil fuel equivalency method has obvious flaws, since wind, solar and hydro generators do not use any primary energy. With the fossil fuel equivalency method, source energy is virtually unchanged as wind and solar are added to the grid.

The DOE proposed an alternative procedure they call the "captured energy" method, whereby the heat content of non-combustible renewable energy generators is assumed to be the same as the output, e.g. 3,412 Btu/kWh.[6] The energy input is assumed to be equal to the output, but what is the real energy input for a wind turbine, hydroelectric turbine or solar panel? The sun would strike the ground anyway, the wind would still blow and the water would still flow downhill. While the captured energy method is clearly better than the fossil fuel equivalency approach, it still makes some spurious assumptions.

The method used to develop the TSD factors used in the ZERO Code$_{ca}$ assumes that the heat content for non-combustible renewable energy generators is zero. The energy inputs of wind, gravity or photons from the sun are assumed to have no value and are wasted if not converted to electricity by photovoltaic panels, wind turbines or hydroelectric plants. Sunshine, wind and gravity are free and an attempt to equate them with some amount of fossil fuel is unproductive.

The "zero heat content" for renewables approach used by the ZERO Code$_{ca}$ also has the advantage of tracking carbon emissions almost exactly on an hourly basis, as shown in Figure 3. When marginal TDS energy is zero, so are marginal carbon emissions. When marginal TSD energy is high, so are marginal carbon emissions. Federal statutes require that state and local energy codes be based on either cost or energy. Basing a code on carbon emissions risks a violation of the preemption rules. But using TDS

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[6] United States Department of Energy, Accounting Methodology for Source Energy of Non-Combustible Renewable Electric Generation, October 2016. This procedure is also documented in a request for information (DE-FOA-0001512), dated February 2, 2016.

energy complies with the federal requirements and also directly addresses carbon emissions.

Marginal vs. Average

Energy Economics and Environment, Inc., a consultant to the California Energy Commission, developed both average and marginal TDS factors, along with emission factors and TDV. On their advice, the ZERO Code$_{ca}$ is based on long-term marginal source energy/emissions. The options are described below.

- *Average* – Total source energy/emissions are divided by total production for each hour.
- *Short-Term Marginal* – Source energy/emissions are based on the mix of *existing* generators that operate at the margin, e.g. carbon emissions and source energy are based on the plants that would come on-line or shutdown when a small increment is added or removed from the load.
- *Long-Term Marginal* – Source energy/emissions are based on the marginal load with consideration of the long-term changes in plant capacity, retirement schedules and additions of new generation.

Long-Term Marginal Carbon Emission Rates

The California electric grid already has a significant amount of low carbon or carbon free generation sources. Power from PG&E is among the cleanest in the country.[7] The CEC report on revisions to the Power Source Disclosure Project in response to Assembly Bill 1110 indicate that power drawn from the California grid results in 305 kg/MWh (672 lb/MWh) when biogenic emissions are not counted and 353 kg/MWh (778 lb/MWh) when biogenic emissions are included. The national average is about double this rate of emissions. The ZERO Code$_{ca}$ uses hourly source energy as the metric to replicate carbon.

The long-term TDS/carbon rates tend to be lower than both the average and the short-term marginal rates, because emissions will consider the construction of new generation sources to meet the marginal load. When the long-term marginal emissions rates are combined with the 2017 historic loads, system wide emissions for the year are 637 lb/MWh, about 5% lower than the CEC reported average with no biogenic emissions and 18% lower when biogenic emissions are included.

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[7] See "Emissions of the 100 Largest Electric Power Producers", Figure 8 and Table 2.

Wind, solar and other renewable energy sources will be the most cost-effective choice in future years. The levelized cost of energy (LCOE) for clean generation sources is projected to be significantly lower in the future than fossil fuel generators. This is already the case with coal. On-shore wind has a lower LCOE than combined-cycle natural gas, and solar is expected to have a lower LCOE by about 2030. See Figure 7.

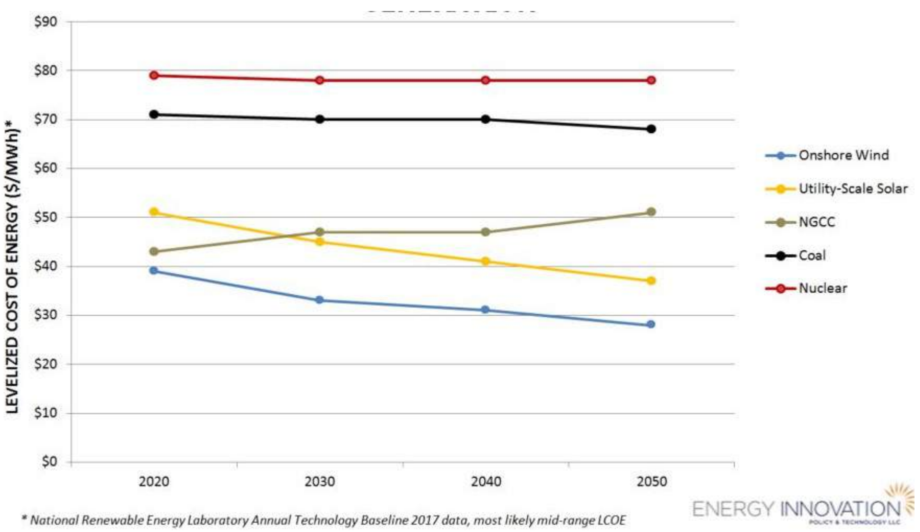

Figure 7 – Projected Levelized Cost of Energy of U. S. Power Generation

Source: http://energyinnovation.org/2018/01/22/renewable-energy-levelized-cost-of-energy-already-cheaper-than-fossil-fuels-and-prices-keep-plunging/

Time Period for Analysis

The marginal source energy factors used in the ZERO Code$_{ca}$ are based on a 15-year time horizon, thus accounting for further improvements to the California grid required by adopted state policy. Nonresidential buildings last for much longer than 15 years, but they are renovated and upgraded on a more frequent basis. For this and other reasons, the CEC uses 15 years as the time horizon for evaluating energy efficiency measures to include in the BEES. Also, there is an urgent need to address climate change in the next decade. For these reasons, the ZERO Code$_{ca}$ uses TDS values for 15 years.

