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ZNE Building Design and Performance Verification Methodologies

Final Report

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CALMAC Report # PGE0387.01

Submitted To:

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Table of Contents

TABLE OF FIGURES

I. Acknowledgements

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2. Executive Summary

2.1 Study Objectives and Application Scenarios

Pacific Gas & Electric Company (PG&E), on behalf of the joint California Investor Owned Utilities (IOUs), contracted with a team led by TRC Energy Services (TRC) to develop verification methodologies for validating predicted energy performance of Zero Net Energy (ZNE) buildings in California. **It is important to note that this project is not intended to develop evaluation protocols specific to individual ZNE programs or initiatives nor is it intended to address all aspects of program evaluation (e.g. free-ridership, Net-to-Gross etc.). Rather it is intended to address how gross energy savings at the unit level (ZNE Building) are to be verified at the design stage as well as once the building is constructed and under operation.**

This study builds upon protocols currently being used to specify and track ZNE building design and performance by early adopters across the country and specifically on efforts within California to develop a unified ZNE recognition effort and the stated policy of ZNE Code buildings currently under development. This study also builds upon verification methodologies currently being used for evaluation of IOU Codes and Standards and IOU Nonresidential New Construction programs.

This study has three main objectives, as listed below. These objectives are interrelated in their intent and scope and together guided the study process.

- Objective I: Develop Draft Verification Methodologies for ZNE Buildings in California based on literature review and review of ZNE building data availability.
- Objective II: Test Verification Methodologies on Sample ZNE Projects. The verification methodologies developed in Objective I will be applied to a small subset of ZNE buildings in California where post-construction monitoring data is available showing actual performance of these buildings.
- Objective III: Propose Final Verification Methodologies based on findings from Objective II.

This project does not develop any ZNE metrics or definitions of its own. Rather, this study develops verification protocols that are applicable and appropriate for the ZNE definitions already in use in California through utility programs and voluntary efforts.

There are currently several utility efforts to promote ZNE buildings, from ZNE pilot programs for residential, commercial and school buildings, new construction programs such as California Advanced Homes Program (CAHP) and Nonresidential New Construction program, Codes and Standards Enhancement (CASE) initiatives and training, outreach and education. Additionally, there are non-utility efforts such as those run by third party program implementers and rating entities (e.g. Build it Green) that promote ZNE. Lastly, the early adopters in the ZNE design and construction community (e.g. residential builders) are constructing ZNE buildings on a voluntary basis and need a common language for promoting ZNE to their customers/clients. All of these efforts need to address or at least be cognizant of the regulatory definition of ZNE included in the 2015 Integrated Energy Policy Report (IEPR)[1] that uses the Time Dependent Valuation (TDV) metric as its basis.

[1] 2015 Integrated Energy Policy Report, California Energy Commission, 2015. (http://www.energy.ca.gov/2015_energypolicy)

With all these efforts addressing ZNE, there is a need to establish some common protocols for what constitutes a ZNE building, especially when there is a mismatch between the regulatory definition (ZNE Code, using TDV) and those used by early adopters (ZNE Site, ZNE Source). Without a common set of data, analysis and verification protocols, it is impossible to know whether everyone is talking about the same ZNE metric and whether they have indeed achieved ZNE.

With this background in mind, this study aims to develop verification methodologies to address ZNE verification challenges for the following programmatic and voluntary efforts:

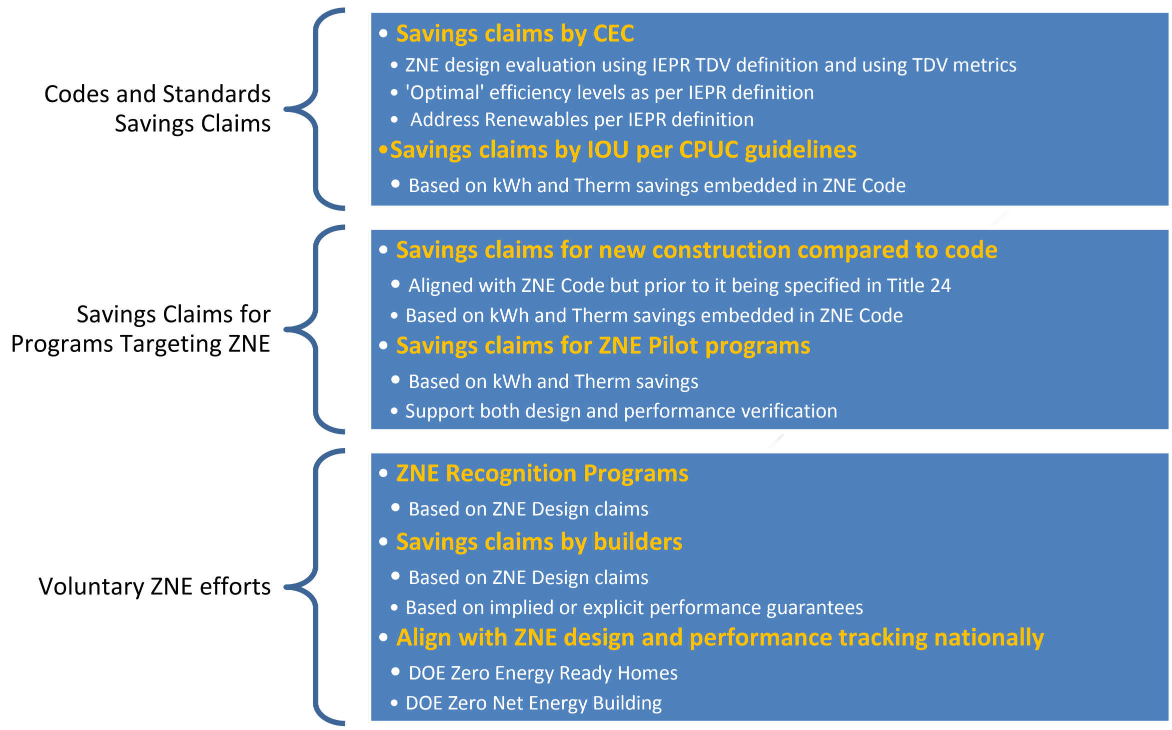

Figure 1: Programs and Voluntary Efforts that Require Evaluation of ZNE Design or Performance

2.2 Key ZNE Terminology

There are several key terms introduced or referenced in this document that have a specific definition and often multiple definitions based on the entity using the term. To avoid confusion to the reader, this section outlines the definitions and explanations for the key terms as they apply to this document:

- **Zero Net Energy (ZNE)** Building – A ZNE building is one where the annual energy use of the building is offset by the energy production onsite through renewable energy means. ZNE includes all energy end uses within the building (including process loads) but does not include electric vehicle charging or other end uses not within the confines of the building itself. There are several definitions for ZNE based on how the energy use accounting is done – site energy, source energy, energy cost, carbon emissions or in the case of California the Time Dependent Valuation (TDV) metric.

- **ZNE Design** – A ZNE Design designation for a ZNE building denotes that the building is designed to be ZNE based on the assumed energy end uses and operation schedules. It is not necessary that a building that achieves ZNE Design also performs as a ZNE building.

- **ZNE Performance** – A ZNE Performance designation denotes that the building is performing as a ZNE building based on actual building operation.

- **ZNE Site** – A building that is designated as ZNE Site is a building that offsets its annual energy use expressed in terms of site kBtu (site energy) with renewable energy generated on site also expressed in terms of site kBtu (site energy). A ZNE Site building could be designated ZNE Site - Design if the designation is based on predicted performance or ZNE Site - Performance if based on actual observed building energy use and renewable generation.
- **ZNE Source** – This definition is similar to the ZNE Site definition, except the metric used is a source kBtu (source energy) that accounts for energy required to extract and transport the raw fuel and losses associated with conversion, transmission and distribution to the point of use (building).This is typically achieved by multiplying site energy values with a multiplier that then generates the source values. These site-to-source conversion factors vary by fuel (electricity, natural gas, propane) as well as the electricity generation mix for a particular utility or region. This report uses national average values for site-to-source energy as used by the US Department of Energy (DOE) for the EnergyStar and Portfolio Manager initiatives. This enables the values to be comparable across the various states and utility territories across the country.
- **ZNE Code** – this definition of ZNE is specific to California and is unlike the definitions of ZNE used elsewhere. As described in detail in Section 4.3, a ZNE Code building is one that achieves ZNE based on the Time Dependent Valuation (TDV) of energy use and generation onsite. ZNE Code is a design rating since it is based on predicted energy performance. It uses the Energy Design Rating (EDR) to express whether a building is ZNE.
- **Time Dependent Valuation (TDV)** – TDV has been used to evaluate cost-effectiveness of energy efficiency and demand response measures for Title 24 since the 2005 Title 24 update. Prior to 2005, a flat value of source energy cost was used to evaluate the value of measures. Under TDV, energy is valued instead on an hourly basis that better reflects the actual cost of energy to the customers, to the utility system and to society. TDV values are calculated separately for the three primarily fuels used in buildings – electricity, natural gas and propane – as well as for the 16 California climate zones. Electricity values change by hour for each hour of the year while natural gas and propane values change by month.

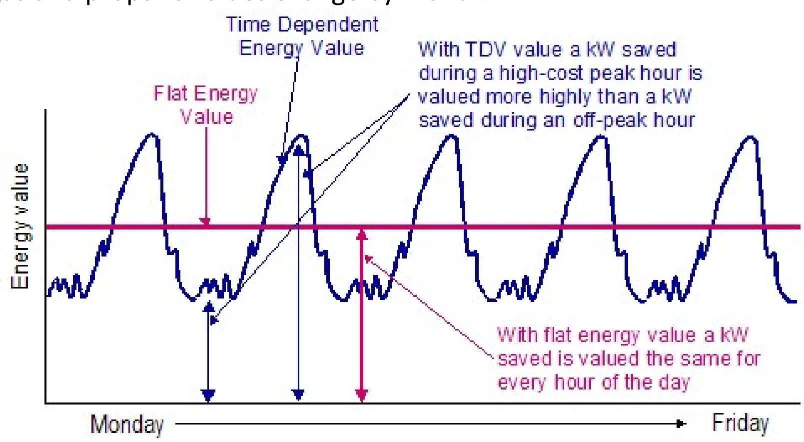

Figure 2: TDV Concept – "Flat" Valuation versus TDV for Electricity Use

The TDV value of electricity is highest during summer peak periods when the overall grid is stressed to full capacity and there is need for additional generation resources. Thus energy saved on peak carries a higher value than energy saved off-peak. As a result, residential HVAC energy savings get higher benefit under TDV (since HVAC usage coincides currently with system peak) and lighting savings get lesser benefits since they occur at night.

- **Energy Design Rating (EDR)** - The EDR is a separate calculation from code compliance calculation and is akin to an energy use intensity, except that it is based on TDV as envisioned in the 2015 IEPR. The EDR is calculated using CEC approved calculations and assumptions in the Title 24 Part 6 (building energy code). Unlike code compliance which is based on regulated loads, EDR includes all energy uses within the building such as space heating, space cooling, water heating, lighting, plug and appliance energy use. The EDR calculation uses a reference home compliant with the 2006 International Energy Conservation Code (IECC), to better align EDR with RESNET calculations for Energy Rating Index (ERI). The reference home gets an EDR score of 100 and the building is considered ZNE Code - Design if the EDR = Zero (0). This is in line with and a direct implementation of the ZNE Code definition outlined in the 2015 IEPR. Note that there is currently no CEC-approved method for calculating EDR for Nonresidential Buildings.
- **Energy Rating Index (ERI)** - The ANSI/RESNET/ICC 301-2014 Standard for the Calculation and Labeling of the Energy Performance of Low-Rise Residential Buildings using an Energy Rating Index was republished in January 2016 with some modifications to outline how a ZNE Design building should be evaluated. The methodology compares the energy performance of an actual home with the energy performance of a reference home of the same geometry, resulting in a relative energy rating called the Energy Rating Index (ERI). Where the energy performance of the actual home and the reference home are equal, the ERI is 100 and where the actual home requires no net purchased energy annually, the ERI is 0 (zero).
- **Energy Use Intensity (EUI)** - The EUI is expressed as kBtu/sf/yr and is a commonly used metric of a building's energy use or performance. It also allows benchmarking and comparisons of buildings. In order to normalize the various fuels in a building, all the energy forms for both use and production/generation are converted to thousands (k) of British Thermal Units (Btu) and then divided by the square feet (sf) of the building with 'yr' representing the 12 month period of data.

2.3 Study Recommendations

The report proposes verification methodologies for the following ZNE metrics: ZNE Design versus ZNE Performance. Within each, the methodologies are further refined based on whether the design is based on ZNE Code that uses the California Integrated Energy Policy Report (IEPR) definition using Time Dependent Valuation (TDV) or using ZNE Site or ZNE Source energy metrics. The methodologies are also separated by whether they are for residential or nonresidential buildings. Section 5 presents the proposed ZNE Evaluation methodologies. Based on the review of data from case study buildings summarized in Section 6, here are the key verification requirements:

ZNE Metric to be Verified	Stage	Verification Metric Residential	Evaluation Metric Nonresidential
ZNE Site	Design	ERI = 0 Predicted Net Site kBtu = 0	Predicted Net Site kBtu = 0
	Performance	Actual Net Site kBtu = 0	
ZNE Source	Design	Predicted Net Source kBtu = 0	
	Performance	Actual Net Source kBtu = 0	
ZNE Code (TDV)	Design	EDR = 0	
	Performance	Calibrated Predicted Net kBtu = Actual Net kBtu	

Figure 3: Key ZNE Verification Metrics by ZNE Criteria

ZNE Metric to be Verified	Stage	Modeled Energy Performance – Annual total of hourly analysis	Utility Net Meter Data – Annual	Separate Energy Use and Renewable Meter Data - Annual	End Use Monitoring – Annual Total and/or Hourly
ZNE Site	Design	Sufficient	Not Required	Not Required	Not Required
	Performance	Not Required	Sufficient	Sufficient	Not Required
ZNE Source	Design	Sufficient with Source Factors	Not Required	Not Required	Not Required
	Performance	Not Required	Sufficient with Source Factors	Sufficient with Source Factors	Not Required
ZNE Code (TDV)	Design	Sufficient with TDV Factors	Not Required	Not Required	Not Required
	Performance	Required but not sufficient by itself	Required along with building details necessary for a calibrated post-construction energy model (see § 5.5.2)		Not Required

Figure 4: Required Data to Verify that a Building Meets the ZNE Criteria by Type of ZNE Criteria

Each of the proposed verification methodologies presented in this document represents a particular type of ZNE building and it is not necessary that a building that is ZNE under one metric (say ZNE Code) is ZNE under another metric (say ZNE Site). Further, a building designed to be ZNE may or may not have ZNE Performance. Thus it is important that ZNE buildings be qualified as ZNE Design or ZNE Performance as well as specify the metric being used (Site/Source/Code). ZNE Verified – a term used by New Buildings Institute (NBI) – may be a good substitute for ZNE Performance.

2.3.1 Establish Standard Documentation Requirements

Based on review of the ZNE case study buildings and specifically the gaps in data availability to conduct verification activities on various ZNE metrics, this section outlines documentation requirements for each of the ZNE metrics of concern. Since most of the required documentation is similar across the ZNE metrics, the report presents the full list of documentation for ZNE Code - Design but for the subsequent metrics, the report presents only those data and results that are unique to those metrics.

ZNE Code – Design: Documentation Requirements

Topic	Subtopic	Submittal Requirements
Analysis Methodology	Software Used for Predictions	Name and version of software (needs to be CEC approved software).
	Period of Analysis	Annual based on hourly analysis
Net Energy Use Onsite	Energy Design Rating (EDR)	EDR calculated using CEC approved methodologies. EDR must be Zero or Negative to show ZNE Code compliance. NOTE: Currently there is no approved CEC method to calculate EDR for Nonresidential Buildings.

Topic	Subtopic	Submittal Requirements
Annual Energy Consumption Onsite	Predicted Electricity Use (kWh)	Total kWh/sf for a 12-month period
	Predicted Fuel Use (Therm)	Total Therm/sf for a 12-month period
	Predicted TDV Use	Total TDV/sf for a 12-month period
	Predicted TDV Use by End Use Category	TDV/sf by end uses for all building end uses for a 12-month period
Annual Renewable Energy Generated Onsite	Predicted Annual Renewable Electricity Produced Onsite Dedicated to Offset Building Energy Use (kWh)	Total kWh/sf for a 12-month period. Note: This feature is not natively available in nonresidential compliance software currently.
	Predicted Onsite Renewable Electricity Generation Dedicated to Offset Building Energy Use (TDV)	Total TDV/sf for a 12-month period. Note: This feature is not natively available in nonresidential compliance software currently.
Background	Project Team	Owner, Developer, Builder, Architect, Mechanical Engineer, Contractor, Energy Consultant, Other Consultants
	Project Goals	ZNE metric targeted; specific goals and targets relevant to ZNE
General Building Information	Project Name	
	Location	City, County, CEC Climate Zone
	Building Type	Type(s) of building occupancies (e.g. Office, Retail, School, Residential Single Family, Residential Multifamily Low-rise, Residential Townhomes)
	Building Size	Conditioned area, # floors, # buildings
	Construction Type	New Construction; Addition/Retrofit
Building Construction	Building Envelope	Framing type, U-factor (wall, roof, floor), U-factor and SHGC (windows), air leakage
	HVAC System	System type, capacity, efficiency, # of systems
	DHW System	System type, capacity, efficiency, # of systems
	Lighting	Lighting efficacy (lumens/watt)
Building Occupancy	Number of Occupants	Default per CEC Residential/Nonresidential ACM procedures.
	Occupancy Schedule	
	Equipment Schedule	
	Lighting Schedule	
Building Commissioning	System Commissioning	Commissioning Report outlining key activities performed – for nonresidential buildings only.
	Building Operations	Building Operations Manual or other documentation outlining building operational strategies
Renewable Energy Systems	Photovoltaic (PV) System Generation Capacity (kW)	Total installed rated capacity in kW DC and kW AC

Topic	Subtopic	Submittal Requirements
	Photovoltaic (PV) System Capacity Dedicated to Offset Home Energy Use (kW)	Total installed rated capacity in kW DC and kW AC dedicated to offset home energy use. Renewable capacity dedicated for Electric Vehicle (EV) or Storage needs to be subtracted from the total generation capacity to calculate this number.
	Photovoltaic (PV) Orientation and Tilt	Orientation in degrees from North (0=North, 90 = East); Tilt (angle from horizontal); If multiple panels used, provide orientation and tilt by each panel 'group'
	Photovoltaic (PV) System Location	Specify location of renewable system (e.g. Roof). System must be installed within the bounds of the 'project' site as defined in the 2015 IEPR
	Photovoltaic (PV) Manufacturer and Make	Make, model number, manufacturer name
	Other Renewable Energy Systems	Rated capacity, total annual output, location onsite, manufacturer and make.
Electric Vehicles	If Electric Vehicle Charging is Anticipated	# of Electric Vehicles Predicted to be Charging at Home
Energy Storage	Energy Storage System	Estimated Storage Capacity