IMPACT ON BUILDING DESIGN

The TDS metric works in exactly the same way as the TDV metric that has been used in California for more than a decade. The electricity and gas use for each hour are converted to hourly source energy by multiplying the consumption for that hour times the TDS factor for that hour and climate zone. CBECC-Com and the other energy analysis tools used for code compliance include procedures that automatically make this calculation.

The process for applying the TDS metric is illustrated in Figure 8 for electricity. Building energy use and on-site PV production are estimated by CEC-approved software (CBECC-Com). The net electricity load is the sum of these. This time series is then multiplied by the TDS time series. In this example, the building achieves zero site energy, but when the TDS weights discount solar production the building no longer achieves zero with TDS as the metric. Integrating battery storage, thermal storage or other techniques to store excess energy in the afternoon for use later in the evening would smooth the net electricity load and help achieve zero TDS energy.

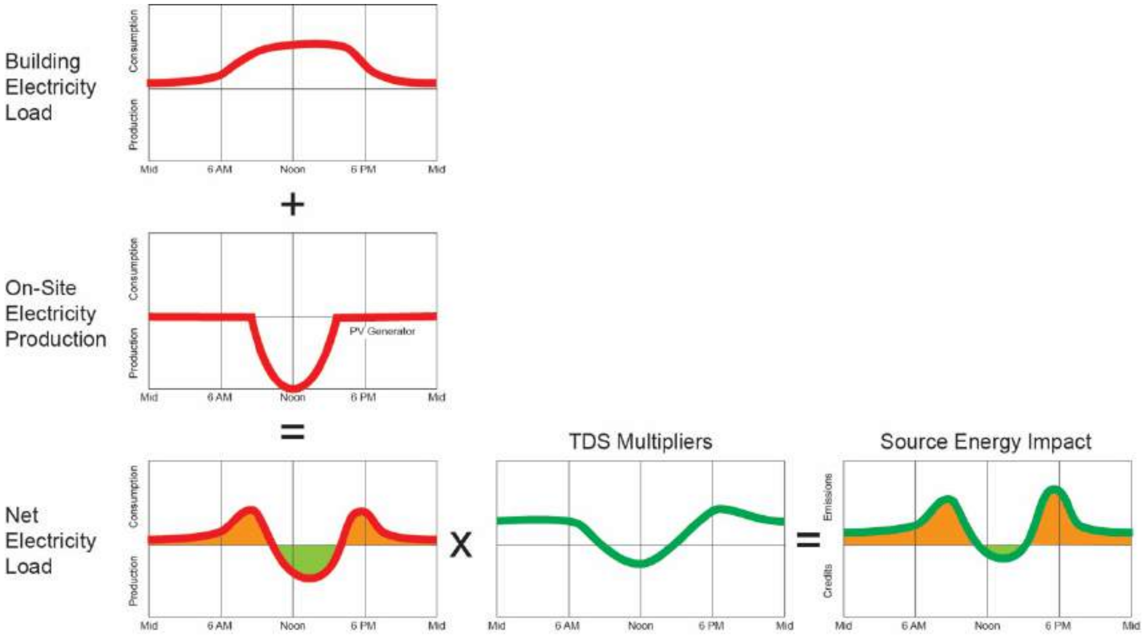

Figure 8 – Using Time-Dependent Source (TDS) as the Metric for the ZERO Code$_{ca}$

Note: Curves are illustrative and are shown only for a single day.

Batteries and Load Shifting Opportunities

TDS energy/carbon emissions can be reduced with a number of design strategies that shift loads from high emission periods to low emission periods. Batteries are the most obvious solution, but more conventional strategies such as thermal storage and high-mass buildings can also be effective.

To shift loads, batteries would be charged during periods when solar is plentiful and TDS/emissions are low; the batteries would be discharged during periods when TDS/emissions are high. The net impact would be to shift load from high emission periods to low emission periods. This concept is illustrated in Figure 9. With more conventional load shifting techniques such as thermal storage (ice or chilled water) traditional control strategies would be reversed. Buildings would make ice when solar is plentiful and TDS/carbon emissions are low. The ice would be melted in the early morning and evening hours to keep the building cool. The traditional controls for high-mass buildings would also be reversed. The cooling equipment would be run in the middle of the day and shut off during periods of high carbon emissions.

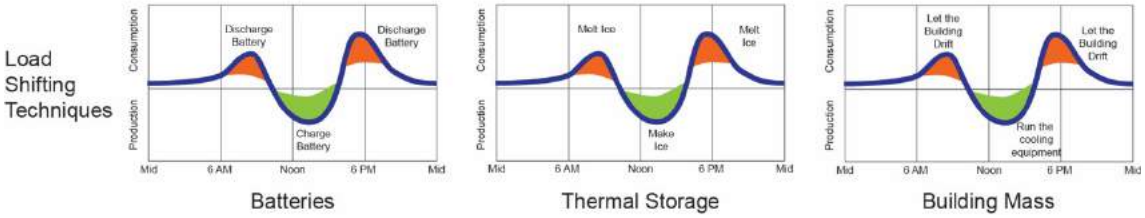

Figure 9 – Load Shifting Techniques

The TSD and carbon emissions metrics provide a larger incentive to incorporate storage than either site energy or TDV. Since power is lost during the process of charging and discharging a battery (the round-trip efficiency is on the order of 90%), installing batteries actually increases site energy. To compare how the different metrics encourage or discourage storage, calculations were done for a three story, roughly 50,000 ft² office building in minimum compliance with the 2019 California BEES. The building has an on-site PV system of about 240 kW at standard test conditions that is sized to produce about as much electricity on an annual basis as the building uses. The building uses natural gas for space heating and water heating.

The net site energy is 5.83 kBtu/ft²-y and adding the battery boosts this to 6.63 kBtu/ft²-y, an increase of 14%. The net TDS energy is 15.18 kBtu/ft²-y and adding the battery reduces this to 5.63 kBtu/ft²-y, a reduction of 63%. A similar percent reduction occurs with the carbon emissions metric, since TDS and carbon track each other very closely. The battery also has a benefit with the TDV metric, although not as great. The net TDV energy is lowered from 45.20 kBtu/ft²-y without a battery to 22.28 kBtu/ft²-y when the battery is added, a reduction of 50%. The schedule for charging and discharging the battery is the same for all metrics.

Table 2 – Battery Storage Credits for Various Metrics

Note: These calculations are based on energy simulations performed by NORESCO as part of the CEC impact study. Hourly PV results were generated by the PVWatts software. The battery has a capacity of about 400 kWh and is charged when TDS is low and discharged when TDS is high.

	Site Energy (*kBtu/ft²-y*)	*Time-Dependent Source (TDS) Energy* (*kBtu/ft²-y*)	*Carbon Emissions* (*lb/ft²-y*)	*Time-Dependent Valued (TDV) Energy* (*kBtu/ft²-y*)
		Building Energy Use		
Electricity	25.90	34.46	4.17	217.28
Gas	5.83	5.97	0.75	12.32
Total	31.72	40.43	4.92	229.60
		On-Site PV System		
Production	-25.90	-25.24	-3.05	-184.40
		Battery		
Charging	8.02	5.79	0.70	54.82
Discharging	-7.22	-15.35	-1.86	-77.42
Net (battery alone)	0.80	-9.55	-1.16	-22.60
		Summary		
Net (without battery)	5.83	15.18	1.87	45.20
Net (with battery)	6.63	5.63	0.71	22.28
Battery Benefit	14%	-63%	-62%	-50%

The CBECC-Com software has been modified to include a battery model. This model has four control modes:

- *Basic*. Battery charges whenever there is excess PV. Battery discharges to meet house load when PV does not cover it. Battery only meets building electric loads and does not put power into grid.

- *Time of Use*. Battery charges whenever there is excess PV. During peak summer months (July-September) discharging starts at the beginning of the peak period (that varies with climate zone) at maximum rate until fully discharged. Other months run with basic control. Battery will put power into grid after meeting building load if discharge rate allows it.

- *Advanced DR Control (TDV).* During peak summer months control knows that it is going to be a peak day and what the peak hours will be. On a peak day, use all PV to charge the battery until it is full. Discharge at maximum rate during highest TDV hours. Otherwise run with basic control. Battery will put power into grid after meeting building load if discharge rate allows it.

- *Advanced DR Control (TDS).* Control knows the hourly time pattern of source energy. In the middle of the day when source energy is low or even zero, use all on-site PV to charge the battery until it is full. In the early evening, when source energy is high, discharge at maximum rate. Otherwise run with basic control. Battery will put power into grid after meeting building load if discharge rate allows it. This control strategy is used to generate the results in Table 2.[8]

Prescriptive Compliance

To enable a prescriptive compliance approach for the ZERO Code$_{ca}$, source energy intensities (SEI) have been developed for common building types in each of the sixteen California climate zones.[9] The prototype buildings used for CEC Title 24 measure analysis were constructed to incorporate the requirements of the 2019 Standards in each of the climate zones and hourly results were generated. These hourly results were then combined with the TDS factors to generate the SEI's, using the equation below.

$$Source\ Energy\ Intensity\ (SEI) = \frac{\sum_{h=1}^{8760} BE_h \times TDS_{h,e} + BG_h \times TDS_{h,g}}{Prototype\ Conditioned\ Floor\ Area}$$

where

BE_h	Prototype building electricity consumption for hour "h"
$TDS_{h,e}$	Time-dependent source multiplier for electricity and hour "h"
BG_h	Prototype building gas consumption for hour "h"
$TDS_{h.g}$	Time-dependent source multiplier for gas and hour "h"

With the prescriptive compliance approach, an estimate of the hourly source energy is obtained by multiplying the SEI chosen from Table 3 times the conditioned floor area of the building in compliance with the 2019 California BEES. This estimate is used to determine the size of the on-site or off-site renewable energy system needed to comply with the ZERO Code$_{ca}$. This estimate is also the basis of the Architecture 2030 Energy Calculator for California. With the prescriptive approach on-site renewable

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[8] The TDS control strategy is not included in CBECC-Res.

[9] Multiple prototypes were modeled for the office, retail and school building types. The SEI for these are calculated as the average weighted by forecasted construction activity.

energy and avoided TDS or carbon emissions may be calculated using the Architecture 2030 website, however, the estimated solar production is modified by the Source Energy Factor to account for the fact that solar energy production aligns with periods of low source energy. See more discussion below.