Figure 5: Proposed ZNE Code Verification Requirements for Documentation

ZNE Design - Site/Source: Documentation Requirements

Topic	Subtopic	Submittal Requirements
Analysis Methodology	Software Used for Predictions	Name and version of software (needs to be ANSI/RESNET/ICC approved software for residential buildings).
	Period of Analysis	Annual based on hourly analysis
Net Energy Use Onsite	Res: Energy Rating Index (ERI)	ERI calculated using ANSI/RESNET/ICC approved methodologies. ERI must be Zero or negative to show Res ZNE Design.
	Nonresidential: Predicted Net Annual Site Energy Use (site kBtu)	Total Predicted Energy Use (site kBtu/sf) - Total Predicted Renewable Electricity Produced Onsite (site kBtu/sf) = Zero or Negative.
	Res/Nonresidential: Predicted Net Annual Source Energy Use (source kBtu)	Total Predicted Energy Use (source kBtu/sf) - Total Predicted Renewable Electricity Produced Onsite (source kBtu/sf) = Zero or Negative.
Building Occupancy	Number of Occupants	Res: default per ANSI/RESNET/ICC 301-2014 Nonresidential: document assumptions made by modeler
	Occupancy Schedule	
	Equipment Schedule	
	Lighting Schedule	

Figure 6: Proposed ZNE Design - Site/Source: Documentation Requirements (excerpt)

ZNE Site – Performance: Documentation Requirements

Topic	Subtopic	Submittal Requirements
Net Energy Use Onsite	Net Annual Actual Energy Use (site kBtu)	Actual Annual Energy Use (site kBtu/sf) - Actual Annual Renewable Electricity Produced Onsite Dedicated to Offset Home Energy Use (site kBtu/sf) = Zero or Negative.
Building Occupancy	Number of Occupants	Actual average number of occupants
	Operating Hours and Schedule	Actual weekly hours of operation, and typical occupancy schedule (weekday and weekend/holiday)
	Vacancy Rate	Confirm that vacancy was less than 10% on an annual basis
	Building System Operation	Confirm that building systems were installed per manufacturer instructions and operational. Note any discrepancies.
	System Commissioning (nonresidential)	Commissioning Report outlining key activities performed
Billing and Metering Data	Electricity Bills	Monthly electricity bills for at least 12 months post-occupancy
	Natural Gas/Fuel Bills	Monthly natural gas/fuel bills for at least 12 months post-occupancy
	Renewable Electricity Metering (Optional)	Monthly renewable electricity production for at least 12 months post-occupancy. If separate PV Meter is not installed onsite, note source of estimate.
Annual Energy Consumption Onsite	Actual Electricity Use (kWh)	Total kWh for a 12-month period post-occupancy
	Actual Fuel Use (Therm)	Total Therm for a 12-month period post-occupancy
	Actual Site Energy Use (site kBtu)	Total site energy use (site kBtu/sf) for a 12-month period post-occupancy
	Actual Energy Use by End Use Category (Optional)	kWh and Therm by end uses - Space Cooling, Space Heating, Ventilation, DHW, Lighting, Appliances and MELs.
Annual Renewable Energy Generated Onsite	Actual Annual Renewable Electricity Produced Onsite dedicated to offset Building Energy Use (kWh)	Total kWh for a 12-month period
	Actual Annual Renewable Electricity Produced Onsite dedicated to offset Building Energy Use (site kBtu)	Total site kBtu/sf for a 12-month period
Weather Data (Optional)	Cooling Degree Days during the period of analysis	Document CDD base 65°F during the period of analysis through review of observed weather from nearest weather station with data availability.

Topic	Subtopic	Submittal Requirements
	Heating Degree Days during the period of analysis	Document HDD base 65°F during the period of analysis through review of observed weather from nearest weather station with data availability.
Significant Operational Variables	Operational Variables compared to Design	Short narrative of incidents or variations that affected the energy use (positive or negative) compared to design stage assumptions.

Figure 7: ZNE Site – Performance: Documentation Requirements

ZNE Source – Performance: Documentation Requirements

Documentation requirements for ZNE Source - Performance are similar to that for ZNE Site - Performance except that for ZNE Source, the analysis is documented in terms of source kBtu per Figure 8. The figure does not repeat documentation requirements outlined in Figure 7 which apply here as well.

Topic	Subtopic	Submittal Requirements
Billing and Metering Data	Electricity Bills	Monthly electricity bills for at least 12 months post-occupancy
	Natural Gas/Fuel Bills	Monthly natural gas/fuel bills for at least 12 months post-occupancy
	Renewable Electricity Metering (Optional)	Monthly renewable electricity production for at least 12 months post-occupancy. If separate PV Meter is not installed onsite, note source of estimate.
Annual Energy Consumption Onsite	Actual Electricity Use (kWh)	Total kWh for a 12-month period post-occupancy
	Actual Fuel Use (Therm)	Total Therm for a 12-month period post-occupancy
	Actual Total Energy Use (kBtu)	Total energy use in Source kBtu for a 12-month period post-occupancy
	Actual Total Energy Use Intensity	Source kBtu/sf for a 12-month period post-occupancy
	Actual Energy Use by End Use Category (Optional)	kWh and Therm by end uses - Space Cooling, Space Heating, Ventilation, DHW, Lighting, Appliances and MELs.
Annual Renewable Energy Generated Onsite	Actual Annual Renewable Electricity Produced Onsite dedicated to offset Home Energy Use (kWh)	Total kWh for a 12-month period
	Actual Onsite Renewable Electricity Generation Dedicated to Offset Home Energy Use (kBtu)	Total source kBtu/sf for a 12-month period
Net Energy Use Onsite	Net Annual Actual Energy Use (source kBtu)	Total Actual Energy Use (kBtu) - Total Actual Renewable Energy Produced Onsite dedicated to offset building energy use (kBtu) = Zero or Negative. Note: For this calculation, onsite fuel and electricity usage are converted to source kBtu

Figure 8: ZNE Source Documentation Requirements (Excerpt)

2.3.2 Identify Entities that will be Responsible for ZNE Verification

Currently, there is no central entity within California that is responsible for verification of ZNE. This is likely to change as ZNE becomes a code mandate and ZNE Design claims will be verified by building departments and HERS raters. These entities need to be trained and coordinated so that the ZNE verification is done consistently across the state. But this is in the future, assuming ZNE Code is put in place. Till then, there is currently no entity that oversees ZNE Code and ZNE Design verification.

There is no requirement for ZNE Performance in current regulatory proceedings and utility programs. Thus it is unknown if there will be a central entity or a coordinated effort to ensure that ZNE verification is done on a consistent basis. The ZNE Recognition program being developed by the California Public Utilities Commission (CPUC) appears to be the right venue for this entity but the ZNE recognition program does not have any ongoing scope or budget to do so. Any entity tasked with ZNE verification will require sufficient support, and adequate training to ensure that verification is accurate and consistent throughout the state.

2.3.3 Develop Standardized Registries for ZNE Buildings

Related to above, there is a need to develop a standardized tracking platform that tracks ZNE Design and ZNE Performance across buildings. Currently, there is no one place where this information is tracked.

NBI is tracking commercial buildings nationally through their efforts with various grants and sponsors as well as in greater depth in California through their efforts with the CPUC. On the residential side, the IOUs completed a ZNE Market Characterization study that identified ZNE buildings in the state, but that was a one-time activity. The Net-Zero Energy Coalition[1] as well as RESNET are both tracking ZNE buildings across the country – but they use differing definitions. Note that these efforts are reliant on self-reporting by building owners and operators of their predicted and actual energy use/energy generation onsite.

2.3.4 Develop Rulesets for ZNE Code - Design Nonresidential Modeling

There are several aspects of the ZNE Code - Design Nonresidential analysis, documentation and verification that are currently unknown. There are no procedures within the compliance tools to address onsite renewable generation, no procedures to calculate the Energy Design Rating and no nonresidential HERS Raters or data registries that can verify and track nonresidential building ZNE Code status.

2.3.5 Develop Verification Methodologies for ZNE Retrofits in Existing Buildings

The verification methodologies proposed in this document are applicable to new construction ZNE buildings only. The methodologies for ZNE performance validation may be applicable to retrofit situations but this study has not conducted detailed analysis of the suitability of the proposed verification methodologies for retrofits. The study team therefore recommends a follow-up study to review ZNE retrofit projects and identify retrofit specific verification methodologies.

[1] http://netzeroenergycoalition.com/wp-content/uploads/2015/04/20150105_nzec_zero_energy_homes_report_booklet_fnl_02.pdf

3. Introduction

Pacific Gas & Electric Company (PG&E), on behalf of the joint California Investor Owned Utilities (IOUs), contracted with a team led by TRC Energy Services (TRC) to develop verification methodologies for validating predicted and actual energy performance of Zero Net Energy (ZNE) buildings in California. **It is important to note that this project is not intended to develop evaluation protocols specific to individual ZNE programs or initiatives nor is it intended to address all aspects of program evaluation (e.g. free-ridership, Net-to-Gross etc.). Rather it is intended to address how gross energy savings at the unit level (ZNE Building) are to be verified at the design stage as well as once the building is constructed and under operation.**

This study builds upon protocols currently being used to specify and track ZNE building design and performance by early adopters across the country and specifically on efforts within California to develop a unified ZNE recognition effort and the stated policy of ZNE Code buildings currently under development. This study also builds upon verification methodologies currently being used for evaluation of IOU Codes and Standards and IOU Non Residential New Construction programs.

This scope represents the first phase of a future larger project. The current study identifies challenges for ZNE verification, tests methods for handling these challenges on a few ZNE buildings, and - based on results - present starting points and recommendations for developing ZNE verification methodologies at a statewide level. In future phases, the project will improve the verification methodologies from the design, construction, and performance perspectives as more data becomes available on ZNE buildings.

3.1 Study Objectives

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- Objective I: Develop Draft Verification Methodologies for ZNE Buildings in California based on literature review and review of ZNE building data availability.
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- **ZNE Performance** – A ZNE Performance designation denotes that the building is performing as a ZNE building based on actual building operation.
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- **ZNE Source** – This definition is similar to the ZNE Site definition, except the metric used is a source kBtu (source energy) that accounts for energy required to extract and transport the raw fuel and losses associated with conversion, transmission and distribution to the point of use (building).This is typically achieved by multiplying site energy values with a multiplier that then generates the source values. These site-to-source conversion factors vary by fuel (electricity, natural gas, propane) as well as the electricity generation mix for a particular utility or region. This report uses national average values for site-to-source energy as used by the US Department of Energy (DOE) for the EnergyStar and Portfolio Manager initiatives. This enables the values to be comparable across the various states and utility territories across the country.
- **ZNE Code** – this definition of ZNE is specific to California and is unlike the definitions of ZNE used elsewhere. As described in detail in Section 4.3, a ZNE Code building is one that achieves ZNE based on the Time Dependent Valuation (TDV) of energy use and generation onsite. ZNE Code is a design rating since it is based on predicted energy performance. It uses the Energy Design Rating (EDR) to express whether a building is ZNE.
- **Time Dependent Valuation (TDV)** – TDV has been used to evaluate cost-effectiveness of energy efficiency and demand response measures for Title 24 since the 2005 Title 24 update. Prior to 2005, a flat value of source energy cost was used to evaluate the value of measures. Under TDV, energy is valued instead on an hourly basis that better reflects the actual cost of energy to the customers, to the utility system and to society. TDV values are calculated separately for the three primarily fuels used in buildings – electricity, natural gas and propane – as well as for the 16 California climate zones. Electricity values change by hour for each hour of the year while natural gas and propane values change by month.

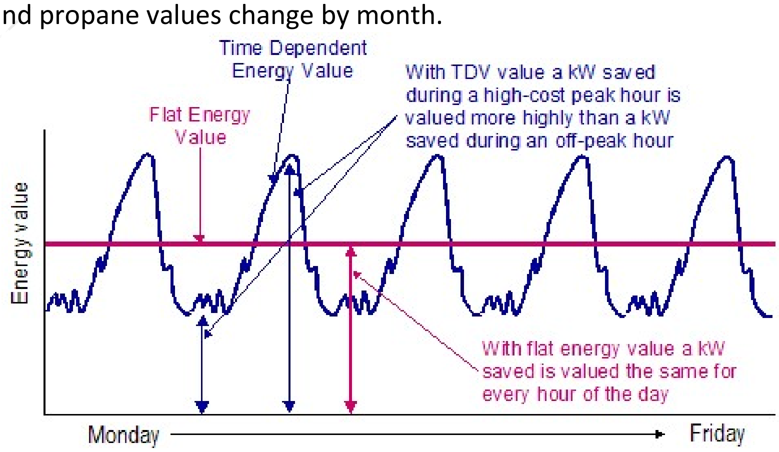

Figure 9: TDV Concept – "Flat" Valuation versus TDV for Electricity Use

The TDV value of electricity is highest during summer peak periods when the overall grid is stressed to full capacity and there is need for additional generation resources. Thus energy saved on peak carries a higher value than energy saved off-peak. As a result, residential HVAC energy savings get higher benefit under TDV (since HVAC usage coincides currently with system peak) and lighting savings get lesser benefits since they occur at night.

- **Energy Design Rating (EDR)** - The EDR is a separate calculation from code compliance calculation and is akin to an energy use intensity, except that it is based on TDV as envisioned in the 2015 IEPR. The EDR is calculated using CEC approved calculations and assumptions in the Title 24 Part 6 (building energy code). Unlike code compliance which is based on regulated loads, EDR includes all energy uses within the building such as space heating, space cooling, water heating, lighting, plug and appliance energy use. The EDR calculation uses a reference home compliant with the 2006 International Energy Conservation Code (IECC), to better align EDR with RESNET calculations for Energy Rating Index (ERI). The reference home gets an EDR score of 100 and the building is considered ZNE Code - Design if the EDR = Zero (0). This is in line with and a direct implementation of the ZNE Code definition outlined in the 2015 IEPR. Note that there is currently no CEC-approved method for calculating EDR for Nonresidential Buildings.
- **Energy Rating Index (ERI)** - The ANSI/RESNET/ICC 301-2014 Standard for the Calculation and Labeling of the Energy Performance of Low-Rise Residential Buildings using an Energy Rating Index was republished in January 2016 with some modifications to outline how a ZNE Design building should be evaluated. The methodology compares the energy performance of an actual home with the energy performance of a reference home of the same geometry, resulting in a relative energy rating called the Energy Rating Index (ERI). Where the energy performance of the actual home and the reference home are equal, the ERI is 100 and where the actual home requires no net purchased energy annually, the ERI is 0 (zero).
- **Energy Use Intensity (EUI)** - The EUI is expressed as kBtu/sf/yr and is a commonly used metric of a building’s energy use or performance. It also allows benchmarking and comparisons of buildings. In order to normalize the various fuels in a building, all the energy forms for both use and production/generation are converted to thousands (k) of British Thermal Units (Btu) and then divided by the square feet (sf) of the building with ‘yr’ representing the 12 month period of data.

3.3 Study Methodology

The study methodology was outlined in a Research Plan that was publicly posted and vetted through extensive stakeholder engagement. This report does not repeat the entire Research Plan here but rather highlights the key aspects of the plan:

3.3.1 Task 1 Project Initiation Meeting and Study Plan Discussion

The study team held a project initiation meeting on April 27, 2015 at PG&E’s offices and using a web-based meeting format. This meeting was attended by:

- The study team leads – Abhijeet Pande, Cathy Chappell
- PG&E and support staff – Rachel Allen (PG&E – study manager); Peter Turnbull, Conrad Asper (PG&E); Dr. Carrie Brown, Anna LaRue, and Margaret Pigman (Resource Refocus LLC)
- California Public Utilities Commission (CPUC) – Cathy Fogel
- California Energy Commission (CEC) – Farakh Nasim
- New Buildings Institute (NBI) – Mark Lyles

- Southern California Edison (SCE) – John Morton
- Sempra Utilities – Chuck Berry, Darrell Brand, Adam Manke

The purpose of this meeting was to:

- Review the project scope and clarify the issues to be studied
- Clarify team member roles, responsibilities, and coordination needs
- Clarify project limitations and schedules

3.3.2 Task 2: Final Research Plan

The study team submitted a draft Research Plan on May 1, 2015 which was posted to the CPUC evaluation project public review website (http://www.energydataweb.com/cpuc/search.aspx). The study team received comments from CPUC staff, CPUC consultants, and IOU staff as well as evaluation stakeholders across the state. The study team addressed their comments and a final Research Plan was posted to the same CPUC evaluation project public review website on July 9, 2015.

3.3.3 Task 3: Data Collection and Analysis

Data collection started with review of existing efforts tracking development of ZNE buildings such as the New Building Institute's Commercial ZNE classification and verification methodologies used in their "Getting to Zero" project and the Living Buildings Challenge. A detailed summary of literature is provided in Section 4 of this document. Next, the study team developed draft research methodologies as outlined in Section 5. Then the study team collected ZNE building data on several recently completed ZNE buildings in California. A complete list of buildings, the available data and summary of energy performance is provided in Section 6 of this document. The draft methodologies were tested against the available data to confirm suitability and scalability.

3.4 Study Team

The study was funded by the IOUs with Rachel Allen (PG&E) providing project oversight and contract management. Dr. Carrie Brown and Anna LaRue (Resource Refocus LLC) supported PG&E on study management. TRC was the lead contractor with Abhijeet Pande as the study lead with support from Cathy Chappell, Dr. Marian Goebes, Vasudha Lathey and others. TRC was supported by subcontractors Energy and Environmental Economics (E3) and Davis Energy Group (DEG).

While he was not part of the study team, Ed Dean from Bernheim + Dean Inc. provided crucial modeling and metered data from ZNE case study projects through a separate effort funded by PG&E. Similarly, while they were not official team members, Michael Wikler and Sean Armstrong (Redwood Energy) provided modeling and metered data for multifamily buildings.

3.5 Application Scenarios for the ZNE Verification Methodologies

There are currently several utility efforts to promote ZNE buildings, from ZNE pilot programs for residential, commercial and school buildings, new construction programs such as California Advanced Homes Program (CAHP) and Nonresidential New Construction program, Codes and Standards Enhancement (CASE) initiatives and training, outreach and education. Additionally, there are non-utility efforts such as those run by third party program implementers and rating entities (e.g. Build it Green) that promote ZNE. Lastly, the early adopters in the ZNE design and construction community (e.g. residential builders) who are constructing ZNE buildings on a voluntary basis and need a common language for promoting ZNE to their customers/clients. All of these efforts need to address or at least be cognizant of the regulatory definition of ZNE included in the 2015 Integrated Energy Policy Report (IEPR) that uses the TDV metric as its basis.

With all these efforts addressing ZNE, there is a need to establish some common protocols for what constitutes a ZNE building, especially when there is a mismatch between the regulatory definition (ZNE Code) and those used by early adopters (ZNE Site, ZNE Source). Without a common set of data, analysis and verification protocols, it is impossible to know whether everyone is talking about the same ZNE metric and whether they have indeed achieved ZNE.