Table 3 – Source Energy Intensities (SEI) by Building Type and Climate for Buildings that Comply with the 2019 BEES (kBtu/ft²-y)

Climate Zone	Office	Retail	School	Restaurant	Hotel	Warehouse	Residential
1	43	39	42	197	33	28	32
2	47	41	40	190	32	22	33
3	43	37	36	190	29	21	30
4	46	40	37	188	30	20	32
5	44	36	36	191	28	20	31
6	45	38	35	187	28	16	31
7	43	36	33	181	27	15	30
8	46	40	36	188	29	16	32
9	47	42	37	185	30	17	33
10	48	44	38	189	31	17	33
11	51	47	43	197	35	24	36
12	48	44	41	189	33	23	34
13	50	47	43	197	35	22	36
14	51	48	43	199	35	23	36
15	53	51	43	209	36	16	38
16	52	49	48	200	39	33	38

Performance Compliance

In order to apply time dependent source (TDS) factors, the CBECC-Com software has been modified to produce an hourly profile of building energy use and on-site renewable energy production, as illustrated graphically in Figure 8. The software has also been modified to:

- Include a battery model to capture the benefits of on-site electric storage
- Add input forms to accommodate information needed for PV and battery modeling
- Produce a ZERO Code$_{ca}$ electronic output summary report, which will be post-processed at the ZERO Code website.

SOURCE ENERGY FACTORS

With site energy and other “flat” metrics, the renewable energy production from wind, solar, geothermal or other renewable energy generators are all treated the same. With dynamic metrics like TDV, TDS, or hourly carbon emissions, this is no longer the case. A MWh of wind production is less intermittent and would deliver energy during times of both low- and high-TDS/carbon while a MWh of solar production would deliver energy mostly during times when TDS/carbon emissions are low. Geothermal provides a baseline load and would also look better than solar. Each renewable energy generation source will have a different source energy factor which can be expressed as in kBtu of annual source energy per kWh of annual renewable energy production. This is conceptually illustrated in Figure 10 for wind and solar.

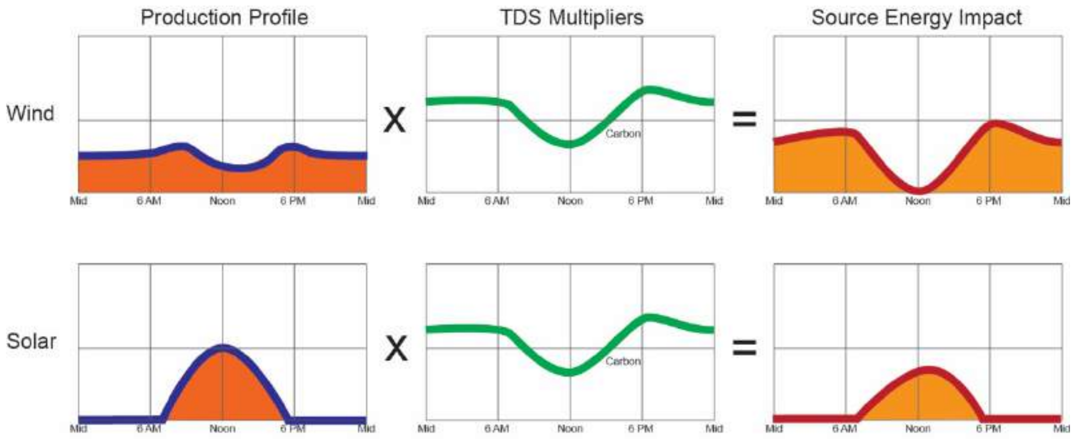

Figure 10 – Source Energy Factors

Note: Curves are illustrative and are shown only for a single day. The actual time-series includes an entire year, e.g. 8,760 hours. Note that with the site energy production profile shown on the left, wind and solar production are roughly equal, but when the TDS weights are applied, wind is significantly greater.

Figure 11 shows the time pattern of solar production that was purchased through the NP15 trading hub in 2012. Figure 12 shows the pattern of wind production for the same year and trading hub. Compare these to the time-dependent source factors in Figure 4 through Figure 6. You will note that solar production aligns closely with periods of low TDS/emission periods; in fact, solar is the reason that there is such a TDS dip in the middle of the day. Wind on the other hand, is more constant throughout the day and even is lower in the middle of the day when solar is abundant. Geothermal plants run continuously and provide baseloads. Hydro plants are dependent on rainfall and season but can modulate to meet loads.

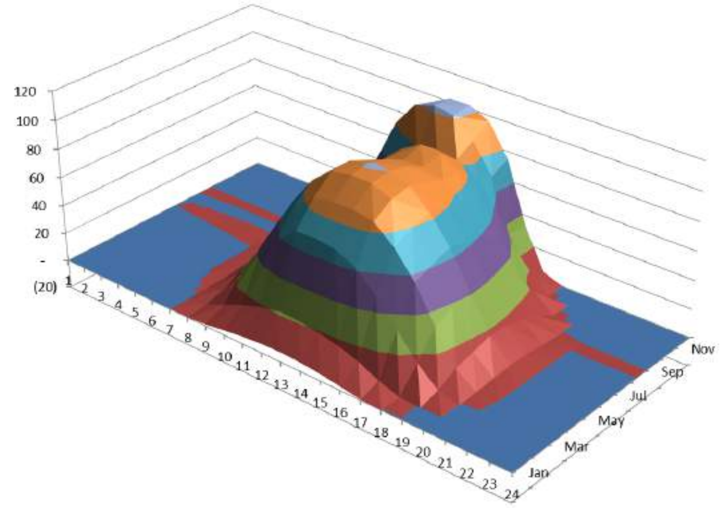

Figure 11 – 2012 Time Pattern of Solar Production – NP15

Source CalSO

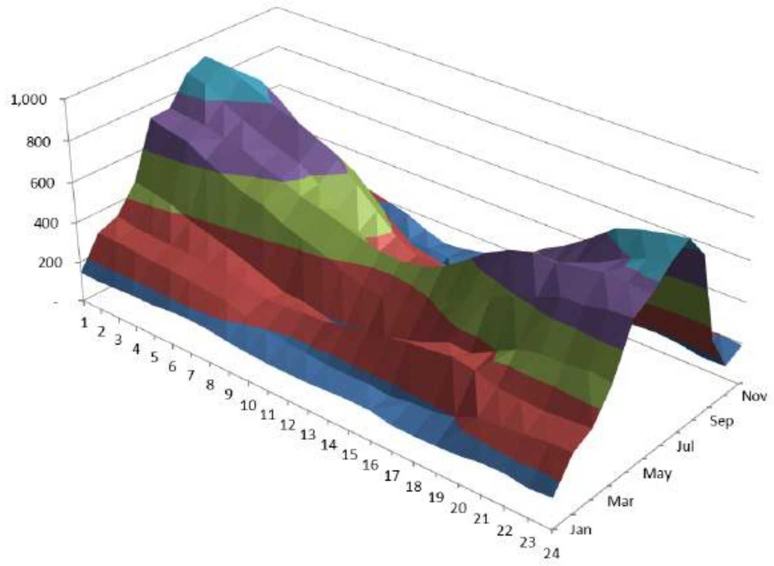

Figure 12 – 2012 Time Pattern of Wind Production – NP15

Source CalSO

With the ZERO Code's performance approach to compliance, on-site PV systems are modeled for the specific climate and design conditions, e.g. collector type, tilt, azimuth, inverter efficiency and other factors. Results are produced and for each hour the TDS factor is applied. This procedure results in an accurate assessment of the impact of the on-site PV system. At times when the TDS factor is zero, no credit is offered at all for solar production because these times align with periods of system-wide curtailment of solar.

When complying with the prescriptive approach using the ZERO Code website, a specific on-site PV system is modeled using PVWatts, but not on an hourly basis. In this case, the source energy avoided by the on-site PV system is calculated by multiplying annual PV production times the source energy factors shown in Table 4. Estimates of avoided carbon emissions and avoided TDV energy are also provided in the table for comparison. The values in this table were developed by simulating the performance of a typical PV system in each of the California climates and applying the hourly TDS, TDV and emissions weights to these results.[10] Note that the source energy factors for solar are in the range of 3,300 source Btu/kWh. With site energy as the metric, the conversion would be 3,412 Btu/kWh.

Table 4 – Avoided Source Energy, Emissions and TDV Factors for On-Site PV Systems

Climate Zone	Avoided Source (Btu/kWh)	Avoided Emissions (lb/MWh)	Avoided TDV Energy (kBtu/kWh)
1	3,296	399	24.10
2	3,330	403	25.79
3	3,322	402	24.39
4	3,322	402	25.12
5	3,293	399	24.17
6	3,260	395	25.55
7	3,277	397	28.02
8	3,307	400	26.93
9	3,319	402	26.04
10	3,295	399	24.94
11	3,322	402	26.04
12	3,287	398	25.77
13	3,274	396	25.20
14	3,292	398	26.53
15	3,304	400	25.44
16	3,344	405	24.13

These values were calculated to generating hourly PV production for each climate using PVWatts. The modeled system used premium collectors facing south and tilted at an angle of 30 degrees. Losses were assumed to be 10% and the inverter efficiency was assumed to be 90%.

To demonstrate how source energy factors are applied, assume that an on-site PV system is estimated to have an annual production of 1,000 MWh. Avoided source

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[10] The solar files used for these simulations do not align with the CEC official weather files or the hourly TDS, emissions or TDV values.

energy, avoided emissions, and avoided TDV would be calculated as shown in the example below for climate zone 3.

Avoided TDS (Source Energy)	1,000 MWh × (1,000 kWh/MWh) × (3,322 Btu/kWh) × (kBtu/1,000 Btu) = 3.322,000 Btu
Avoided Emissions	1,000 MWh × (402 lb/MWh) = 402,000 lb = 182 metric tons
Avoided TDV Energy	1,000 MWh × (1,000 kWh/MWh) × (24.39 kBtu/kWh) = 24,390,000 kBtu

Source energy factors also apply to off-site procurement of renewable energy, but in this case, California averages are used since the location of the wind or solar resources will be different from the building site. Table 5 shows the factors for wind, solar, geothermal and eligible hydroelectric systems. Biomass systems qualify as renewable energy in California, but these are not credited by the ZERO Code$_{ca}$ since they produce significant carbon emissions.[11]

Table 5 – Avoided Source Energy, Emissions and TDV Factors for Off-Site Renewable Energy

Off-Site Renewable Energy Generation Source	*Avoided Source Energy (Btu/kWh)*	*Avoided Emissions (lb/MWh)*	*Avoided TDV Energy (kBtu/kWh)*
Wind	5,374	650	28.06
Solar	3,542	429	27.77
Geothermal	5,190	628	27.57
Hydro	5,190	628	27.57

The values for wind and solar are based on the average of power procured through the NP-15 and SP-15 trading hubs for 2012. Annual average values are used for geothermal and hydro.

Carbon emissions at the generation plant for wind, solar and hydroelectric are insignificant, but with geothermal, this is not the case. Emissions at geothermal plants are very low but vary considerably depending on the location of the geothermal reservoir.[12]

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[11] The combustion of biomass and biogas results in significant emissions that may or may not be offset to some degree by the counterfactual (the emissions that would occur anyway). Biomass plant emissions are five to six times greater than the average of the California grid.