With this background in mind, this study aims to develop verification methodologies to address ZNE verification challenges for the following programmatic and voluntary efforts:

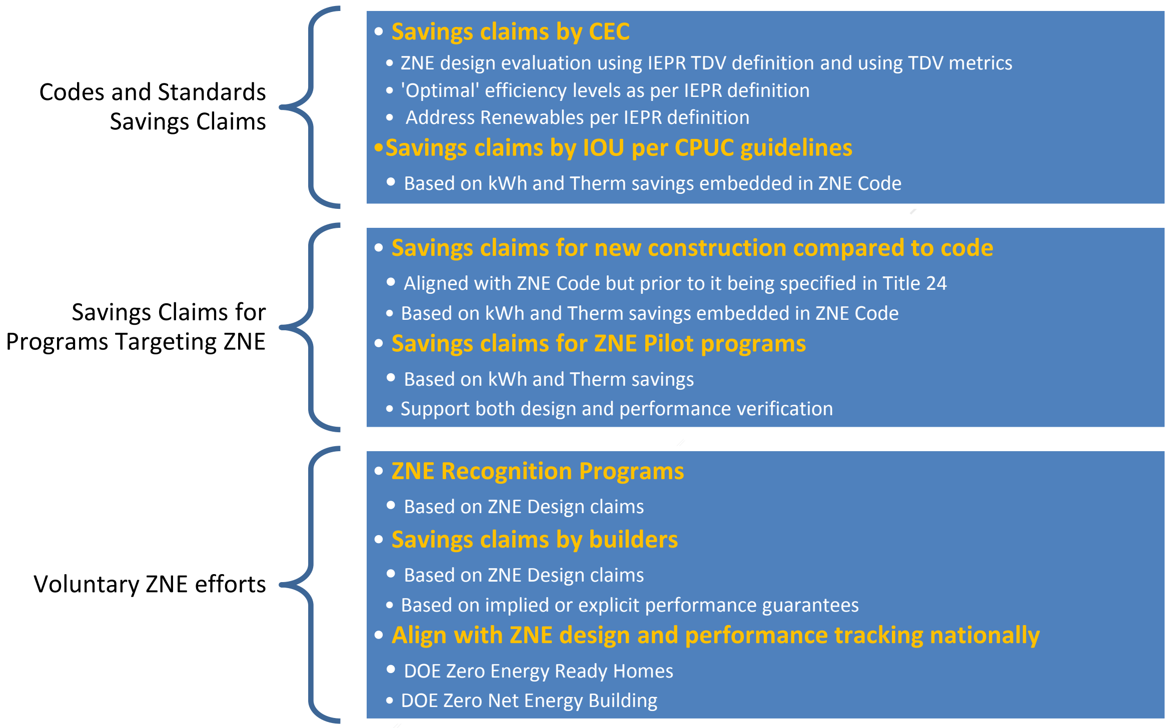

Figure 10: Programs and Voluntary Efforts that Require Verification of ZNE Design or Performance

The rest of this document assumes that all of these applications are relevant considerations for developing verification methodologies, and that the data and analysis needs will differ systematically across applications.

It should be noted again that this project is only addressing how to verify that the building is indeed ZNE (whether at design stage or in performance) and not intended to address all of the aspects of evaluation of utility programs referenced above.

3.6 Limitation of Project Scope

To help frame the review of the proposed methodologies, the following limitations of the study are important:

- This project is not intended to develop evaluation protocols specific to individual ZNE programs or initiatives, nor is it intended to address all aspects of program evaluation (e.g. free-ridership, Net-to-Gross etc.). Rather it is intended to address how gross energy savings at the unit level (ZNE Building) are to be verified at the design stage as well as once the building is constructed and under operation.

- This project is not intended to be a re-visioning exercise of 'ZNE Definitions' and the relative merits and drawbacks of the IEPR ZNE definition. Rather this study focuses on operational challenges and solutions to evaluating status of buildings designed or operated to the various ZNE definitions.
- The study has a limited budget and therefore is not intended to answer each and every question that may arise during the course of the study. It is likely and is intended that this study will raise certain verification-related questions that will need further efforts through follow-up studies.
- This study focuses on the implications of potential policy choices regarding ZNE buildings. It does not presume particular policy choices as being preferable and presents the complexities or lack thereof for various policy choices. This study is not intended to make particular policy recommendations.
- This study will identify the challenges for ZNE verification, test methods for handling these challenges on a few ZNE buildings, and - based on results - present starting points and recommendations for developing ZNE verification methodologies at a statewide level. This study will not propose the final verification methodologies that should be used at the statewide level.
- This study is not an exhaustive verification exercise of ZNE efforts to date.
- Performance data is limited on ZNE buildings to date. Coupled with limited study budget, the project will apply the draft verification methodologies to those small number of ZNE buildings in the state where energy performance data is readily available. This study does not have the budget or scope to collect any additional or primary building energy use data.
- This study is not a technical analysis of measure level savings within ZNE buildings. The goal is to evaluate the overall whole building energy performance and not to validate the energy performance or effectiveness of any one particular strategy incorporated into the building.
- This study will not develop any new TDV values or other such primary data needed to evaluate ZNE buildings.
- This study will focus primarily on new construction projects although there are examples of ZNE retrofits in the case studies covered.

4. Literature Review

The study team began by reviewing existing literature of ZNE-related studies to understand what information is already available to help achieve the study objectives:

- *An Evaluation Framework for Residential Zero Net Energy Buildings (Mahone et al, 2014)*[1]
- *New Building Institute's Commercial ZNE classification and verification methodologies used in their "Getting to Zero" project*[2,3]
- *Research recommendations from prior IOU ZNE research projects including, but not limited to: Road to ZNE study*[4]*, ZNE Technical Feasibility study*[5]*, Residential ZNE Market Characterization*[6]
- *2015 Integrated Energy Policy Report (CEC)*[7]
- *ANSI/RESNET/ICC 301-2014*[8]
- *Draft New Residential Zero Net Energy Action Plan 2014-2020 (CPUC)*[9]
- *2017 Time Dependent Valuation and Lifecycle Cost methodology update (CEC)*[10]
- *ZNE building case studies – PG&E monograph; the many case studies produced by NBI and the IOUs' Emerging Technologies (ET) programs*
- *2006 California Energy Efficiency Evaluation Protocols (including the specific protocols for the Codes & Standards program)*[11]

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[1] Retrieved from: http://aceee.org/files/proceedings/2014/data/papers/2-1038.pdf

[2] Retrieved from: http://newbuildings.org/sites/default/files/2014_Getting_to_Zero_Update.pdf

[3] New Buildings Institute, proposed Draft ZNE Technical Criteria for ZNE Recognition for CPUC

[4] 2012, HMG, "Road to ZNE: Mapping Pathways to ZNE Buildings in California". Available at http://www.energydataweb.com/cpucFiles/pdaDocs/897/Road%20to%20ZNE%20FINAL%20Report.pdf

[5] 2012, Arup, "Technical Feasibility of ZNE Buildings in California (ZNE Technical Feasibility)". Available at http://calmac.org/publications/California_ZNE_Technical_Feasibility_Report_CALMAC_PGE0326.01ES.pdf

[6] 2015, TRC. "Residential ZNE Market Characterization". Available at http://www.calmac.org/publications/TRC_Res_ZNE_MC_Final_Report_CALMAC_PGE0351.01.pdf

[7] 2015, California Energy Commission, Proposed 2015 IEPR, pp. 1-57. Available at http://www.energy.ca.gov/2015_energypolicy/

[8] Retrieved from: http://www.resnet.us/blog/wp-content/uploads/2016/01/ANSI-RESNET-ICC_301-2014-Second-Edition-Publish-Version.pdf

[9] California Public Utilities Commission, & California Energy Commission. (2013). New Residential Zero Net Energy Action Plan 2014-2020. Retrieved from http://www.cpuc.ca.gov/NR/rdonlyres/D8EBFEE4-76A5-47AC-A8F3-6E0DAB3A9E5D/0/DRAFTZNE_Action_Plan_Comment.pdf

[10] Retrieved from: http://www.energy.ca.gov/title24/2016standards/prerulemaking/documents/2014-07-09_workshop/2017_TDV_Documents/

[11] Retrieved from: http://www.calmac.org/events/evaluatorsprotocols_final_adoptedviaruling_06-19-2006.pdf

- *Market Transformation White Papers (K. Keating & R. Prahl)*[1]
- *Certified High Performance HVAC Specifications; 2020 Mandatory Performance Levels – and – ZNE, ET, and CAHP Program Performance Levels Today (Rick Chitwood, November 22, 2014)*

4.1 Literature Review Summary

Figure 11 shows the criteria established by seven entities broken down based on whether the ZNE definition targets ZNE Design versus ZNE Performance.

Relevant Standard/Effort	Design	Performance
2015 California Integrated Energy Policy Report (IEPR) 2016 CalGreen Tier III (ZNE Code)	Energy Design Rating (EDR) = 0 (based on TDV)	NA
ANSI/RESNET/ICC 301-2014 (ZNE Design)	Energy Rating Index (ERI) = 0 (based on site energy)	NA
New Buildings Institute (NBI) ZNE Watchlist	ZNE Emerging (Net site kBtu/sf ≤0)	ZNE Verified (Net site kBtu/sf = 0)
NBI proposed Draft ZNE Technical Criteria for ZNE Recognition for CPUC	ZNE Commitment, ZNE Emerging (Net site kBtu/sf = 0)	ZNE Verified (Net site kBtu/sf = 0)
International Living Future Institute (ILFI)	NA	Net kWh = 0
DOE Zero Energy Ready Home	RESNET HERS Rating (based on site energy)	NA
DOE Zero Net Energy Building	NA	Net Source kBtu = 0

Figure 11: Summary of ZNE Definitions Targeted by Various Entities

Within California, the 2015 IEPR is the official document that outlines the stated policy of achieving ZNE for residential and commercial new construction. This definition of ZNE is specific to ZNE Design as it is intended to be a code mandate – hence also called the ZNE Code definition. The specifics of how the ZNE Code definition is to be calculated are still being determined by the California Energy Commission (CEC) but what is known is that the key metric for evaluating whether the building is ZNE Code is whether the energy simulation analysis done using approved software provides an EDR of zero. The EDR itself uses the TDV metric embedded in California Title 24 compliance. EDR is intended to account for whole building energy use as well as onsite renewable generation at the project level. This ZNE Code definition is being codified through proposed 2016 updates to the state green code (CalGreen) through a voluntary Tier III for energy performance of residential new construction.

Outside of California, the RESNET HERS protocols have been codified into the ANSI/RESNET/ICC Standard 301-2014 which was re-published with updates in February 2016. The ANSI standard uses an ERI metric very similar to the California EDR metric for designating a building to be ZNE Design. In fact ERI and EDR share a lot of commonalities in their analysis methods, and both the CEC and RESNET intend to further coordinate on the two metrics to fully harmonize their methodologies and results.

New Buildings Institute (NBI) has been maintaining a ZNE Watchlist for the California Public Utilities Commission (CPUC) that uses separate criteria for ZNE Design versus ZNE Performance. ZNE Emerging is the name given to buildings (or districts) that have a publically stated goal of ZNE but do not yet meet the definition of ZNE verified. These may be in the planning or design phase, under construction or have

[1] Available on CPUC's EE Public Documents area http://www.energydataweb.com/cpuc/search.aspx

been in operation for less than a year. Others may have been operating for 12 months or longer, but their measured energy has either yet to achieve net zero or the measured data to document ZNE verified status was not available. A ZNE Verified designation is given to a project that has demonstrated over a period of at least 12 consecutive months that the net site energy use is zero or negative. Net site use is computed based on converting all fuels to equivalent site kBtu/sf (Energy Use Intensity or EUI).

NBI is also developing technical criteria for a proposed California ZNE Recognition Program through the auspices of the CPUC. For this recognition program, there are two separate ZNE Design designations – ZNE Commitment describes organizations, such as local governments, school districts, or companies, that have established ZNE policy goals or targets; ZNE Emerging is assigned to those buildings where the building is designed to be ZNE or to those buildings where the construction is complete but less than a year of performance data is available. For ZNE performance, there is a proposed ZNE Verified designation that is the same as the one used for the ZNE Watchlist.

The International Living Future Institute (ILFI) includes ZNE as part of an overall holistic design through their Living Building Challenge and also offers a standalone net zero building certification program. This voluntary certification program is based on ZNE Performance but unlike other definitions described in this document, this program requires an all-electric design. ZNE designation is awarded to those projects where the net electricity usage onsite is zero on an annual basis.

Department of Energy (DOE) has two flavors of ZNE – for the ZNE Ready Homes[1] initiative, the ZNE designation is based on ZNE Design, whereas DOE also recently released a new definition for ZNE buildings[2] that is based on ZNE Performance. The ZNE Ready Homes definition in fact does not require renewables, rather that the home is ready for renewables. Thus it does not guarantee a ZNE Design, just the capability to achieve it if an appropriate renewable energy system is installed. The new common definition for ZNE buildings proposed by DOE is a performance metric that requires "An energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy."

The following sections provide details on each of these initiatives and how they address ZNE verification.

4.2 An Evaluation Framework for Residential Zero Net Energy Buildings

Prior to the development of regulatory ZNE parameters discussed in the subsections below, an ACEEE paper developed by TRC and PG&E for the 2014 ACEEE Summer Study identified key research questions for ZNE verification that are summarized below:

4.2.1 ZNE Design vs. ZNE Performance

The verification methodologies will necessarily be different if the goal of the ZNE building is to show that the building is designed to be ZNE versus that it performs as a ZNE building. For a ZNE Design definition, the building will be evaluated based on predicted performance, most likely through whole building energy simulation tools. Post-construction, there are two types of verification possible – a. construction validation and b. performance validation. Construction validation is an extension of the ZNE Design

[1] U.S. Department of Energy Zero Energy Ready Homes Initiative - http://energy.gov/eere/buildings/zero-energy-ready-home

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

verification and focuses on whether the building is constructed as designed. While ZNE Design and ZNE construction are both specific to the asset alone, ZNE Performance validation needs to incorporate both the asset as well as the operational aspects of a building. While ZNE Design has predictive power and can be established prior to occupancy, ZNE Performance cannot be established until at least a minimal amount of data is available and then processed using a standardized methodology. A simple measurement of "energy out" vs. "energy in" can be straightforward. It would be more useful and informative, however, if this could be supplemented by measurement of the key parameters governing performance: actual weather conditions, operational schedules, appliance and plug loads, renewable energy system performance, as well as the inherent efficiency of the asset (such as that established during the ZNE construction verification). Issues around the timeframe of this data collection and analysis therefore become important considerations for ZNE Performance verification.

4.2.2 Timeframe for Considering a Building ZNE

For ZNE Design, the time frame is determined by the underlying energy analysis that uses default weather files and accounts for 'predicted first year' savings.

For ZNE Performance on the other hand, there are several considerations necessary to determine the time frame over which the performance is to be verified. One of the important considerations is whether 'first year' performance is sufficient to ascertain that a building is performing at ZNE levels. Any given year (especially the first year of occupancy) could give erroneous results due to ongoing commissioning of systems, changes and adjustments made by building occupants and operators as well as the actual weather in that given year.

Another question related to the timeframe is persistence of savings, which in turn will be affected by weather and operational issues. The verification framework must address whether a ZNE building's performance over a set timeframe (e.g., one year) is incidental due to mitigating factors such as mild weather or people staying out of their homes for extended periods, or whether the observed performance is an indicator of meeting ZNE goals based on 'average' and long term weather conditions. Verification activities may need to be repeated over specified times to ascertain that the building continues to perform at ZNE levels of performance. If the building is found to not sustain ZNE performance there may need to be correction actions such as re-commissioning or retro-commissioning and operational changes in order to ensure sustained ZNE performance.

4.2.3 Accounting for Multiple Fuels

There are various ZNE definitions used across the country and they differ in how they address the use of multiple fuels onsite. Offsetting electricity usage with renewables such as photovoltaics that generate onsite electricity is easier in terms of the accounting due to both using the same unit of measurement. With natural gas consumption, additional calculations need to be made to determine the equivalent energy content of the onsite renewable electricity generation that will be needed to offset the project's natural gas consumption. Onsite biogas generation can be used as a direct offset for natural gas consumption. For the purpose of California ZNE buildings, the verification methodologies need to account for all fuels used onsite.

4.2.4 Impact of Human Behavior

Notwithstanding the various complexities in designing and evaluating ZNE buildings that have already been described, perhaps the biggest challenges result from the widely-varying behavioral patterns of building occupants. A white paper published by Ecotope and NBI in 2011[1] looked at the potential impacts of design and operational strategies on whole building energy use using an energy simulation parametric study. This white paper shows that the energy use of the building could change between -25% to +60% compared to the design intent depending on how the building is actually commissioned (or not) and operated.

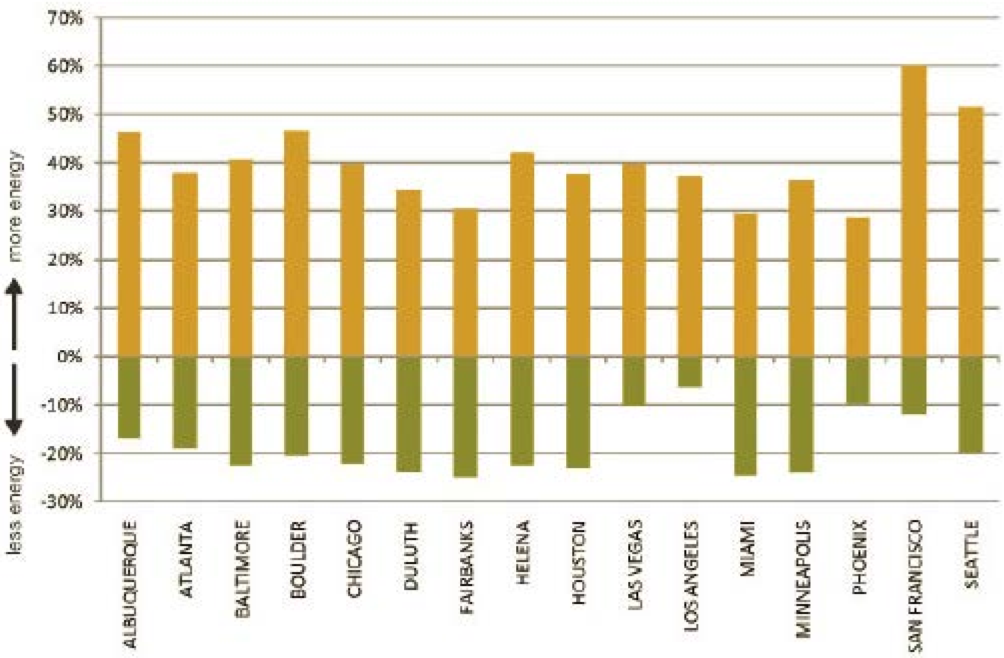

Figure 12: Impact of Variables Associated with Commissioning, Operations and Maintenance

For ZNE Performance verification, it thus becomes necessary to account for real time operation and behavior of building operators and occupants. Whole building energy measurements will provide little detail of how occupant behavior contributed to that performance unless specific data collection efforts are expended to capture these behaviors and operational characteristics.

4.3 2015 IEPR Definition of ZNE Code Buildings

The 2015 Integrated Energy Policy Report (IEPR) provides the following background and rationale for the IEPR: "*Senate Bill 1389 (Bowen, Chapter 568, Statutes of 2002) requires the California Energy Commission to prepare a biennial integrated energy policy report that assesses major energy trends and issues facing the state's electricity, natural gas, and transportation fuel sectors and provides policy recommendations to conserve resources; protect the environment; ensure reliable, secure, and diverse energy supplies; enhance the state's economy; and protect public health and safety (Public Resources Code § 25301[a]). The Energy Commission prepares these assessments and associated policy recommendations every two years, with updates in alternate years, as part of the Integrated Energy*

[1] "*Sensitivity Analysis: Comparing the Impact of Design, Operation, and Tenant Behavior on Building Energy Performance*", Ecotope and New Buildings Institute, White Paper, 2011. http://newbuildings.org/sites/default/files/SensitivityAnalysisReport.pdf

Policy Report. Preparation of the Integrated Energy Policy Report involves close collaboration with federal, state, and local agencies and a wide variety of stakeholders in an extensive public process to identify critical energy issues and develop strategies to address those issues."