[12] See for instance, "Systematic Review of Life Cycle Greenhouse Gas Emissions from Geothermal Electricity", NREL 68474, September 2017 and "Greenhouse Gases from Geothermal Power Production", Energy Sector Management Assistance Program, Technical Report 009/16, April 2016.

OFF-SITE RENEWABLE ENERGY PROCUREMENT

Many buildings will not able to reach zero with on-site generation sources. This is true for energy intensive buildings like restaurants but also for tall buildings and buildings on shaded sites. The ZERO Code$_{ca}$ encourages on-site renewable energy systems when feasible, but also allows for the procurement of off-site renewable energy to make up for what can't be generated on-site. As such, the ZERO Code$_{ca}$ encourages but does not require on-site renewable energy. It recognizes various methods to procure off-site renewable energy, such as community solar and virtual power purchase agreements, but discounts these options to account for the added risk and uncertainty, compared to on-site systems.

For example, the default discount factor for off-site procurement through a virtual power purchase agreement is 0.75. If 100 MWh were procured, only 75 MWh could be counted toward offsetting building energy use. The rest would have to be on-site renewable energy or provided through some other off-site procurement method. Alternatively, if 100 MWh were needed to get to zero, a virtual power purchase agreement for 133 MWh/y could be purchased to offset all of the building energy use, e.g. $133 \times 0.75 = 100$.

Available procurement methods are discussed in detail in a separate Architecture 2030 document titled *Off-Site Procurement of Renewable Energy*.[13] The procurement methods discussed in this document are summarized in Table 6. The methods are grouped into three classes based on a number of specific criteria and a separate procurement factor is recommended for each class.

It is expected that governments or other entities that adopt the ZERO Code$_{ca}$ will make some changes to the procurement factors to address their special circumstances. Some of the procurement options may be eliminated and others added.

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[13] This document can be downloaded from the ZERO Code website at www.zero-code.org.

Table 6 – Default Off-Site Renewable Energy Procurement Methods and Requirements

Source: ZERO Code Off-Site Procurement of Renewable Energy, Technical Support Document, Architecture 2030, April 2018

Class	*Procurement Factor (PF)*	*Procurement Method*	*Additional Requirements*
1	0.75	Community Renewables	
		REIFs	Entity must be managed to prevent fraud or misuse of funds.
		Virtual PPA	
		Self-Owned Off-Site	Provisions shall prevent the generation asset from being sold separately from the building.
2	0.55	Green Retail Tariffs	The offering shall not include the purchase of unbundled RECs.
		Direct Access	The offering shall not include the purchase of unbundled RECs.
3	0.20	Unbundled RECs	The vintage of the RECs shall align with building energy use.

The following requirements apply to all off-site renewable energy procurement methods.

1. The building owner shall sign a legally binding contract to procure qualifying off-site renewable energy.
2. The procurement contract shall have duration of not less than 15 years and shall be structured to survive a partial or full transfer of ownership of the property.
3. RECs and other environmental attributes associated with the procured off-site renewable energy shall be assigned to the building project for the duration of the contract.
4. The renewable energy generating source shall be photovoltaic systems, solar thermal power plants, geothermal power plants, and wind turbines.
5. The generation source shall be located where the energy can be delivered to the building site by the same utility or distribution entity; the same ISO or RTO; or within integrated ISO's (electric coordination council).
6. The off-site renewable energy producer shall maintain transparent accounting that clearly assigns production to the ZNC building. Records on power sent to or purchased by the building shall be retained by the building owner and made available for inspection by the Authority Having Jurisdiction (AHJ) upon request.

The process of creating the procurement classes and the procurement factors is well documented.[14] The criteria used to evaluate the various default procurement options are shown below.

- *Additionality*. Additional renewable energy generating capacity is added to the grid in proportion to the energy demand of the building.
- *Long-Term Commitment*. The building developer makes a long-term commitment to procure renewable energy and the commitment is structured to survive a sale of the property.

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[14] Architecture 2030, ZERO Code Off-Site Procurement of Renewable Energy, Technical Support Document, April 2018, https://zero-code.org/wp-content/uploads/2018/04/Zero-Code-TSD-OffSiteRenewables.pdf.

- *Assignment to ZNC Building*. The renewable energy installed or procured is directly assigned to the building through a transparent accounting procedure.

- *Grid Management Capability*: The renewable energy production can be managed to supply the grid when power is needed but to avoid over-generation for low-load conditions.

- *Environmental Impact*. The renewable energy system has minimal impact on natural resources and habitat.

- *Inspirational/Educational Value*. The renewable energy system is visible asset associated with the building. As such it has the ability to inspire and educate building developers, designers and the public on the benefits of renewable energy.

- *Incremental Acquisition*. The renewable energy can be procured or installed in increments to match the exact loads of the building (some procurement options require a minimum contract that may exceed the needs of the building).

- *Permanent Financing*. The cost of the renewable energy system or procurement is known at the time the building is constructed and can be included in the permanent financing for the project.

Architecture 2030 has developed a spreadsheet where each of the evaluation criteria can be given a weight to represent their relative importance. Each procurement option is then qualitatively judged relative to each criterion and the results are then translated into numeric scores upon which the procurement factors are based.

Requiring more Renewable Energy than the Building Uses

The ZERO Code$_{ca}$ can result in more electricity from renewable energy sources being generated than the building uses. There are three reasons that this may occur.