The 2015 IEPR outlines the CEC and CPUC joint vision for infrastructure and efficiency improvements necessary in the energy sector – including Zero Net Energy (ZNE). As part of this vision, the 2015 IEPR outlines a definition for what constitutes a ZNE Code building – in other words, what would the state energy codes consider as ZNE for code compliance purposes. It should be noted that energy efficiency programs funded by various utilities and public/private entities will be pegged against this definition. This is because code sets the baseline for new construction programs and those programs targeting ZNE new construction will need to ensure that any ZNE projects they are incenting now will meet the ZNE Code definition.

It is also important to note that the ZNE Code building is a ZNE Design rating only. The ZNE Code definition does not guarantee that the building performs as a ZNE building.

The 2015 IEPR definition of ZNE Code building is one where "*the value of the energy produced by on-site renewable energy resources is equal to the value of the energy consumed annually by the building, at the level of a single "project" seeking development entitlements and building code permits, measured using the California Energy Commission's Time Dependent Valuation metric. A ZNE Code Building meets an Energy Use Intensity value designated in the Building Energy Efficiency Standards by building type and climate zone that reflect best practices for highly efficient buildings*."

There are three important things to note in this definition:

1. ZNE Code definition is based on Time Dependent Valuation (TDV) of energy efficiency and renewable generation onsite.
2. ZNE Code definition is applied at the "project" level so that it is possible to have PV systems that are shared between buildings as long as all the buildings are part of a single "project". This opens up the door for community-based renewables.
3. ZNE Code definition is based on a minimum level of energy efficiency as outlined in the Title 24 building energy standards.

4.4 CEC Proposed 2016 CalGreen ZNE Tier

The CEC has proposed updates to the CalGreen (California Green Building Standards Code) (Title 24 Part 11) that adds a ZNE Code tier to the voluntary requirements of CalGreen Section A4.203.1.2. Currently there are two tiers in the CalGreen requirements – Tier 1 and Tier 2. CEC has proposed a new Tier 3 also called the ZNE Tier. CEC has proposed the following definitions for the three tiers in a document posted on the CEC website as part of a Title 24 2016 update rulemaking workshop[1]:

1. Tier 1: Buildings complying with the first level of advanced energy efficiency shall have either an Energy Budget that is no greater than 85 percent of the Title 24, Part 6 Energy Budget for the Standard Design Building, OR an Energy Design Rating showing a 15% or greater reduction in its Energy Budget component compared to the Standard Design Building, as calculated by Title 24, Part 6 Compliance Software approved by the Energy Commission.

[1] Referenced from: http://www.energy.ca.gov/title24/2016standards/rulemaking/documents/#15daycalgreen

2. Tier 2: Buildings complying with the first level of advanced energy efficiency shall have either an Energy Budget that is no greater than 70 percent of the Title 24, Part 6 Energy Budget for the Standard Design Building, or an Energy Design Rating showing a 30% or greater reduction in its Energy Budget component compared to the Standard Design Building, as calculated by Title 24, Part 6 Compliance Software approved by the Energy Commission.
3. Tier 3 (Zero Net Energy Design): Buildings complying with this elective designation shall have on-site renewable energy generation sufficient to achieve an Energy Design Rating of zero (0) as calculated by Title 24, Part 6 Compliance Software approved by the Energy Commission, and –
   a. Single family Buildings in Climate Zones 6 and 7, and low-rise multifamily buildings in Climate Zone 3, 5, 6, and 7 shall comply with Tier 1; and
   b. Single family Buildings in Climate Zones 1 through 5 and 8 through 16 and low-rise multifamily building in Climate Zones 1, 2, 4, and 8 through 16 shall comply with Section Tier 2.

The key concept behind the ZNE Tier is the Energy Design Rating (EDR). The EDR is similar to a code compliance calculation in that it is based on TDV. However, it includes all building energy uses, not just the regulated loads.

The EDR is calculated using CEC approved calculations and assumptions in the Title 24 Part 6 (building energy code). Like RESNET calculations for Energy Rating Index (ERI), EDR uses a reference home compliant with the 2006 International Energy Conservation Code (IECC). An EDR of 100 indicates that the proposed home meets the IECC 1006 requirements, and an EDR of 0 indicates a ZNE Code - Design

4.5 ANSI/RESNET/ICC 301-2014

The ANSI/RESNET/ICC 301-2014 Standard for the Calculation and Labeling of the Energy Performance of Low-Rise Residential Buildings using an Energy Rating Index was republished in January 2016 with some modifications to outline how a ZNE Design building should be evaluated.

The methodology compares the energy performance of an actual home with the energy performance of a reference home of the same geometry, resulting in a relative energy rating called the Energy Rating Index (ERI). Where the energy performance of the actual home and the reference home are equal, the ERI is 100 and where the actual home requires no net purchased energy annually, the ERI is 0 (zero).

The Energy Rating Reference Home used for this comparative analysis has the energy attributes of the 2006 International Energy Conservation Code (IECC) *Standard Reference Design*. Thus, the Energy Rating Index is relative to the minimum building energy efficiency requirements of the 2006 IECC. Because the Energy Rating Index score accounts for all lighting, appliances and miscellaneous energy loads, there is never a 1-to-1 correspondence between code compliance (even under the 2006 IECC) and an Energy Rating Index score of 100.

The ERI is relevant in California for those projects that want to use this index on a voluntary basis. However, a ZNE rating based on the ERI does not meet the IEPR or the Title 24 code requirements nor does it meet the ZNE Code definition.

The ERI is calculated per below:

Energy Rating Index = PEfrac * (TnML / TRL) * 100

where

PEfrac = (TEU - OPP) / TEU

TEU = Total energy use of the Rated Home including all rated and non-rated energy features where all fossil fuel site energy uses (Btufossil) are converted to equivalent electric energy use (kWheq) using the formula *kWheq = (Btufossil * 0.40) / 3412*

OPP = On-Site Power Production.

TnML = $nMEUL_{HEAT}$ + $nMEUL_{COOL}$ + $nMEUL_{HW}$ + EUL_{LA} (MBtu/y).

TRL = $REUL_{HEAT}$ + $REUL_{COOL}$ + $REUL_{HW}$ + $REUL_{LA}$ (MBtu/y).

nMEUL = normalized Modified End Use Loads (for heating, cooling, or hot water) as computed using an Approved Software Rating Tool.

EUL_{LA} = The Rated Home end use loads for lighting, appliances and MELs converted to MBtu/y, where MBtu/y = (kWh/y)/293 or (therms/y)/10, as appropriate.

$REUL_{LA}$ = The Reference Home end use loads for lighting, appliances and MELs converted to MBtu/y, where MBtu/y = (kWh/y)/293 or (therms/y)/10, as appropriate.

4.6 New Buildings Institute's California ZNE Watchlist

The new California ZNE Watchlist[1], produced with support from the California Public Utilities Commission, tracks buildings that are either "ZNE Verified" or "Ultra-low Energy". The list also includes "Emerging ZNE" buildings, those buildings built or in progress with stated goals to meet zero energy performance. These are defined as:

- **ZNE Verified buildings (or districts)** have been documented to have met, over the course of a year, all net site energy use through onsite renewables. The energy use of all fuels (electric, natural gas, steam, etc.) is counted and offset by production from onsite renewables.
- **ZNE Emerging buildings (or districts)** have a publically stated goal of ZNE but do not yet meet the definition of ZNE Verified. These may be in the planning or design phase, under construction or have been in operation for less than a year. Others may have been operating for 12 months or longer, but their measured energy has either yet to achieve net zero or the measured data to document ZNE Verified status was not available.
- **Ultra-low Energy Verified buildings** have 12 or more months of metered data that documents energy performance comparable to ZNE buildings (typically 60-80% better than the national industry average). These buildings expand the set of building examples with design strategies and technologies that have resulted in ultra-low energy use. These buildings may have limited renewable resources onsite but do not have a known stated goal of ZNE.

Evaluation Requirements:

Buildings that appear on the verified lists have had 12 months of energy data reviewed by NBI analysts or other verified sources to determine if the energy performance qualifies as ZNE or Ultra-low Energy. NBI uses the data to calculate the Energy Use Intensity (EUI)[2] and the buildings that have been verified as ZNE have either a zero net building EUI or a negative net building EUI.

[1] Available at: http://newbuildings.org/resource/california-zne-watchlist-december-2015/

[2] The (total or net) building use of all forms of site energy in kBtu/sf/yr.

4.7 Living Future Institute ZNE Certification

Net Zero Energy Building (NZEB) Certification™ is a program operated by the International Living Future Institute using the structure of the Living Building Challenge. It is one of three Certification paths under the Living Building Challenge and revolves around the core requirement that one hundred percent of the project's energy needs must be supplied by on-site renewable energy on a net annual basis, without the use of on-site combustion. In addition, NZEB certified buildings must also meet the following requirements of the Living Building Challenge:

- Imperative One, Limits to Growth, dealing with appropriate siting of buildings[1]
- Imperative 19, Beauty and Spirit[2]
- Imperative 20, Inspiration and Education[3]

Evaluation Requirements:

- Energy Narrative: A two to three page narrative that is written by the energy designers or engineers, that describes the energy system, including:
  - Anticipated building's needs and operational issues
  - Design strategy
  - All subsystems of the energy-using and energy-producing systems
  - The energy storage system (if present)
- Energy System Schematic: A schematic drawing of the energy system
- Photographs of the systems, particularly portions that will be hidden from view at time of audit due to completion of construction.
- Energy Bills: Utility bills for a continuous 12-month period, beginning with the designated start date of the performance period. If the project is not connected to a utility, or is sub-metered from a utility meter serving a larger area, and therefore has no energy bills, the energy or mechanical engineer must provide a letter, stamped with her or his professional seal and signed by both the engineer and the owner, substantiating that this is the case.
- Energy Production and Demand Table (See Figure 13 below)

[1] Projects may only be built on greyfields or brownfields: previously developed sites that are not classified as on or adjacent to any sensitive ecological habitats.

[2] The project must contain design features intended solely for human delight and the celebration of culture, spirit and place appropriate to its function and meaningfully integrate public art.

[3] Educational materials about the operation and performance of the project must be provided to the public to share successful solutions and to motivate others to make change.

Living Building Challenge 3.0
Energy Production and Demand Table
Project Name:

	Performance Month	1	2	3	4	5	6	7	8	9	10	11	12	
Performance Period	Actual Month & Year (fill in name/year)	Month Year	Month Year	Month Year	Month Year	Month Year	Month Year	Month Year	Month Year	Month Year	Month Year	Month Year	Month Year	Annual
	Energy units (fill in)													
Energy Production	Photovoltaics (location 1)													0
	Photovoltaics (location 2)													0
	Micro-hydro-turbines													0
	Wind power													0
	Municipal Power (if grid tied)													0
	Other (describe)													0
	Total Energy Production	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Energy Demand	Heating													0
	Cooling													0
	Hot Water													0
	Lighting													0
	Ventilation													0
	Computer Services													0
	Pumps													0
	Vertical Transportation													0
	Plug Loads/ Equipment													0
	Other (list)													0
	Total Energy Demand	0	0	0	0	0	0	0	0	0	0	0	0	**0**
EUI	**Project Energy Use Intensity (EUI)**													
Modelled (optional)	Modelled energy production													0
	Modelled energy demand													0
	Predicted delta	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 13: Living Building Challenge Evaluation Data Table (source: Living Buildings Challenge)

The building is considered ZNE if the Total Energy Production is equal to or greater than the Total Energy Demand during the year. There is an optional data entry for comparing the actual energy production and energy demand against predicted values to compare the actual performance against predicted performance.

4.8 NBI California ZNE Recognition Program

In partnership with Resource Media, NBI developed a ZNE Recognition Proposal in January 2014 for the CPUC. During 2014, NBI led a statewide advisory group to make recommendations for the development of a proposed ZNE Commitment & Recognition Proposal. In 2015, NBI researched and developed a memo on the proposed ZNE Technical Recognition Criteria. Currently there are no resources allocated to develop the commitment campaign, however the technical recognition criteria is moving ahead in partnership with NBI, the CPUC and AIA. This technical criteria is being piloted as part of the Prop 39 ZNE Schools Recognition Program which will be launched in Summer/Fall of 2016.

As noted above, the proposed Initiative operates on two levels. The first level is a **California ZNE Leadership Commitment Campaign** designed to encourage California corporations and government entities to commit to ZNE and other low carbon practices. These commitments would be specific and tangible, highly visible, and a key part of California's leadership in carbon reduction. The second level is an awards program focused on recognizing actual achievements in the design, construction and operation of ZNE homes and buildings. The **ZNE Performance Awards** would be developed in a partnership between a broad coalition of government and utilities working with specific trade associations and other groups involved in the built environment.

Recognition Levels:

- **ZNE Commitment:** Recognize projects with a formal public commitment from an entity (e.g. Policy Resolution).
- **ZNE Emerging Buildings**: Recognize projects that are on the path to zero net energy by identifying ZNE as an end goal. This award would encourage early goal setting, buy-in from owners and project delivery teams, and would provide valuable recognition to designers and contractors that are advocating for and delivering ZNE projects.
- **ZNE Verified Buildings:** Recognize projects that have demonstrated ZNE Performance, reward the owners and design teams that have achieved this goal and elevate ZNE in the market.

1 – ZNE COMMITMENT	2 – ZNE EMERGING BUILDING	3 – ZNE VERIFIED BUILDING
Requires formal public commitment from an entity (e.g. Policy Resolution) – higher value may be placed on the scale of commitment or potential public or industry impact: • Single building (e.g. City Hall) • Multiple buildings (e.g. Campbell School Districts 8 school buildings) • Campus/District (e.g. Fort Hunter Liggett) • Portfolio (e.g. Department of Motor Vehicles, County of Santa Barbara Resolution)	Acknowledges the project team (including owner, utilities etc.) involved in design as well as the project designed. Requires submittal of building plans/designs or other validation if non-building leadership: a. **Innovative Design Leadership**: This may be a building designed but not built or a contribution to the building industry through other innovation or research b. **Constructed for ZNE (awarded at Occupancy):** A building on the path to zero but does not have a full year of data and or has not installed all renewables.	Acknowledges the projects, their owners and design teams that have achieved a ZNE outcome. Performance verification based on 12 consecutive months of actual energy generation and use. **a. Operating at Zero Net Energy** b. **Zero Net Energy + Emissions/+/or Water**

Figure 14: NBI CA Recognition Program Proposed ZNE Levels

Proposed Measurement Criteria:

This recognition program proposes a validation framework for a ZNE building using an analysis of Energy Use Intensity (EUI).

Proposed Evaluation Criteria:

The verification criteria strive to balance between the desire to 'keep it simple' without sacrificing the credibility of the program. The verification criteria have been separated into recommendations for *primary items* (Table 1) which are essential for maintaining the credibility of the program, and *secondary* *items* (Table 2) which are considered optional. **Items in italics indicate information that would be required for projects seeking ZNE Verified Building recognition.**

TOPIC	SUBTOPIC	SUBMITTAL REQUIREMENT
Written Narrative	Introduction	Tell the story of your project: What or who motivated you to pursue ZNE, what is exceptional/exemplary in your design, what hurdles did you face, what do you want others know, what brought you the most reward, how will your project influence others to go ZNE?
	Passive Energy Efficient Design Strategies	List passive design and daylighting strategies applied to get to ZNE
	Active Energy Efficient Design Strategies	List critical technologies used to get to ZNE. Identify those that you have not previously used on projects.
Background	Project Team	Owner, Architect, Mechanical Engineer, Contractor, Commissioning agent, other consultants
	Project Goals	Describe the project goals. Identify the specific goals and metrics established for this project relevant to ZNE.
General Building Information	Project Name	
	Location	Include City, County and CA Climate Zone
	Building Use Type	
	Size	Sq.ft, # of buildings
	Construction Type	New Construction or Retrofit/Addition
Building Occupancy	*Vacancy Rate**	Building cannot exceed a 10% vacancy rate
	Number of full time staff	Number of full-time staff or modeled staffing assumption
	Typical Schedule	Hours occupied/week
	Schedule	Typical or assumed weekly schedule (e.g. 9-5, M-F)
Annual Energy Consumption at the Site	Estimated Whole-Building Energy Use Intensity (EUI)	kBtu/sf/yr for most recent 12-month period
	*Actual Whole-Building Energy Use Intensity (EUI)**	
	Estimated Electricity Use	Total kWh for most recent 12-month period
	*Actual Electricity Use**	
	Estimated Natural Gas Use	Total BTU for most recent 12- month period
	*Actual Natural Gas Use**	
Annual Energy Generated at the Site	Estimated Onsite Renewable Production	kBtu/sf/yr. for most recent 12-month period
	*Actual Onsite Renewable Production **	
	Estimated Renewable Electricity Generated (kWh)	Total kWh for 12-month period

TOPIC	SUBTOPIC	SUBMITTAL REQUIREMENT
	*Actual Renewable Electricity Generated (kWh)**	
	*Other Actual** or Estimated Renewable Energy Source (example Biomass)	Total for 12-month period
	Estimated Cogeneration	Total for 12-month period
	*Actual Cogeneration**	
Net Energy Use at the Site	Demonstrate ZNE Design	Estimated Whole-Building EUI minus estimated Onsite Generation is equal to or less than Zero
	Demonstrate ZNE Performance	Actual Whole-Building EUI minus Actual Onsite Generation is equal to or less than Zero
Annual Source Energy and Emissions	*Actual Annual Source EUI**	*Source EUI (kBtu/sf/yr.) for 12-month period*
	Estimated Annual Source EUI	Source EUI (kBtu/sf/yr.) for 12-month period
	Estimated Annual Carbon Emissions	CO_2 lbs./sf
Renewable Energy Systems	Photovoltaics	Rated capacity, total annual output, location onsite and system manufacturer
	Solar Thermal	Rated capacity, total annual output, location onsite and system manufacturer
	Other	Rated capacity, total annual output, location onsite and system manufacturer
Energy Storage	Active Energy Storage Systems	Actual or estimated storage capacity
	Passive Energy Storage Strategies	List all strategies
Demand Response	Automated Demand Response functionality	List all approaches including a brief description of how and when the system responds to an event.
	Passive Strategy	Percent of load reduced during peak events
Post Occupancy Activities	*Commissioning**	List key commissioning tasks performed
	*Energy Monitoring and Verification Strategies**	List energy monitoring technology, tools and strategies used to verify building energy performance
	*Operator Engagement Strategies**	Specify key tools and documentation provided to building operator and any trainings required
	*Occupant Engagement Strategies**	Describe any lease agreements related to energy performance, regular occupant energy conservation approaches, operation trainings, and other engagement efforts

Figure 15: Proposed Primary (Required) Technical Criteria for ZNE Recognition Program

TOPIC	SUBTOPIC	SUBMITTAL REQUIREMENT
Weather	Cooling Degree Days	Based on 65°F
	Cooling Design Temperature	0.4% occurrence
	Heating Degree Days	Based on 65°F
	Heating Design Temperature	99.6% occurrence
Envelope	Window to wall ratio	Percent
	Glazing	U-Value and SHGC
	Floor	U-Value
	Opaque Walls	U-Value
	Ceiling	U-Value
End Uses/Annual Design Loads	Heating	Actual or Estimated total power and kBtu/sf/yr.
	Cooling	Actual or Estimated total power, kBtu/sf/yr. and sf/ton
	Ventilation	Actual or Estimated total power and cubic foot/person
	Lighting	Actual or Estimated total power and LPD
	Service Hot Water	Actual or Estimated total power
	Plug Loads	Actual or Estimated Watts/sf
Other Categories	Estimated Costs	Cost/sf and description of incremental costs associated with reaching ZNE
	Utility Support/Incentives	Describe how local utility may have contributed to project (e.g. funding, Tech. Assistance, etc.)
	Special Studies and/or Research	Describe any related studies and or research
	Awards	List other notable awards for the project
	Policy Drivers or Motivations	List any that contributed to setting ZNE goal
	Community Outreach and Engagement	Describe the types of community outreach and engagement efforts done as part of the project.

Figure 16: Proposed Secondary (Optional) Technical Criteria for ZNE Recognition Program

4.9 DOE Zero Energy Ready Homes Program

The DOE Zero Energy Ready Home (DOE ZERH) is a recognition program for builders making zero energy ready homes that are energy efficient and have improved air quality. Single family, multifamily, and residential portions of mixed-use buildings are eligible for this qualification. To qualify as a DOE Zero Energy Ready Home, a home must meet all applicable local building codes, meet the requirements of either the Performance Path or the Prescriptive path of the program, and be verified and field-tested in accordance with HERS Standards by an approved verifier.

The DOE ZERH program builds upon the ENERGY STAR® for Homes version 3 and the Building America program. The goal is to have a building that is ready to be a ZNE building by emphasizing the energy efficiency of the building. According to the DOE ZERH website, these homes are designed to be at least 40-50% more efficient than a typical new home, corresponding to a RESNET HERS score in the low to mid 50s depending on the size of the home and the region it is built in.

Homes may qualify for DOE Zero Energy Ready Home using either the Prescriptive Path or Performance Path. There are specific modifications to the requirements for California where regional program requirements have been developed. This section outline the California specific requirements as outlined on the DOE ZERH website located here:

http://energy.gov/sites/prod/files/2015/05/f22/DOE%20Zero%20Energy%20Ready%20Home%20CALIFORNIA%20Program%20Requirements%20-%20Rev05%2005182015.pdf .

4.9.1 DOE Zero Energy Ready Home Prescriptive Path for California

The prescriptive path provides a single set of measures that can be used to construct a DOE Zero Energy Ready Home labeled home. Modeling is not required, but no tradeoffs are allowed.

Follow these steps to use the prescriptive path:

1. Assess eligibility by using the number of bedrooms in the home to be built to determine the conditioned floor area (CFA) of the Benchmark Home (see Figure 17). If the CFA of the home to be built exceeds this value, the performance path shall be used.
2. If the prescriptive path is eligible for use based on the prior step, build the home using the mandatory requirements for all labeled homes (Figure 18), and all requirements of the DOE Zero Energy Ready Home Target Home (Figure 19). The rigor of the specifications in Figure 19 shall be met or exceeded.
3. Verify that all requirements have been met, using an approved verifier. The term '"verifier" refers to the person completing the third-party inspections required for qualification. This party may be a certified Home Energy Rater, Rating Field Inspector, BOP Inspector, or an equivalent designation as determined by a Verification Oversight Organization. All home certified through the Prescriptive Path shall be submitted to DOE (email: zero@newportpartnersllc.com).

Bedrooms in Home to be Built	0	1	2	3	4	5	6	7
Conditioned Floor Area Benchmark Home	1,000	1,000	1,600	2,200	2,800	3,400	4,000	4,600

Figure 17: Benchmark Home Size

Area of Improvement	Mandatory Requirements
1. ENERGY STAR for Homes Baseline	☐ Certified under ENERGY STAR Qualified Homes Version 3 program requirements for the State of California[10].
2. Envelope[11]	☐ Fenestration shall meet or exceed ENERGY STAR requirements or California 2013 Building Energy Efficiency Standards window requirements in table 150.1-A, *whichever is more stringent* [12, 13] ☐ Ceiling, wall, floor, and slab insulation shall meet or exceed 2012 IECC levels or California 2013 Building Energy Efficiency Standards insulation requirements in table 150.1-A, *whichever is more stringent*.[14]
3. Duct System	☐ Ducts located within the home's thermal and air barrier boundary or optimized to achieve comparable performance [15]
4. Water Efficiency	☐ Hot water delivery systems shall meet efficient design requirements[16]
5. Lighting & Appliances[17]	☐ All installed refrigerators, dishwashers, and clothes washers are ENERGY STAR qualified. ☐ 90% of lighting fixtures are ENERGY STAR qualified or ENERGY STAR lamps (bulbs) in minimum 90% of sockets ☐ All installed bathroom ventilation and ceiling fans are ENERGY STAR qualified
6. Indoor Air Quality	☐ Certified under EPA Indoor airPLUS [18]
7. Renewable Ready	☐ Provisions of the DOE Zero Energy Ready Home PV-Ready Checklist are Completed; (Solar Hot Water Ready provisions are encouraged but not required)[19]
8. Air Infiltration	☐ For all CA Climate Zones 1-16, must be tested to achieve air infiltration levels at or below: 3 ACH50 for single family detached dwellings, or 4 ACH50 for attached single-family dwellings and dwellings in multifamily buildings[20]

Figure 18: DOE Zero Energy Ready Home Mandatory Requirements for All Labelled Homes in California

HVAC Equipment			
	Hot Climates (2012 IECC Zones 1,2)	**Mixed Climates** (2012 IECC Zones 3, 4 except Marine)	**Cold Climates** (2012 IECC Zones 4 Marine 5,6,7,8)
AFUE	80%	90%	94%
SEER	18	15	13
HSPF	8.2	9	10
Geothermal Heat Pump	ENERGY STAR EER and COP Criteria		
ASHRAE 62.2 Whole-House Mechanical Ventilation System	1.4 cfm/W; no heat exchange	1.4 cfm/W; no heat exchange	1.2 cfm/W; heat exchange with 60% SRE
Insulation and Infiltration			
• Insulation levels shall meet the 2012 IECC and achieve Grade 1 installation, per RESNET standards. • Infiltration (ACH50): 3 in CZ's 1-2 | 2.5 in CZ's 3-4 | 2 in CZ's 5-7 | 1.5 in CZ 8			
Windows			
	Hot Climates (2012 IECC Zones 1,2,)	**Mixed Climates** (2012 IECC Zones 3, 4 except Marine)	**Cold Climates** (2012 IECC Zones 4 Marine 5,6,7,8)
SHGC	0.25	0.25	any
U-Value	0.4	0.3	0.27
Homes qualifying through the Prescriptive Path with a total window-to-floor area greater than 15% shall have adjusted U-values or SHGCs.			
Water Heater			
ENERGY STAR levels for the system Energy Factor, as follows: - Gas/propane systems of ≤ 55 gallons, EF = 0.67 - Gas/propane systems of > 55 gallons, EF = 0.77 - Electric systems, EF = 2.0 For heating oil water heaters use EF = 0.60			
Thermostat			
• Programmable thermostat (except for zones with radiant heat)			
Lighting & Appliances			
• For purposes of calculating the DOE Zero Energy Ready Home Target Home HERS Index, homes shall be modeled with an ENERGY STAR dishwasher, ENERGY STAR refrigerator, ENERGY STAR ceiling fans, and ENERGY STAR lamps (bulbs) in 80% of sockets or 80% of lighting fixtures are ENERGY STAR Qualified.			

Figure 19: DOE Zero Energy Ready Home Target Home for Prescriptive Path in California

4.9.2 DOE Zero Energy Ready Home Performance Path for California

The Performance Path requires all mandatory requirements in Figure 18 to shall be met, but provides flexibility to select a custom combination of measures that meet the performance level of the DOE Zero Energy Ready Home HERS Target Home (Figure 19). Modeling is required, but measures can be optimized for each particular home or builder. In California, there are three options available for the Performance Path:

- **Performance Option (A)**: This is similar to the Performance Path for the DOE National Zero Energy Ready Home (details below). This option requires the use of RESNET HERS software.
- **Performance Option (B)**: Homes in California may select a custom combination of measures for each home that is equivalent in performance to at least 25% better than the California 2013 Building Energy Efficiency Standards. This option allows software used for California Title 24 compliance.
- **Performance Option (C)**: Homes in California may demonstrate equivalence with the National Program Requirements Target Home (Figure 19) and Mandatory Requirements (Figure 18) by creating two California Title 24 models and showing equivalence with the Alternative Equivalent Target Home. This option allows software used for California Title 24 compliance.

Performance Option (A)

The following steps are required to use the performance option (A):

1. Determine the HERS index for the DOE ZERH target home. Target Home is identical to the home that will be built, except that it is configured with the energy efficiency features of the DOE ZERH as defined in Figure 18 and Figure 19. Note, any state energy code requirements that exceed those specified on Figure 19 take precedence for purposes of determining the DOE ZERH Target Home
2. A size modification factor is calculated using the following equation:
   Size Modification Factor = [CFA $_{\textit{Benchmark Home}}$ ***/ CFA*** $_{\textit{Home to be Built}}$***]*** $^{0.25}$*, but not to exceed 1.0*

   Where: CFA Benchmark Home = Conditioned Floor Area of the Benchmark Home, using Figure 14; CFA Home to be Built = Conditioned Floor Area of the Home to be Built. Since the Size Modification Factor cannot exceed 1.0, it only modifies the HERS Index score for homes larger than the CFA of the Benchmark Home.
3. The HERS Index of the DOE ZERH Target Home is calculated using RESNET-accredited software using the equation shown below:
   ZERH HERS Target = HERS Index of Target Home x Size Modification Factor
4. Calculate HERS index of the home using the actual set of energy measures to be installed in the building. Compare the HERS index using actual measures against the HERS Target established above. If the HERS index of the home with proposed measures is at or below the HERS Target, the home passes.
5. The home is constructed using the measures proposed and ensuring that it meets all mandatory requirements for ZERH and applicable state codes.
6. Verify that all requirements have been met with the constructed home using an approved verifier.

Performance Option (B)

The process for option B is per below:

1. Calculate the size modification factor as outlined in step 2 of performance option (A) above
2. Using a California Title 24-2013 accredited software calculate the CA ZERH Energy Savings Target Percentage per the equation below:

   California DOE ZERH Energy Savings Target Percentage = 1-[SAF x 75%]

   where SAF is the size modification factor calculated in step 1
3. Calculate the energy use of the rated home (home built to the measure specifications that are to be actually built) using the same CA Title 24 accredited software. The home passes if the energy use of the home is lower than the 2013 Title 24 standard by a factor at least equal to or higher than the savings target percentage calculated in step 2. Note that target energy savings/use are based on Time Dependent Valuation and only take into account the Title-24 regulated end-uses which include heating, cooling, ventilation, and water heating.
4. The home is constructed using the measures proposed and ensuring that it meets all mandatory requirements for ZERH and applicable state codes.
5. Verify that all requirements have been met with the constructed home using an approved verifier.

Performance Option (C)

Option C allows the use of California Title 24 accredited software to calculate an alternate HERS index akin to Option A. To do so, the calculations are done by establishing two Title 24 models – one for the proposed home and one for an Alternative Equivalent Target Home. The equivalence to Option A is established by showing that the energy use of the proposed home is at least 25% less than the alternative equivalent target home accounting for the home size modification factor. As with options A and B, the home must be constructed and verified by an approved verifier to be eligible for DOE recognition.

4.10 DOE Zero Energy Buildings: A Common Definition

In 2014, the U.S. Department of Energy (DOE) Building Technologies Office contracted with the National Institute of Building Sciences to establish definitions, associated nomenclature and measurement guidelines for zero energy buildings, with the goal of achieving widespread adoption and use by the building industry. The following definitions for Zero Energy Buildings were developed, which provided some variations to accommodate the collections of buildings where renewable energy resources were shared.

- *Zero Energy Building (ZEB):* An energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.
- *Zero Energy Campus*: An energy-efficient campus where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.
- *Zero Energy Portfolio*: An energy-efficient portfolio where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.
- *Zero Energy Community:* An energy-efficient community where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.

The measurement and implementation guidelines identified the methodologies for establishing the following details:

4.10.1 Measurement Boundaries

The definitions require the use of a defined site boundary, which represents a meaningful boundary that is functionally part of the building(s). The site boundary should include the point of utility interface and defines the boundary for energy accounting in terms of building energy consumption, on-site renewable energy production, delivered energy and exported energy, as shown in Figure 20 below.

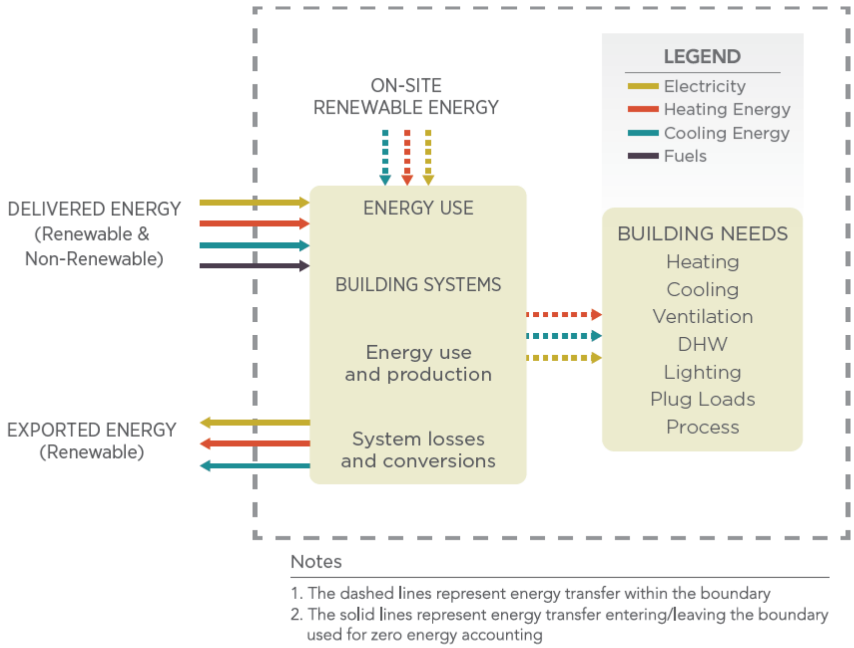

Figure 20: Site Boundary of Energy Transfer for Zero Energy Accounting

The site boundary for a Zero Energy Building (ZEB) could be around the building footprint if the on-site renewable energy is located within the building footprint, or around the building site if some of the on-site renewable energy is on-site but not within the building footprint. Delivered energy and exported energy are measured at the site boundary. The site boundary for a Zero Energy Campus, Community of Portfolio allows for group of project sites at different locations to be aggregated so that the combined on-site renewable energy could offset the combined building energy from the aggregated project sites.

4.10.2 Energy Accounting and Measurements

ZEB energy accounting would include energy used for heating, cooling, ventilation, domestic hot water (DHW), indoor and outdoor lighting, plug loads, process energy and transportation within the building. Vehicle charging energy for transportation inside the building would be included in the energy accounting. On-site renewable energy may be exported through transmission means other than the electricity grid such as charging of electric vehicles used outside the building. Delivered energy to the building includes grid electricity, district heat and cooling, renewable and non-renewable fuels. A ZEB balances its energy use so that the exported energy to the grid or other energy network (i.e., campus or facility) is equal to or greater than the delivered energy to the building on an annual basis. A ZEB may only use on-site renewable energy in offsetting the delivered energy. On-site renewable energy is energy produced from renewable energy sources within the site boundary.

4.10.3 Source Energy Calculations

The Zero Energy Building definition uses national average ratios to accomplish the conversion to source energy to ensure that no specific building will be credited (or penalized) for the relative efficiency of its energy provider(s). Source energy is calculated from delivered energy and exported energy for each energy type using source energy conversion factors. The source energy conversion factors utilized are from ASHRAE Standard 105. While on-site renewable energy is a carbon-free, zero-energy-loss resource, when it is exported to the grid as electricity, it displaces electricity that would be required from the grid. In ZEB accounting, the exported energy is given the same source energy conversion factor as the delivered energy to appropriately credit its displacement of delivered electricity. Figure 21 summarizes the national average source energy conversion factors for various energy types.

Energy Form	Source Energy Conversion Factor (r)
Imported Electricity	3.15
Exported Renewable Electricity	3.15
Natural Gas	1.09
Fuel Oil (1,2,4,5,6,Diesel, Kerosene)	1.19
Propane & Liquid Propane	1.15
Steam	1.45
Hot Water	1.35
Chilled Water	1.04
Coal or Other	1.05

Figure 21: National Average Source Energy Conversion Factors

Source energy (Esource) is calculated using the following formula, and the $E_{source} \leq 0$ for the building to be a Zero Energy Building.

$$E_{source} = \Sigma_i(E_{del,i} r_{del,i}) - \Sigma_i(E_{exp,i} r_{exp,i})$$

Where:

$E_{del,i}$ is the delivered energy for energy type *i*;
$E_{exp,i}$ is the exported on-site renewable energy for energy type *i*;
$r_{del,i}$ is the source energy conversion factor for the delivered energy type *i*;

$r_{exp,i}$ is the source energy conversion factor for the exported energy type *i*;

5. Proposed Verification Methodologies

The study team recommends the following verification methodologies for ZNE buildings based on whether the ZNE building is *designed* to be ZNE (ZNE Design) or is being *operated* or intended to be operated as a ZNE building (ZNE Performance). The specifics of the verification methodologies vary based on whether the building is residential or non-residential and whether the building is supposed to be ZNE based on the ZNE Code or based on ZNE Site and ZNE Source definitions.

Each verification methodology described below specifies the following:

- **Verification Requirements**: Who should be conducting the verification, What should they verify
- **Documentation Requirements**: Data inputs, Data outputs and formats, System details on energy using and generating devices, Calculation or data analysis showing building meets the ZNE criteria
- **Analysis Procedures**: Data inputs needed, Calculations or data analysis to be performed, Recommendations on who should conduct the analysis

5.1 Proposed ZNE Design and Performance Verification Process

As outlined in Section 3.5, there are several programmatic and non-programmatic efforts that have a need to verify ZNE design and or ZNE performance. Each one of them has unique verification needs based on whether they target ZNE Code, ZNE Design or ZNE Performance metrics. Figure 22 outlines the current California initiatives and the ZNE metrics of interest as well as the verification criteria and approach.