- If a building uses energy sources other than electricity (natural gas, for instance), renewable energy generation must be greater than building electricity demand to make up for the gas use. The ZERO Code$_{ca}$ permits gas use in buildings but requires that it be offset by additional electricity generation, in a manner consistent with the USDOE Common Definition for Zero Energy Buildings.[15]

- Using hourly source energy (TDS) as the metric in lieu of site energy may result in more electricity being generated than the building uses when solar is the renewable energy source. The avoided source energy and carbon emissions from a MWh of solar are lower because production aligns more closely with periods in California when carbon emissions are low.

- Procurement factors of less than one directly result in the acquisition of more renewable energy than the building uses. For instance, if 100 MWh is needed and the procurement factor is 0.80, then 125 MWh would need to be procured. As an option, only 80 MWh/y could be counted and the remaining 20 MWh/y could be produced by an on-site PV system. Either way, more electricity is being produced than the building is using. In the first instance, over production is 25 MWh/y and in the second 20 MWh/y.

So the question becomes, is overproduction a problem or is it a beneficial feature of the ZERO Code$_{ca}$ approach? Over production was first raised as a potential problem when the concept of procurement factors was introduced to the ASHRAE Standard 189.1 committee. The issue was dismissed in the 189.1 context because the standard only requires that about half of the building energy use be offset by on-site or off-site renewable energy. Procurement factors of less than one serve to increase the amount of renewable energy that must be procured. A procurement factor of 0.75 does not result in over-generation; the renewable energy requirement is simply increased from 50% to 67%.

When the code experts at PG&E were briefed on the ZERO Code$_{ca}$, the issue was raised again with the question, what will happen to all the extra electric energy that is being generated? It was noted that California already has to curtail solar production for many hours during the year; adding more solar to the grid will not help.

The ZERO Code$_{ca}$ recognizes a number of methods to install or procure renewable energy. With green tariffs and community solar, it is not possible to procure more electricity than the building uses. NEM (net energy metering) rules also discourage the installation of on-site renewable energy systems that produce more electricity than the building uses on an annual basis. However, there are no inherent limits on the other options, e.g. virtual PPAs, direct-owned renewable energy systems, renewable energy

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[15] USDOE, A Common Definition for Zero Energy Buildings, September 2015.

investment funds, or unbundled RECs. These procurement options can be used to acquire as much renewable energy as needed or desired.

The ZERO Code$_{ca}$ developers acknowledge that the three factors, (1) additional renewable energy production to make up for gas use, (2) low source energy factors for solar, and (3) procurement factors lower than one, could result in more electricity being generated than the building uses. However, we believe that the approach is justified for several reasons, as noted below.

- The ZERO Code$_{ca}$ is a reach standard that will not affect all buildings. It only applies to new construction in jurisdictions that choose to adopt the ZERO Code$_{ca}$. Requiring the installation or procurement of more renewable energy generation than the building uses, will be absorbed by existing buildings and new construction that does not comply with the ZERO Code$_{ca}$. The requirement will accelerate the transition to a carbon free grid, since renewable energy production needed to comply with the ZERO Code$_{ca}$ will not count toward the RPS requirements of retail electricity providers in California.

- Hourly source energy (the TDS metric) will offer no credit for buildings that feed power to the grid during likely periods of curtailment. Solar energy that is not coupled with batteries will be credited less because the hourly source energy /carbon emission rates are lowest during times when solar production is highest.

- In the long run (the next decade or so), we expect the ZERO Code$_{ca}$ or its derivatives to evolve and the building industry will become more comfortable with off-site procurement methods. As this happens and other issues are addressed, the procurement factors will increase and approach one, the value used for on-site production.

With regard to the gas issue, using hourly source energy/carbon as a metric will encourage more buildings to electrify without making it mandatory. The source and carbon emissions from electric equipment are significantly better than comparable gas equipment. To illustrate, Table 7 compares electric and gas water heaters in terms of carbon emissions. Heat pumps are by far the lowest with emissions less than 18% of a conventional gas water heater. Even electric resistance water heaters have only two-thirds of the emissions of conventional gas equipment. Electrification is an emerging issue especially for residential buildings and the concept has many proponents.[16]

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[16] Billimoria, Sherri, Mike Henchen, Leia Guccione, and Leah Louis-Prescott. The Economics of Electrifying Buildings: How Electric Space and Water Heating Supports Decarbonization of Residential Buildings. Rocky Mountain Institute, 2018, http://www.rmi.org/insights/reports/economics-electrifying-buildings/.

Table 7 – Comparison of Electric and Gas Water Heaters

	Heat Pump		*Electric Resistance*		*Condensing Gas*		*Conventional Gas*	
Annual Energy Use[1]	915	kWh/y	3493	kWh/y	212	therms/y	264	therms/y
Site Energy	3,122	kBtu/y	11,918	kBtu/y	21,200	kBtu/y	26,400	kBtu/y
Conversion	3412	kBtu/y	3412	kBtu/y	100000	Btu/therm	100000	Btu/therm
Percent of Conventional Gas	12%		45%		80%		100%	
Source Energy	4,749	kBtu/y	18,128	kBtu/y	21,711	kBtu/y	27,036	kBtu/y
Conversion	5,190	Btu/kWh	5,190	Btu/kWh	102410	Btu/therm	102410	Btu/therm
Percent of Conventional Gas	18%		67%		80%		100%	
Emissions	575	lb/y	2,194	lb/y	2,735	lb/y	3,405	lb/y
Conversion	628	lb/MWh	628	lb/MWh	12.90	lb/therm	12.90	lb/therm
Percent of Conventional Gas	17%		64%		80%		100%	
TDV	25,098	kBtu/y	95,813	kBtu/y	41,940	kBtu/y	52,227	kBtu/y
Conversion	27.43	kBtu/kWh	27.43	kBtu/kWh	197.83	kBtu/therm	197.83	kBtu/therm
Percent of Conventional Gas	48%		183%		80%		100%	

1 Annual consumption is from the EnergyGuide labels.

2 Average annual values are used for source, emissions and TDV.

The methods of off-site procurement are new to the building industry and come with a lot of risks. These risks are the reason that the procurement factors are less than one. As procurement mechanisms improve and verification/certification programs emerge, the risks will decline significantly. As risks are reduced, the off-site procurement factors of the more favorable options will approach one.