Verification Need	ZNE Metric of Interest	ZNE Criteria	Verification Approach
Codes and Standards	ZNE Code - Design (Based on TDV)	Design: EDR = 0	Energy Simulation
		Performance: site energy use	Calibrated Energy Simulation
Utility Incentive Programs	ZNE Code - Design	Design: EDR = 0	Energy Simulation
	ZNE Site - Design	Design: Net site energy use	Energy Simulation
	ZNE Site - Performance	Performance: Net site energy use	Utility Billing Analysis
Voluntary and Recognition Programs	ZNE Site - Performance	Performance: Net site energy use	Utility Billing Analysis
	ZNE Source - Performance	Performance: Net source energy use	Utility Billing Analysis with Source factors

Figure 22: Proposed Verification Approaches by Use Case

5.1.1 Codes and Standards Savings Verification

To verify that a building designed to ZNE Code is indeed a ZNE Code building, the key criteria of interest is whether the Energy Design Rating (EDR) of the building is Zero (0) or lower. The proposed procedures to verify the EDR are outlined in Section 5.4.1. Note that these recommended procedures are based on the current understanding of the CEC thinking on the 2019 Title 24 and EDR calculations and are subject to change as the CEC finalizes these concepts.

Note that EDR itself is based on the Time Dependent Valuation (TDV) concept and not on site/source energy. However, any programmatic efforts to develop and implement ZNE Code through Title 24 will be evaluated based on the underlying site energy savings (kWh, therm). As is noted in Sections 5.5.2 and 8, ZNE Code is intentionally an asset rating and there is no intention for the TDV portion of the definition to be a performance metric. Therefore the verification methodologies for the energy savings are designed to address the underlying site energy use, rather than verification of the TDV metric itself.

To verify these site energy savings, there are two versions of savings:

1. Savings claimed by the CEC for each code update based on first year savings for all new construction and retrofit activities affected by the code change. For ZNE Code, this would mean savings for the first year of all residential new construction in California after the ZNE Code requirements go into effect.
2. Savings claimed by the IOUs for their efforts to support development of the said code updates through the Codes and Standards Enhancement (CASE) and other code advocacy initiatives for building and appliance standards.

The savings claims of the IOU are a subset of the savings claims by the CEC and include a whole host of considerations including unit energy savings at the building level, energy use and market baselines, naturally occurring market adoption (NOMAD) and most importantly, attribution of specific savings to the IOU code advocacy efforts as seen in Figure 23.

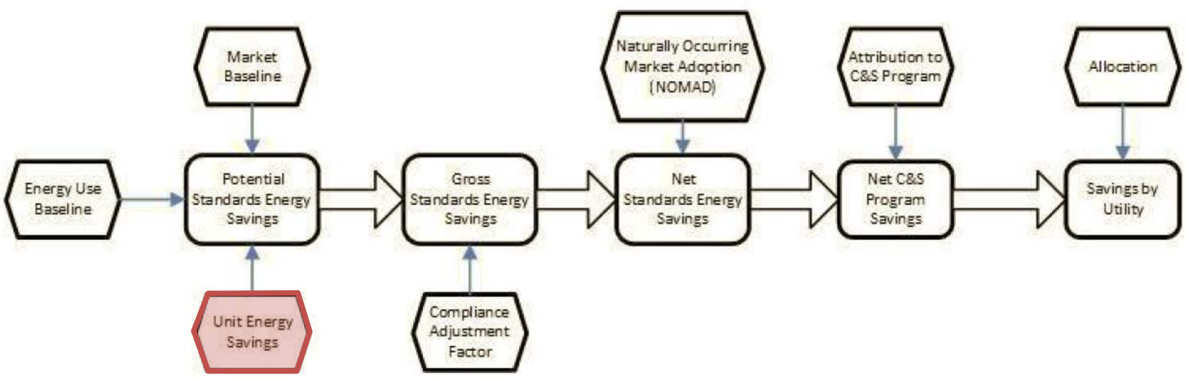

Figure 23: Codes and Standards Advocacy Program Evaluation Protocols

This study focuses only on the Unit Energy Savings portion of this larger evaluation effort. To establish whether the individual building is ZNE or not, and to estimate the savings from that building (typically through analysis of prototypes by building type), building energy simulation is the preferred approach.

For the IOU codes and standards program, their savings claims for supporting the development of ZNE Code will be verified using procedures developed for the CPUC led evaluation efforts. These procedures will not be developed till the 2019 Title 24 code change efforts are completed and the ZNE Code is adopted by the CEC for residential buildings. While it is impossible and out of the scope of this study to predict what the CPUC evaluation protocols will look like for ZNE Code, this study uses the current evaluation procedures for the 2012-2013 program years as reference. Under this evaluation protocol, the ex-ante unit energy savings are based on energy simulation models. Ex-post, the evaluators review permit data, conduct site visits to verify specific measures are installed, and develop calibrated energy simulation models that include actual measures installed in the building but use the default schedules and weather assumptions used for the ex-ante savings estimates. Section 8 has specifics on how a post-construction calibration could be conducted for savings verification.

5.1.2 Utility Incentive Programs

For utility incentive programs, there is currently no one ZNE metric that is prevalent due to the fact that ZNE is still a niche market and not a systemic part of the utility program portfolio. As a result, IOU programs have used various metrics – ZNE Code, ZNE Site and ZNE Source - for their programmatic efforts to encourage ZNE.

For programs targeting ZNE at the design stage, the verification focuses on whether the design meets the intended ZNE definition and confirms the underlying savings claims in site kWh and Therm. This is done through building energy simulation analysis using approved software tools. The specifics of the verification procedures will vary based on the ZNE metric used as outlined in Section 5.2.

For those programs targeting ZNE performance, the savings verification is largely based on verification of utility bills and renewable energy generation as summarized in Section 5.2.

5.1.3 Voluntary and Recognition Efforts

While codes and standards and utility programs are driven by broader policy consideration, the early adopters of ZNE are not constrained by the policy decisions or the choice of the ZNE Code metric chosen by California policy makers. Indeed the most commonly used metric for ZNE is ZNE Site based on performance verification, followed by ZNE Source based on performance verification.

For voluntary programs, recognition programs and others where ZNE Performance is the intended goal, the study proposes that the Performance verification focus on validating savings claims made during the design phase, but more important, verify that the building meets the intended ZNE Performance definition based on utility meter data analysis.

5.2 ZNE Design and ZNE Performance Require Separate Methodologies

It is important to note that a building can be both ZNE Design and ZNE Performance, but each of these requires a separate verification process. This is because, while it is feasible, it is not guaranteed that a building that meets the ZNE Design criteria will necessarily meet the ZNE Performance criteria. Specifically, a building designed to be ZNE Code - Design is not guaranteed to be ZNE in performance since the ZNE Code - Design uses TDV values that are not compatible with field verification for reasons outlined in Section 8.

Likewise, it is also possible to be ZNE Performance but not meet the ZNE Design criteria, depending on the size of the onsite renewable generation and energy efficiency features of the building, as well as operational characteristics of the building.

Further, as outlined in the previous section and Figure 22, there are various ZNE metrics that can be used. Figure 24, outlines the differences in the verification procedures and activities necessary to verify ZNE. Due to these differences, the verification requirements are presented separately for each ZNE metric and stage in the following sub-sections of the report.

ZNE Metric	Stage	Criteria Used to Prove Building is ZNE	Key Verification Activity	Energy Unit Used
ZNE Code	Design	EDR = 0	Design Energy Simulation Model	TDV
	Performance	Delta of Predicted versus Actual Net Energy Use	Calibrated Energy Simulation based on As-Built Conditions	kBtu (site)
ZNE Site	Design	Predicted Net Energy Use = 0	Design Energy Simulation Model	kBtu (site)
	Performance	Actual Net Energy Use = 0	Utility Billing Analysis; Weather Normalization may be required	kBtu (site)
ZNE Source	Design	Predicted Net Energy Use = 0	Design Energy Simulation Model	kBtu (source)
	Performance	Actual Net Energy Use = 0	Utility Billing Analysis; Weather Normalization may be required	kBtu (source)

Figure 24: Verification Procedures Based on ZNE Metric of Interest

5.3 Persistence of ZNE Performance

In this report and in the methodologies described below, ZNE Performance is evaluated based on a continuous 12-month period after the building is completely occupied and all building systems are operation and commissioned. This is important since most of the projects where the study team reviewed building performance data had initial periods of a few weeks to few months where the energy use was not representative of the intended operation of the buildings – either due to lack of full occupancy, or due to the equipment onsite not functioning as intended. Thus if data from the first 12-months post-construction are used, they are likely to provide an erroneous verification of the building's performance. Therefore the verification methodologies require that the evaluator use data from the period post-commissioning and full occupancy.

Another aspect of persistence of ZNE Performance is if the same building performs as a ZNE building in the first year post-commissioning and continues to do so each year thereafter. Currently, the number of buildings where more than one qualified full year of energy data is available is limited if at all available. Where data was available, it was incomplete – either the renewable energy generation data was not available, or there were data gaps in the building energy use data. Thus it is too early to say whether ZNE Performance persists over time.

This document does not propose a methodology that looks at this savings persistence, but encourages future efforts by the CPUC and IOUs to conduct analysis of existing ZNE buildings once sufficient billing data is available to determine if the performance persists, or if it does not, how to address it. The study team anticipates that persistence of ZNE Performance will require a new metric that looks closely at building operations and evaluates the chances of performance persisting over time.

5.4 ZNE Design Evaluation

This section outlines the documentation, modeling and verification procedures required for buildings that are designed to be ZNE. The goal of a ZNE Design rating is to assign an 'asset value' to the building such that the building is 'capable of being a ZNE building, assuming the building is operated per the assumptions made in the predictive analyses'. ZNE Design by nature is a predictive exercise and occurs prior to the building being constructed. As such the verification methodologies are all based on predictive analysis and review of such predictive analysis. There is no guarantee that a ZNE Design building will actually operate as a ZNE Performance building.

5.4.1 ZNE Code - Design

The ZNE Design metric for residential buildings per the CEC is the ZNE Code metric as outlined in Sections 4.3 and 4.4 of this document. Note that this section references procedures that are currently being developed and finalized and are therefore subject to change. Specifically, the calculations for EDR are still being finalized and the TDV values used for ZNE Code - Design are also subject to change. Specifically, the CEC has not given any guidance on how nonresidential buildings are to be addressed for ZNE Code, but this report assumes that the CEC will use similar protocols and procedures as they apply for residential buildings. With those caveats, the following methodologies are proposed to verify whether a building meets the ZNE Code designation:

Verification Procedures

A designated entity must verify the model inputs and outputs to confirm that the modeled EDR ≤ 0. Further, the designated entity must verify that the energy use of regulated end uses (heating, cooling, DHW) is per the CEC efficiency requirements for ZNE Code. The designated entity must verify the PV system size, orientation, tilt and efficiency as well as confirm the PV capacity dedicated to offset home energy uses.

Currently, code compliance is the domain of local code officials within building departments. However, verifying ZNE Code is not within the domain of these code officials until Title 24 officially requires this for the 2019 Title 24 requirements or a local jurisdiction adopts a ZNE mandate ahead of 2020. One option is to have the HERS rater confirm the ZNE code documentation and upload the relevant information to the HERS/Compliance registries. Unlike residential buildings where there are standardized procedures such as HERS for tracking building compliance documentation, there is no centralized database or independent verification entity for nonresidential building compliance. Thus there is a need to establish new authorities and tracking procedures to verify and document ZNE Code - Design for nonresidential buildings.

Analysis Requirements

The building must be analyzed using a building energy simulation software approved by the California Energy Commission for use with the 2016 Title 24 Part 6 and Part 11 energy code compliance. Currently, there is one software platform for residential buildings – CBECC-Res – which is approved for use with 2016 Title 24. There are three compliance software based on that platform – CBECC-Res, EnergyPro version 7.0 and Right-Energy Title 24 – that are approved for compliance.

As of the date of writing this report, the capability of the energy simulation software to produce an Energy Design Rating (EDR) is being developed for CBECC-Res and not available for general use. These capabilities in turn depend on updating the CEC approved rulesets outlined in the Residential Alternative Compliance Method (ACM) reference manual. The software must use default assumptions for operation schedules for all energy end uses and default assumption on unregulated loads (MELs, lighting etc.) as outlined in the 2016 res ACM.

On the nonresidential side, the building must be analyzed using a building energy simulation software approved by the California Energy Commission. The compliance software currently does not natively calculate renewable electricity generation onsite, so a separate calculation is necessary to calculate renewable electricity generation using a third-party software that is capable of providing hourly production outputs. The hourly production outputs then need to be multiplied with CEC approved TDV factors to get an annual TDV value of renewable onsite generation. The energy simulation software must produce an Energy Design Rating (EDR) using CEC approved rulesets outlined in the Nonresidential Alternative Compliance Method (ACM) reference manual. Currently, these rulesets are not clearly defined nor is the procedure to calculate the EDR. Thus there is no tool available for general use or for researchers using the compliance tools that offer the capability to calculate EDR.

The energy simulation software must confirm the solar photovoltaic (PV) Sizing, Orientation, Tilt and Efficiency (including efficiency of inverters). The model shall make a note if electric vehicle (EV) charging, or electric storage is designed to be supported by the PV output. If either or both EV and storage are to be supported by PV output, the model must designate a specific capacity of the PV system dedicated for EV and/or storage and designate a specific capacity of the PV system dedicated for home energy use loads. The EDR calculation must be done using only that portion of the PV system dedicated to offset home energy use.

Documentation Requirements

To assist with the ZNE verification efforts, the study team recommends that the following categories of information be recorded consistently and made available to the verifiers:

1. Analysis methodology – software used and period of analysis
2. ZNE Metric – Energy Design Rating (EDR)
3. Annual energy use – predicted electricity, natural gas and propane usage, predicted TDV energy use by end use categories
4. Annual renewable generation – predicted annual renewable energy generation in kWh, therm and TDV
5. Building information – name, location, occupancy type, size, construction details, schedules of operation
6. Renewable energy system details – location, size, tilt, orientation, size of the system dedicated to offset the building energy use
7. Building commissioning and/or operational manual

These details are likely to be documented in an official CEC compliance form starting January 2017, but these forms are as of yet under development.

5.4.2 ZNE Design - Site/Source

For residential buildings using the ZNE Design metric outside of the ZNE Code metric, the study team proposes that the methodology be based on the procedures outlined in the ANSI/RESNET/ICC 301-2014 standard. For nonresidential buildings using the ZNE Design metric outside of the ZNE Code metrics, there are a broader array of choices including software used, calculation assumptions used, outputs generated and verification procedures. While the specifics may differ by building type, this section combines them into a common set of verification methodologies.

Verification Procedures

Residential: A designated entity must verify the model inputs and outputs to confirm that the modeled ERI ≤ 0. The designated entity must verify the PV system size, orientation, tilt and efficiency as well as confirm the PV capacity dedicated to offset home energy uses.

Nonresidential: A designated entity must verify that the net energy use of the building meets either the ZNE Design Site or the ZNE Design Source definitions per above. The entity must also verify that the assumptions used for the energy analysis are properly documented – including details of the renewable onsite electricity generation. Unlike ZNE Design for residential, there is no designated authority for commercial buildings, so it is important that there be a centralized database or registry where all ZNE Design buildings are tracked in a consistent manner.

Analysis Requirements

Residential: The building must be analyzed using a building energy simulation software that produces an Energy Rating Index (ERI) using approved rulesets outlined in the ANSI/RESNET/ICC 301-2014 standard.

The energy simulation software must confirm the solar photovoltaic (PV) Sizing, Orientation, Tilt and Efficiency (including efficiency of inverters). The model shall make a note if electric vehicle (EV) charging, or electric storage is designed to be supported by the PV output. If either or both EV and storage are to be supported by PV output, the model must designate a specific capacity of the PV system dedicated for EV and/or storage and designate a specific capacity of the PV system dedicated for home energy use loads. The ERI calculation must be done using only that portion of the PV system dedicated to offset home energy use.

Nonresidential: Unlike residential buildings, there is no set software or analysis procedures that are universally used for ZNE Design analysis of nonresidential buildings. From a verification perspective it is important therefore to establish some common protocols for analysis. These protocols include the following:

- The predictions of building energy use and onsite renewable energy generation must be done using a commercially available hourly energy simulation software – ideally the same software is used for analysis of building energy uses as well as renewable energy generation.
- The analysis must generate annual predicted total building energy use and annual predicted total onsite renewable generation in site energy terms (kWh, Therm, kBtu) as well as source energy (kBtu).
- ZNE Design for Site Energy is achieved when Predicted Annual Energy Use (site kBtu) - Predicted Annual Onsite Renewable Generation (site kBtu) = zero or negative. Note that all onsite fuel and electricity usage is converted to site kBtu.
- ZNE Design for Source Energy is achieved when Predicted Annual Energy Use (source kBtu) - Predicted Annual Onsite Renewable Generation (source kBtu) = zero or negative. Note that all

onsite fuel and electricity usage is converted to source kBtu using standard national average numbers presented in Section 6.4.1.

Documentation Requirements

The ZNE Design - Site/Source Residential has similar documentation requirements as the ZNE Code - Design Residential criteria. The key differences are that ZNE Design - Site/Source Residential is based on the ERI metric and the associated assumptions embedded in the ANSI/RESNET/ICC 301-2014 standard, whereas ZNE Code - Design Residential uses TDV as a metric.

For ZNE Design - Site/Source nonresidential, the documentation requirements are the same as ZNE Code - Design nonresidential, except that there are no set default values for building occupancy and schedules, thus it is imperative that the documentation explicitly provide the assumptions made by the energy modeler.

5.5 ZNE Performance Evaluation

Evaluation of ZNE Performance is based on having at least 12 consecutive months of billing data as well as renewable energy generation data. In practice, there are several potential reasons why data may be missing for certain time periods or for certain end uses. The study team recommends three potential methods to address data gaps:

1. Gather additional data till a minimum of 12 consecutive months of data is available – while this is the correct approach technically, there are implications on the timeline when the verification is conducted. A single lost day of data may delay verification for months, which is impractical.
2. Remove the missing data periods from the analysis - this is perhaps the simplest since there is no additional analysis or time periods involved. However, this approach is fraught with errors if the missing data periods are extensive or at key periods such as peak cooling or heating seasons.
3. Estimate missing values – in this approach missing values are estimated using correlation of energy use and generation based on outdoor dry bulb temperature and solar insolation.

5.5.1 ZNE Site/Source Performance

Analysis needs to confirm that net energy use is zero or negative through analysis of utility bills. For the ZNE Site metric, the energy use is expressed in terms of annual kWh and therm totals for all building energy end uses and renewable generation. For the ZNE Source metric, the energy use is expressed in terms of the equivalent source energy use in terms of kBtu/sf for all building energy end uses and renewable generation. To generate the annual total, the building must have 12 consecutive months of energy use data. Since the building may or may not have PV systems sized to offset EV charging or support electricity storage onsite, the analysis needs to confirm that PV system output is pro-rated for the portion of the PV system designated to offset building energy use.

For nonresidential buildings, completion of building commissioning is a necessary step before a building can be evaluated for ZNE Performance.

Verification Requirements

The primary mode of verification for the ZNE Site/Source Performance metric is review of utility billing data as outlined in the Analysis requirements section. From a verification perspective, there are four key issues to be verified:

a. Was the building occupancy as intended?
b. Was the energy generation onsite supporting building energy use only or other uses like EV charging?

c. Was the energy generation onsite metered separately from building energy use? Or was the building on a net-energy meter such that only the net energy use data is available through utility bills?
d. Was the weather during the period of analysis within the range of normal weather patterns?

Criteria	Verification Process
Building Occupancy	Confirm that the building was occupied throughout the 12-months or note any exceptions such as extended periods of non-occupancy. This needs to be provided by the building owner/occupant or utility billing analysis needs to be sophisticated enough to detect long periods of non-occupancy.
Renewable Energy Dedicated to Building Energy Use Offset	Confirm that the energy produced onsite was offsetting building energy use only. If not, need to pro-rate production to that portion of the renewable system designated for building energy use offset. To do so, there would need to be documentation provided by the building owner/occupant or alternately the building/designer during the design stage of the project.
Is renewable energy separate metered? Or is there a net-meter?	If there is a separate meter for the renewable energy generation, the calculation is easy since the meter data for both energy use and renewable generation is available. This is the preferred option. However, most buildings do not have a separate utility meter for renewable generation and are on a single net-energy meter. In such instances the verification can only confirm if the net energy use is zero, positive or negative. A net energy use of zero or negative on an annual basis would qualify the building as ZNE. However, there are chances of false positives if the renewable system was oversized to account for non-building end uses or false negatives if the renewable system was sized for the building end uses only but the owner/occupant adds other uses such as electric vehicles.
Weather Patterns	Using the measured CDD and HDD from a local weather station, the evaluator can confirm if the weather was in line with 'normal' conditions based on the average weather files used for building design analysis. If weather was too hot or cold outside of the typical min-max range, this would necessitate a normalization of the energy use and output.

Figure 25: Verification Process for ZNE Site

Monitoring-Based Validation (Optional)

An additional step beyond utility meter data analysis is to confirm the energy use breakdown by end uses – including building energy end uses (HVAC, lighting, DHW, appliances, MELs etc.) as well as electric vehicles and storage. This step is not necessary for verifying whether the building is ZNE but is important to confirm why a building is or is not ZNE. It will also help eliminate issues with false positives or false negatives identified in Figure 25.

Analysis Requirements

Analysis needs to confirm that net energy use is zero or negative through analysis of utility bills. For the ZNE Site metric, the energy use is expressed in terms of annual site kBtu/sf total for all building energy end uses and fuels (electricity, natural gas, propane), whereas for ZNE Source metric, the analysis is done using annual source kBtu/sf. To generate the annual total, the building must have 12 consecutive months of energy use data. Since the building may or may not have PV systems sized to offset EV charging or support electricity storage onsite, the analysis needs to confirm that PV system output is pro-rated for the portion of the PV system designated to offset building energy use.

For residential buildings, there is typically no formal commissioning process involved but for ZNE analysis it is important that all building systems were installed correctly and that the energy use reflected in the bills are representative of how the building typically operates. For this reason, it is recommended that the billing analysis be done after the building is occupied as intended and the systems are deemed functional through functional testing by the relevant trades.

For nonresidential buildings, completion of building commissioning is a necessary step before a building can be evaluated for ZNE Performance.

Documentation Requirements

Documentation requirements for ZNE Site/Source Performance are similar to those of ZNE Design with the key addition of monthly utility bills and renewable energy generation based on actual performance of the building (compared to the predicted values used for ZNE Design).

5.5.2 ZNE Code Crosswalk to ZNE Site/Source Performance

Various stakeholders have requested a methodology to evaluate a ZNE building that is built to the ZNE Code (TDV based) definition. It should be noted here that a ZNE Code building is a building 'designed to be ZNE'. There are several reasons for that including the fact that the ZNE Code building is an asset rating and makes standardized assumptions about the building occupancy, schedules and weather.

As outlined in Section 8, there are several proposed approaches to evaluating how a building designed to the ZNE Code/TDV definition can be evaluated. As explained in that section, the easiest and perhaps the best approach is to look at the underlying predicted site energy use of the ZNE Code building and compare that against the actual energy use once occupied.

To get an accurate estimate of predicted savings, the study team recommends the following approach:

- Step 1: Generate energy model as required for ZNE Code - Design to calculate predicted site kWh, therm and kBtu usage on an annual basis (see Section 5.4.1)
- Step 2: Replace assumptions on MELs, Lighting, Appliances, and Schedules with 'expected' schedules/efficiencies if done at the design stage. If done post-occupancy, use 'actual' schedules/efficiencies instead. Substitute the standard weather files with actual weather data where feasible to isolate energy differences due to weather differences between code assumptions and real world performance.
- Step 3: Calculate modified site kWh, therm, and kBtu usage on an annual basis
- Step 4: Document resulting calibrated predicted kWh, therm, kBtu energy use
- Step 5: Compare the actual monitored site energy use (kWh, therm, kBtu) with the calibrated predicted kWh, therm, and kBtu energy use.
- Step 6: Compare the actual monitored net site energy use (site kBtu) with the calibrated predicted net site energy use (site kBtu)

An added level of analysis that may provide more accuracy but also increase complexity of the analysis would look at the predicted versus actual energy use not just by the annual totals but by various time of use categories such as summer peak, winter peak, weekday, weekend among others.

6. Verification of Proposed Methodologies

6.1 ZNE Methodologies Verification Process

The proposed ZNE Code, ZNE Design and ZNE verification methodologies outlined in Section 0 and Section 5.5 were tested on a sample of ZNE buildings. The goal of this process was to examine if the data and submittal requirements proposed as part of these methodologies could be fulfilled by actual ZNE buildings. The study team also hoped to identify potential barriers and implementation challenges through this verification process and use the ZNE case study assessment findings to further inform the ZNE verification procedures and recommendations outlined in Section 7. The study team conducted the following activities during this verification process:

- *ZNE Case Study Selection:* The buildings were chosen from a subset of ZNE buildings constructed in California and where building energy use data was being collected through current IOU and other research efforts. The study team's case study selection criteria required the projects to be constructed as ZNE buildings using any of the ZNE Code, Design or Performance metrics defined in Section 5.3 and Section 5.4.
- *Data collection:* The study team requested information of the building design and performance including energy modeling results and metered performance data. The data requested was used by the study team to understand the project background, building construction, building occupancy, and annual energy consumption onsite, annual renewable energy generated onsite, net energy use onsite, renewable energy systems, electric vehicles and energy storage.
- *Data review and analysis:* The study team conducted a detailed review of data that was made available through the selected case studies and developed an analysis methodology which the study team used to analyze the case studies and verify the proposed methodologies.
- *Summary of Findings:* the study team identified some common trends during the data collection and analysis process which provided useful insights into the structure and the implementation potential of the proposed methodologies. These findings were used to inform the overall recommendations by the study team elaborated upon in Section 6.

6.2 ZNE Case Study Selection

The study team worked with our team member Davis Energy Group (DEG) who had collected energy consumption data for a number of residential buildings through field monitoring and billing data analysis. Additionally, the study team received energy use prediction and consumption data for nonresidential projects from Ed Dean from Bernheim + Dean Inc., who had collected and analyzed data for two volumes of ZNE Case Studies funded by PG&E.

There were an additional four buildings where the study team sought the required information for this study but the project contacts were unable to provide the necessary data due to issues with data permissions and availability of data. In the end the study team received and analyzed data on twelve (12) buildings - eight (8) nonresidential buildings and four (4) residential buildings.

The study team did not have any intentional selection bias in favor of all-electric buildings, however, ten (10) of the twelve (12) buildings were all-electric projects. Two residential projects had natural gas consumption for space heating and water heating. As appropriate, the study team factored in all fuels for the purposes of this evaluation. The name, address and location of the projects have been kept confidential due to the data sharing agreements governing the use of building data made available to the study team. The table below provides a summary of the building types, climate zone, size, and ZNE goals of the buildings.

	BUILDING TYPE	CLIMATE ZONE	BUILDING SIZE (Sq.Ft.)	ZNE GOAL
BUILDING 1	Commercial Office	4	31,759	Site – Performance
BUILDING 2	Commercial Office	3	20,020	Site – Performance
BUILDING 3	Museum	3	190,000	Site – Performance
BUILDING 4	Educational, Office	3	45,001	Site – Performance
BUILDING 5	Commercial Office	4	6,557	Site – Performance
BUILDING 6	Commercial Office	4	49,000	Site – Performance
BUILDING 7	Library	4	6,300	Site – Performance
BUILDING 8	Library	3	9,300	Site – Performance
BUILDING 9	Single Family Residential	11	3,268	Site – Performance
BUILDING 10	Single Family Residential	4	3,170	Source – Performance
BUILDING 11	Single Family Residential	13	2,064	Code; Source – Performance
BUILDING 12	Single Family Residential	12	2,032	Site – Performance

Figure 26: Summary of the ZNE Case Studies

6.3 Data Collection

The study team used the submittal requirements defined in the ZNE Code, ZNE Design and ZNE performance verification methodologies (Section 0 and Section 5.5) to inform the data collection process. The following data was requested for each project:

- Project Background and Information: Details about the design team, building type, size and location.
- Building Construction: Details about the construction type, envelope, lighting and building systems.
- Project ZNE Goals: ZNE criteria the building was designed for: ZNE Code (TDV), ZNE Design, or ZNE Performance (Site/Source).
- Energy Consumption Data: Details of the monthly and annual modeled and monitored data for all fuel types. The energy consumption data was requested to be broken down into all major individual end uses (heating, cooling, ventilation, DHW, lighting etc.) where it was available. Since the projects selected for this study had been part of IOU research and monitoring studies, this data was generally available. However, this is not expected to be the case for the 'average' ZNE building that is not part of any research effort.
- Energy Generation Data: Details of the renewable systems installed (capacity, installation details, manufacturer etc.), and the monthly and annual modeled and monitored data for all renewable generation sources.

If relevant, the projects were also asked to provide details of the building commissioning, simulation/modeling analysis methods and software used, energy storage, electric vehicles, or any other relevant information critical to the energy performance of the project.

6.4 Data Review and Analysis

The study team reviewed energy use and generation data for twelve buildings (eight nonresidential and four residential) that were designed to be ZNE using various metrics (site energy, source energy or TDV). While the study team is grateful to the team members and others that provided the requested data, a few data gaps and limitations were evident (See Figure 27 below). These include:

- The data for all projects varied in terms of the amount of data available, format of the data, level of detail (by end uses, hourly vs monthly).
- The eight nonresidential projects were designed as all-electric buildings and there was no natural gas consumption data available for these buildings.
- Of the four residential buildings, two were designed to be all-electric and did not have any natural gas consumption.
- Lack of modelled renewable energy generation data and TDV/ERI/EDR values. The lack of TRV/ER/EDR metrics did not allow the study team to conduct ZNE Code assessments. The ZNE Design assessments were done on the basis of modeled energy consumption data, but not on the basis of EDR or ERI ratings.
- None of the buildings had data on occupancy, operational schedules and commissioning.

<table>
<tr><th rowspan="2">PROJECT NAME</th><th colspan="6">Modelled Energy Use</th><th colspan="4">Monitored Energy Use</th><th colspan="4">Modeled Energy Generation</th><th colspan="4">Monitored Energy Generation</th></tr>
<tr><th>kWh</th><th>Therm</th><th>Site kBtu</th><th>Source kBtu</th><th>TDV</th><th>ERI/EDR</th><th>kWh</th><th>Therm</th><th>Site kBtu</th><th>Source kBtu</th><th>kWh</th><th>Therm</th><th>Site kBtu</th><th>Source kBtu</th><th>kWh</th><th>Therm</th><th>Site kBtu</th><th>Source kBtu</th></tr>
<tr><td>BUILDING 1</td><td>✓</td><td>NA</td><td colspan="2" rowspan="8">Calculated by the Study Team</td><td colspan="2" rowspan="12">Not Available. Could not be Calculated by the Study Team due to Data Gaps.</td><td>✓</td><td>NA</td><td colspan="2" rowspan="12">Calculated by the Study Team</td><td colspan="4" rowspan="12">Not Available. Could not be Calculated by the Study Team due to Data Gaps.</td><td>✓</td><td>NA</td><td colspan="2" rowspan="12">Calculated by the Study Team</td></tr>
<tr><td>BUILDING 2</td><td>✓</td><td>NA</td><td>✓</td><td>NA</td><td>✓</td><td>NA</td></tr>
<tr><td>BUILDING 3</td><td>✓</td><td>NA</td><td>✓</td><td>NA</td><td>✓</td><td>NA</td></tr>
<tr><td>BUILDING 4</td><td>✓</td><td>NA</td><td>✓</td><td>NA</td><td>✓</td><td>NA</td></tr>
<tr><td>BUILDING 5</td><td>✓</td><td>NA</td><td>✓</td><td>NA</td><td>✓</td><td>NA</td></tr>
<tr><td>BUILDING 6</td><td>✓</td><td>NA</td><td>✓</td><td>NA</td><td>✓</td><td>NA</td></tr>
<tr><td>BUILDING 7</td><td>✓</td><td>NA</td><td>✓</td><td>NA</td><td>✓</td><td>NA</td></tr>
<tr><td>BUILDING 8</td><td>✓</td><td>NA</td><td>✓</td><td>NA</td><td>✓</td><td>NA</td></tr>
<tr><td>BUILDING 9</td><td>X</td><td>NA</td><td colspan="2">X</td><td>✓</td><td>NA</td><td>✓</td><td>NA</td></tr>
<tr><td>BUILDING 10</td><td>✓</td><td>✓</td><td colspan="2">Calculated</td><td>✓</td><td>✓</td><td>✓</td><td>NA</td></tr>
<tr><td>BUILDING 11</td><td>X</td><td>✓</td><td colspan="2">X</td><td>✓</td><td>✓</td><td>✓</td><td>NA</td></tr>
<tr><td>BUILDING 12</td><td>✓</td><td>NA</td><td colspan="2">Calculated</td><td>✓</td><td>NA</td><td>✓</td><td>NA</td></tr>
</table>

Figure 27: ZNE Case Studies- Data Availability and Gaps

6.4.1 Data Analysis Methodology

The goal was to verify the individual methodologies for the ZNE Code, Design and Performance buildings. However, out of the twelve case studies, ten projects were designed to be ZNE Site - Performance buildings and two were designed to be ZNE Source - Performance buildings. Building 11 also had a stated goal of being ZNE Code, but the TDV values and modeled energy generation data were not available for the verification of that methodology. Thus, the process was primarily focused on ZNE Site and Source Performance verification. The verification methodology is described below in detail.

Energy Metrics Calculated by the study team

The study team reviewed and analyzed the data provided by the case studies and calculated the following performance metrics:

- *Annual total Energy Use (kBtu):* Site energy consumption for the building converted to site and source energy consumption -using the energy multipliers described below.
- *Annual Total Energy Use Intensity (kWh/Sq.ft; kBtu/Sq.Ft.):* Site and source energy consumption for the building divided by the total conditioned area in the building.
- *Annual Onsite Renewable Electricity Generation Dedicated to Offset Building Energy Use (kBtu):* Total site energy generation by the building by all fuel types converted to site and source energy generation in kBtu- using the energy multipliers described below.
- *Annual Net Annual Energy Use (site kWh and source kBtu):* Site and source energy consumption after subtracting the total renewable energy generation dedicated to offset building energy use.

Assumptions for Source Energy Multipliers

The study team was provided site electricity (kWh) consumption for all twelve projects along with and natural gas (therm) for two residential projects. For consistency and comparability, all energy performance were expressed in thousand British thermal units (kBtu) and were annualized to 12 calendar months. The study team used the thermal conversion factor of 3.41 to convert electricity consumption from kWh to kBtu, and a conversion factor of 100 to convert natural gas consumption from therm to kBtu[1]. The total site energy consumption (kBtu) was converted to source energy consumption (kBtu) using a U.S. national average conversion factor of 3.14 for the site-to-source conversions[2].

Although these conversion factors are widely used by the federal government and nationally, there are other numbers which are also used in the industry. The study team realizes that the site-to-source conversion factors are unique to specific power plants and differ across regions of the country. The numbers for California in the various IOU territories will deviate to some degree than the ones used in this study. However, the choice of using national numbers was made to enable fair comparisons with other ZNE buildings located in other parts of the country. The use of national source-site ratios ensures that no specific building will be credited (or penalized) for the relative efficiency of its utility provider.

ZNE Code Assessment:

For the ZNE Code assessment, the study team primarily needed to verify if the building model inputs and outputs confirmed that the modeled EDR ≤ 0. For nonresidential buildings, it was necessary to verify if the annual energy generation (TDV/sf) was adequate to offset the annual energy consumption (TDV/sf) for the building. The ZNE Code Assessment could not be conducted due to the lack of availability of EDR and TDV values of any of the projects.

ZNE Design Assessment:

The study team needed to verify if the building' model inputs and outputs to confirm that the modeled ERI ≤ 0. The study team also needed to verify that the PV system size, orientation, tilt, efficiency, as well as confirm the PV capacity designed was adequate to offset the building' energy uses. The modeled PV generation data, and the ERI metrics of conducting a ZNE Design assessment were not available for these projects, so the study team was unable to determine if any of these buildings has been designed with the ANSI/RESNET/ICC metrics in mind.

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[1] https://portfoliomanager.energystar.gov/pdf/reference/Thermal%20Conversions.pdf

[2] https://portfoliomanager.energystar.gov/pdf/reference/Source%20Energy.pdf

ZNE Performance Assessment:

The study team needed to verify if the case studies met the ZNE Performance status by confirming if the net energy use in the case studies was zero or negative. This was done through the analysis of utility bills and renewable energy generation data for all buildings for 12 consecutive months. The study team examined the energy generation and energy consumption data on an annual and a monthly basis.

1) *Annual Energy Performance:* All projects were analyzed on the basis of their net energy use over a continuous twelve month period, and evaluated for being a net energy producer or consumer. The study team examined the annual net site and source energy use intensities (EUI) for the projects. Where data was available, the ZNE evaluation utilized natural gas data. The net EUI's were compared on the basis of site energy use (kWh, therm), site EUI (kBtu/sf) and source EUI (kBtu/sf). A successful ZNE building was expected to have a zero or negative net EUI on an annual basis.
2) *Monthly Energy Performance:* If available, the study team compared the modeled and monitored end use consumption profiles on a monthly basis. The monthly end use comparison was done to examine the seasonal ZNE Performance variations and to identify any distinctive anomalies between the modeled and monitored data.

The study team did not attempt to hypothesize on the potential reasons why some projects did not meet the desired ZNE status or why the monitored energy use in some building deviated significantly from the modeled energy use. More work will need to be done to understand the design intent, energy use profiles, renewable energy generation and occupant behaviors to understand the performance of these buildings in detail. Additionally, the ZNE evaluation is limited to those twelve months for which the energy consumption was monitored and evaluated, and does not guarantee that these buildings will continue to maintain its ZNE status in subsequent years.

6.5 Summary of Findings

The study team's verification process revealed that the data provided by all buildings was adequate to conduct a ZNE site and source performance assessment according to the methodologies proposed by the study team. The results showed that eleven out of the twelve buildings were able to meet their ZNE goals. Building 3 could not meet its ZNE Site - Performance goals. See Figure 28 for a summary of results. A detailed summary of all the individual case studies is available in the Appendix, section 8.