Green Tariffs

Green tariffs are offered by PG&E, Sonoma Clean Power, San Francisco, Palo Alto and others in the state. None of the programs are structured at present to require the building owner to make a long-term commitment.

Because of the difficulty of structuring long-term commitments and other risks, the default procurement factor for green tariffs is 0.55. The Architecture 2030 Technical Support Document on off-site procurement states that when a green tariff is based in full or in part on unbundled RECs, that this should be considered. This section provides a procedure for considering RECs.

The process builds from the Power Content Labels, which all electricity providers in California are required to make available to their customers (see Table 8). The PG&E Solar Choice program, San Francisco's CleanPower and Sonoma Clean Power's Evergreen program do not use RECs. Furthermore, 100% of their offering is from a single generation source: solar for PG&E, wind for San Francisco, and geothermal for SCP. The Source Energy Factor (SEF) for the offering is equal to the SEF for the 100% generation source. The PaloAltoGreen portfolio is 1% solar and 99% wind. In this case, the SEF for the offering is 1% of the SEF for solar and 99% of the SEF for wind. The default tariff for Palo Alto is broken into two parts, the portion that is contracted for directly and the portion that is offset through the purchase of unbundled RECs (see the last two columns in Table 8). In this case, the type of RECs (solar, wind, etc.) is not disclosed so they are assumed to generally align with the renewable energy under contract. The percent for each generation source is multiplied times the SEF for that generation source and summed at the bottom of the table in the row labeled "Avoided Source Energy". They are then multiplied times the Procurement Factor which assumed to be 0.55 except for unbundled RECs which are assumed to be 0.20. The last step in the process is to multiply the SEF by the PF to get the credit for energy purchased through the tariff. In the case of the standard Palo Alto tariff that includes RECs, the SEF*PF is calculated separately for contract energy and RECs and summed.

Table 8 – Comparison of Green Tariff Offerings

	2016 California Generation Mix	Avoided Source Energy Factor (Btu/kWh)	PG&E	San Francisco	Sonoma Clean Power	Palo Alto		
							Standard	
			Solar Choice	Super Green	Evergreen	PA Green	Contract	RECs
Renewables	26%		100%	100%	100%	100%	27%	49%
Biomass	2%	0					11%	21%
Geothermal	4%	5190			100%			
Hydroelectric	2%	5190					1%	
Solar	8%	3542	100%			1%	3%	5%
Wind	9%	5374		100%		99%	12%	23%
Other Sources	60%		0%	0%	0%	0%	25%	0%
Coal	4%							
Hydroelectric	10%						25%	
Natural Gas	36%							
Nuclear	9%							
Other	0%							
Unspecified	14%							
Avoided Source Energy (Btu/kWh)			3542	5374	5190	5356	803	1413
Procurement Factor			55%	55%	55%	55%	55%	20%
Tariff Credit (Btu/kWh purchased)			1948	2956	2855	2946	724	

Summary of Source Energy Accounting for Off-Site Renewable Energy

The avoided TDS, emissions from off-site renewable energy procurement are multiplied by the procurement factors from Table 6 (or a modified version of this table). The process is shown below in equation form. Net source energy of zero or less would achieve compliance with the ZERO Code$_{ca}$.

$$Net\ Source = Source_{BldgElect} + Source_{BldgGas} - AvoidedSource_{On-Site} - AvoidedSource_{Off-Site}$$

$$Net\ Source = \sum_{h=1}^{8760} BE_h \cdot TDS_{e,h} + \sum_{h=1}^{8760} BG_h \cdot TDS_{g,h} - \sum_{h=1}^{8760} OnSiteRE_h \cdot TDS_{e,h} - \sum_{p=1}^{n} PF_p \cdot \left[\sum_{r=1}^{q} OffSiteRE_{r,p} \cdot SEF_r\right]$$

where

Net Source =The net carbon emissions which represent the emissions from building energy less the avoided emissions from on-site and off-site renewable energy.

BE_h = Building electricity use for the hth hour of the year

$TDS_{e,h}$ = Time-dependent source factor for electricity use in the hth hour of the year

BG_h = Building gas use for the hth hour of the year

$TDC_{g,h}$ = Time-dependent source factor for gas use for the hth hour of the year

$OnSiteRE_h$ = On-site renewable energy production for the hth hour of the year

$OffSiteRE_{r,p}$ =Off-site renewable energy procurement for the rth generation source and for the pth procurement method

PF_p = Renewable energy factor for the pth procurement method from Table 6 (or similar table for California)

SEF_r = Source energy factor for the rth generation source from Table 5.

h = Index for the hour of the year

p = Index for the procurement method

r = Index for the renewable energy generation source

n = Number of procurement methods

q = Number of renewable energy generation sources for the p^{th} procurement method

With the prescriptive approach, the hourly summations in the following equations are simplified as shown below.

Net Source = Conditioned Floor Area × Source Energy Intensity
– On-Site PV Production × Source Energy Factor
– Off-Site RE Procurement × Source Energy Factor × Procurement Factor