	ZNE Goal	**Met Goal* (Y/N)**	**Net Site Energy**			**Net Source Energy**
			kWh	**Therm**	**kBtu/sf**	**kBtu/sf**
BUILDING 1	Site Performance	Y	(16,404)	-	(1.76)	(5.53)
BUILDING 2	Site Performance	Y	(25,472)	-	(4.34)	(13.63)
BUILDING 3	Site Performance	**N**	**472,110**	**-**	**8.48**	**26.62**
BUILDING 4	Site Performance	Y	(52,397)		(3.97)	(12.47)
BUILDING 5	Site Performance	Y	(4,476)	-	(2.33)	(7.31)
BUILDING 6	Site Performance	Y	(80,005)	-	(5.57)	(17.49)
BUILDING 7	Site Performance	Y	(18,609)	-	(10.08)	(31.65)
BUILDING 8	Site Performance	Y	(12,503)	-	(4.59)	(14.40)
BUILDING 9	Site Performance	Y	(1,938)	-	(2.02)	(6.35)
BUILDING 10	Source Performance	Y	521	65	0.56	(2.63)
BUILDING 11	Code; Source Performance	Y	2,666	192	4.41	(6.07)
BUILDING 12	Site Performance	Y	(1,259)	-	(2.11)	(6.64)

Figure 28: ZNE Building Assessment Summary

*NOTE: the study team was unable to verify ZNE Code goals due to lack of TDV values

Given below is a summary of findings from the verification process of the three methodologies proposed by the study team.

- *ZNE Code Assessment:* The Building 11 amongst the case studies was the only project which targeted a ZNE Code status. However, to be able to verify the ZNE methodology or the targeted ZNE Code goal for the building due to the lack of TDV values available for the assessment.
- *ZNE Design - Site/Source Assessment:* the study team was unable to verify if any of these buildings were designed to be ZNE Design projects due to lack of modeled renewable energy generation data and the ERI values for any of the projects.
- *ZNE Performance (Site/Source) Assessment:* the study team was adequately able to conduct a ZNE site and source performance assessment of all the case studies available for this project. The building provided only the site performance data for all projects, and the study team had to use DOE's energy multipliers to convert the site energy consumption/generation to source metrics. This implies that most projects will not be able to provide source energy metrics and it might be worthwhile to build these conversion factors in California's approved building energy performance software tools. Figure 29 summarizes the results from the ZNE Performance assessment. Eleven out of the twelve buildings are ZNE according to the site energy use metrics, but Building 10 and 11 do not meet the ZNE Site - Performance criteria. As mentioned earlier, Building 3 does not meet either the ZNE Site or the ZNE Source - Performance metrics.

	Monitored Energy Use				**Monitored Energy Generation**				**Monitored Net Energy Use**			
	kWh	**Therm**	**Site kBtu/sf**	**Source kBtu/sf**	**kWh**	**Therm**	**Site kBtu/sf**	**Source kBtu/sf**	**kWh**	**Therm**	**Site kBtu/sf**	**Source kBtu/sf**
BUILDING 1	250,049	-	27	84	266,453	-	29	90	(16,404)	-	(2)	(6)
BUILDING 2	131,615	-	22	70	157,087	-	27	84	(25,472)	-	(4)	(14)
BUILDING 3	**2,460,950**	**-**	**44**	**139**	**1,988,839**	**-**	**36**	**112**	**472,110**	**-**	**8**	**27**
BUILDING 4	215,159	-	16	51	267,556	-	20	64	(52,397)	-	(4)	(12)
BUILDING 5	35,955	-	19	59	40,431	-	21	66	(4,476)	-	(2)	(7)
BUILDING 6	201,737	-	14	44	281,742	-	20	62	(80,005)	-	(6)	(17)
BUILDING 7	35,121	-	19	60	53,730	-	29	91	(18,609)	-	(10)	(32)
BUILDING 8	62,850	-	23	72	75,353	-	28	87	(12,503)	-	(5)	(14)
BUILDING 9	11,460	-	12	38	13,398	-	14	44	(1,938)	-	(2)	(6)
BUILDING 10	9,357	65	12	34	10,849	-	12	37	(1,492)	65	**1**	(3)
BUILDING 11	6,629	192	20	44	9,590	-	16	50	(2,961)	192	**4**	(6)
BUILDING 12	8,147	-	14	43	9,406	-	16	50	(1,259)	-	(2)	(7)

Figure 29: ZNE Performance Assessment Summary Results

Finally, the study team compared the modelled energy consumption and the monitored energy consumption data for all the twelve buildings. Figure 30 summarizes the results from that comparative analysis. It is interesting to note that only Building 10's monitored energy performance was closer to its predicted energy performance. In the rest of the buildings, the actual energy consumption was either significantly lesser or higher than its predicted value. For ZNE buildings, any signification deviation from a building's predicted performance has immediate implications on the sizing of its renewable systems and also has cost implications for the building owner/developer. The study team did not have enough information to analyze if the monitored performance deviations occurred due to inaccurate modeling of the building or due to limitations of the simulation softwares used. However, it was important to observe that most of these ZNE buildings did not perform as predicted by their energy modeling results, and it will be important to provide the building industry the needed education and tools for better prediction of the overall building energy performance of ZNE projects.

BUILDING #	Modeled Energy Use				Monitored Energy Use				Monitored VS. Modelled Difference			
	kWh	Therm	Site kBtu/sf	Source kBtu/sf	kWh	Therm	Site kBtu/sf	Source kBtu/sf	kWh	Therm	Site kBtu/sf	Source kBtu/sf
BLDG 1	197,010	-	21	66	250,049	-	27	84	21%		21%	21%
BLDG 2	151,237	-	26	81	131,615	-	22	70	-15%		-15%	-15%
BLDG 3	2,668,019	-	48	150	2,460,950	-	44	139	-8%		-8%	-8%
BLDG 4	237,570	-	18	57	215,159	-	16	51	-10%		-10%	-10%
BLDG 5	47,720	-	25	78	35,955	-	19	59	-33%		-33%	-33%
BLDG 6	277,737	-	19	61	201,737	-	14	44	-38%		-38%	-38%
BLDG 7	50,292	-	27	86	35,121	-	19	60	-43%		-43%	-43%
BLDG 8	47,711	-	18	55	62,850	-	23	72	24%		24%	24%
BLDG 9	-	-	-	-	11,460	-	12	38				
BLDG 10	9,220	99	13	34	9,357	65	12	34	1%	-52%	-8%	-2%
BLDG 11	-	-	-	-	6,629	192	20	44				
BLDG 12	6,424	-	11	34	8,147	-	14	43	21%		21%	21%

Figure 30: Building Energy Modeling and Energy Monitoring Data Comparison

7. Recommendations

The study team has proposed verification methodologies for the following ZNE metrics: ZNE Design versus ZNE Performance. Within each, the methodologies are further refined based on whether the design is based on the California Integrated Energy Policy Report (IEPR) definition using Time Dependent Valuation (TDV) or using Site or Source energy metrics. The methodologies are also separated by whether they are for residential or nonresidential buildings. In Section 5 the study presented the proposed ZNE Evaluation methodologies. Based on the review of data from case study buildings summarized in Section 6, here are the key verification requirements:

ZNE Metric to be Verified	Stage	Verification Metric Residential	Evaluation Metric Nonresidential
ZNE Site	Design	ERI = 0 Predicted Net Site kBtu = 0	Predicted Net Site kBtu = 0
	Performance	Actual Net Site kBtu = 0	
ZNE Source	Design	Predicted Net Source kBtu = 0	
	Performance	Actual Net Source kBtu = 0	
ZNE Code	Design	EDR = 0	
	Performance	Calibrated Actual Net kBtu = Predicted Net kBtu	

Figure 31: Key ZNE Verification Metrics by ZNE Criteria

ZNE Metric to be Verified	Stage	Modeled Energy Performance – Annual total of hourly analysis	Utility Net Meter Data – Annual	Separate Energy Use and Renewable Meter Data - Annual	End Use Monitoring – Annual Total and/or Hourly
ZNE Site	Design	Sufficient	Not Required	Not Required	Not Required
	Performance	Not Required	Sufficient	Sufficient	Not Required
ZNE Source	Design	Sufficient with Source Factors	Not Required	Not Required	Not Required
	Performance	Not Required	Sufficient with Source Factors	Sufficient with Source Factors	Not Required
ZNE Code	Design	Sufficient with TDV Factors	Not Required	Not Required	Not Required
	Performance	Required but not sufficient by itself	Required along with building details necessary for a calibrated post-construction energy model (see § 5.5.2)		Not Required

Figure 32: Required Data to Verify that a Building Meets the ZNE Criteria by Type of ZNE Criteria

Each of the proposed verification methodologies presented in this document represents a particular type of ZNE building and it is not necessary that a building that is ZNE under one metric (say ZNE Code) is ZNE under another metric (say ZNE Site). Further, a building designed to be ZNE may or may not have ZNE Performance. Thus it is important that ZNE buildings be qualified as ZNE Design or ZNE Performance as well as specify the metric being used (Site/Source/Code). ZNE Verified – a term used by New Buildings Institute (NBI) – may be a good substitute for ZNE Performance.

7.1 Establish Standard Documentation Requirements

Based on review of the ZNE case study buildings and specifically the gaps in data availability to conduct verification activities on various ZNE metrics, this section outlines documentation requirements for each of the ZNE metrics of concern. Since most of the required documentation is similar across the ZNE metrics, the report presents the full list of documentation for ZNE Code - Design but for the subsequent metrics, the report presents only those data and results that are unique to those metrics.

7.1.1 ZNE Code – Design: Documentation Requirements

Topic	Subtopic	Submittal Requirements
Analysis Methodology	Software Used for Predictions	Name and version of software (needs to be CEC approved software).
	Period of Analysis	Annual based on hourly analysis
Net Energy Use Onsite	Energy Design Rating (EDR)	EDR calculated using CEC approved methodologies. EDR must be Zero or Negative to show ZNE Code compliance. NOTE: Currently there is no approved CEC method to calculate EDR for Nonresidential Buildings.
Annual Energy Consumption Onsite	Predicted Electricity Use (kWh)	Total kWh/sf for a 12-month period
	Predicted Fuel Use (Therm)	Total Therm/sf for a 12-month period
	Predicted TDV Use	Total TDV/sf for a 12-month period
	Predicted TDV Use by End Use Category	TDV/sf by end uses for all building end uses for a 12-month period
Annual Renewable Energy Generated Onsite	Predicted Annual Renewable Electricity Produced Onsite Dedicated to Offset Building Energy Use (kWh)	Total kWh/sf for a 12-month period. Note: This feature is not natively available in nonresidential compliance software currently.
	Predicted Onsite Renewable Electricity Generation Dedicated to Offset Building Energy Use (TDV)	Total TDV/sf for a 12-month period. Note: This feature is not natively available in nonresidential compliance software currently.
Background	Project Team	Owner, Developer, Builder, Architect, Mechanical Engineer, Contractor, Energy Consultant, Other Consultants
	Project Goals	ZNE metric targeted; specific goals and targets relevant to ZNE
General Building Information	Project Name	
	Location	City, County, CEC Climate Zone
	Building Type	Type(s) of building occupancies (e.g. Office, Retail, School, Residential Single Family, Residential Multifamily Low-rise, Residential Townhomes)
	Building Size	Conditioned area, # floors, # buildings
	Construction Type	New Construction; Addition/Retrofit
Building Construction	Building Envelope	Framing type, U-factor (wall, roof, floor), U-factor and SHGC (windows), air leakage

Topic	Subtopic	Submittal Requirements
	HVAC System	System type, capacity, efficiency, # of systems
	DHW System	System type, capacity, efficiency, # of systems
	Lighting	Lighting efficacy (lumens/watt)
Building Occupancy	Number of Occupants	Default per CEC Residential/Nonresidential ACM procedures.
	Occupancy Schedule	
	Equipment Schedule	
	Lighting Schedule	
Building Commissioning	System Commissioning	Commissioning Report outlining key activities performed – for nonresidential buildings only.
	Building Operations	Building Operations Manual or other documentation outlining building operational strategies
Renewable Energy Systems	Photovoltaic (PV) System Generation Capacity (kW)	Total installed rated capacity in kW DC and kW AC
	Photovoltaic (PV) System Capacity Dedicated to Offset Home Energy Use (kW)	Total installed rated capacity in kW DC and kW AC dedicated to offset home energy use. Renewable capacity dedicated for Electric Vehicle (EV) or Storage needs to be subtracted from the total generation capacity to calculate this number.
	Photovoltaic (PV) Orientation and Tilt	Orientation in degrees from North (0=North, 90 = East); Tilt (angle from horizontal); If multiple panels used, provide orientation and tilt by each panel 'group'
	Photovoltaic (PV) System Location	Specify location of renewable system (e.g. Roof). System must be installed within the bounds of the 'project' site as defined in the 2015 IEPR
	Photovoltaic (PV) Manufacturer and Make	Make, model number, manufacturer name
	Other Renewable Energy Systems	Rated capacity, total annual output, location onsite, manufacturer and make.
Electric Vehicles	If Electric Vehicle Charging is Anticipated	# of Electric Vehicles Predicted to be Charging at Home
Energy Storage	Energy Storage System	Estimated Storage Capacity

Figure 33: Proposed ZNE Code Verification Requirements for Documentation

7.1.2 ZNE Design - Site/Source: Documentation Requirements

Topic	Subtopic	Submittal Requirements
Analysis Methodology	Software Used for Predictions	Name and version of software (needs to be ANSI/RESNET/ICC approved software for residential buildings).
	Period of Analysis	Annual based on hourly analysis
Net Energy Use Onsite	Res: Energy Rating Index (ERI)	ERI calculated using ANSI/RESNET/ICC approved methodologies. ERI must be Zero or negative to show Res ZNE Design.
	Nonresidential: Predicted Net Annual Site Energy Use (site kBtu)	Total Predicted Energy Use (site kBtu/sf) - Total Predicted Renewable Electricity Produced Onsite (site kBtu/sf) = Zero or Negative.
	Res/Nonresidential: Predicted Net Annual Source Energy Use (source kBtu)	Total Predicted Energy Use (source kBtu/sf) - Total Predicted Renewable Electricity Produced Onsite (source kBtu/sf) = Zero or Negative.
Building Occupancy	Number of Occupants	Res: default per ANSI/RESNET/ICC 301-2014 Nonresidential: document assumptions made by modeler
	Occupancy Schedule	
	Equipment Schedule	
	Lighting Schedule	

Figure 34: Proposed ZNE Design - Site/Source Documentation Requirements (excerpt)

7.1.3 ZNE Site – Performance: Documentation Requirements

Topic	Subtopic	Submittal Requirements
Net Energy Use Onsite	Net Annual Actual Energy Use (site kBtu)	Actual Annual Energy Use (site kBtu/sf) - Actual Annual Renewable Electricity Produced Onsite Dedicated to Offset Home Energy Use (site kBtu/sf) = Zero or Negative.
Building Occupancy	Number of Occupants	Actual average number of occupants
	Operating Hours and Schedule	Actual weekly hours of operation, and typical occupancy schedule (weekday and weekend/holiday)
	Vacancy Rate	Confirm that vacancy was less than 10% on an annual basis
	Building System Operation	Confirm that building systems were installed per manufacturer instructions and operational. Note any discrepancies.
	System Commissioning (nonresidential)	Commissioning Report outlining key activities performed
Billing and Metering Data	Electricity Bills	Monthly electricity bills for at least 12 months post-occupancy
	Natural Gas/Fuel Bills	Monthly natural gas/fuel bills for at least 12 months post-occupancy
	Renewable Electricity Metering (Optional)	Monthly renewable electricity production for at least 12 months post-occupancy. If separate PV Meter is not installed onsite, note source of estimate.

Topic	Subtopic	Submittal Requirements
Annual Energy Consumption Onsite	Actual Electricity Use (kWh)	Total kWh for a 12-month period post-occupancy
	Actual Fuel Use (Therm)	Total Therm for a 12-month period post-occupancy
	Actual Site Energy Use (site kBtu)	Total site energy use (site kBtu/sf) for a 12-month period post-occupancy
	Actual Energy Use by End Use Category (Optional)	kWh and Therm by end uses - Space Cooling, Space Heating, Ventilation, DHW, Lighting, Appliances and MELs.
Annual Renewable Energy Generated Onsite	Actual Annual Renewable Electricity Produced Onsite dedicated to offset Building Energy Use (kWh)	Total kWh for a 12-month period
	Actual Annual Renewable Electricity Produced Onsite dedicated to offset Building Energy Use (site kBtu)	Total site kBtu/sf for a 12-month period
Weather Data (Optional)	Cooling Degree Days during the period of analysis	Document CDD base 65°F during the period of analysis through review of observed weather from nearest weather station with data availability.
	Heating Degree Days during the period of analysis	Document HDD base 65°F during the period of analysis through review of observed weather from nearest weather station with data availability.
Significant Operational Variables	Operational Variables compared to Design	Short narrative of incidents or variations that affected the energy use (positive or negative).

Figure 35: ZNE Site - Performance Documentation Requirements

7.1.4 ZNE Source – Performance: Documentation Requirements

Documentation requirements for ZNE Source - Performance are similar to that for ZNE Site - Performance except that for ZNE Source, the analysis is documented in terms of source kBtu per Figure 36. The figure does not repeat the rest of the documentation requirements outlined in Figure 35 which apply here as well.

Topic	Subtopic	Submittal Requirements
Billing and Metering Data	Electricity Bills	Monthly electricity bills for at least 12 months post-occupancy
	Natural Gas/Fuel Bills	Monthly natural gas/fuel bills for at least 12 months post-occupancy
	Renewable Electricity Metering (Optional)	Monthly renewable electricity production for at least 12 months post-occupancy. If separate PV Meter is not installed onsite, note source of estimate.
Annual Energy Consumption Onsite	Actual Electricity Use (kWh)	Total kWh for a 12-month period post-occupancy
	Actual Fuel Use (Therm)	Total Therm for a 12-month period post-occupancy
	Actual Total Energy Use (kBtu)	Total energy use in Source kBtu for a 12-month period post-occupancy

	Actual Total Energy Use Intensity	Source kBtu/sf for a 12-month period post-occupancy
	Actual Energy Use by End Use Category (Optional)	kWh and Therm by end uses - Space Cooling, Space Heating, Ventilation, DHW, Lighting, Appliances and MELs.
Annual Renewable Energy Generated Onsite	Actual Annual Renewable Electricity Produced Onsite dedicated to offset Home Energy Use (kWh)	Total kWh for a 12-month period
	Actual Onsite Renewable Electricity Generation Dedicated to Offset Home Energy Use (kBtu)	Total source kBtu/sf for a 12-month period
Net Energy Use Onsite	Net Annual Actual Energy Use (source kBtu)	Total Actual Energy Use (kBtu) - Total Actual Renewable Energy Produced Onsite dedicated to offset building energy use (kBtu) = Zero or Negative. Note: For this calculation, onsite fuel and electricity usage are converted to source kBtu

Figure 36: ZNE Source Documentation Requirements (Excerpt)

7.2 Identify Entities that will be Responsible for ZNE Verification

Currently, there is no central entity within California that is responsible for verification of ZNE. This is likely to change as ZNE becomes a code mandate and ZNE Design claims will be verified by building departments and HERS raters. These entities need to be trained and coordinated so that the ZNE verification is done consistently across the state. But this is in the future, assuming ZNE Code is put in place. Till then, there is no current entity that oversees ZNE Code and ZNE Design verification.

There is no requirement for ZNE Performance in current regulatory proceedings and utility programs. Thus it is unknown if there will be a central entity or a coordinated effort to ensure that ZNE verification is done on a consistent basis. The ZNE Recognition program being developed by the California Public Utilities Commission (CPUC) appears to be the right venue for this entity but the ZNE recognition program does not have any ongoing scope or budget to do so. Any entity tasked with ZNE verification will require sufficient support, and adequate training to ensure that verification is accurate and consistent throughout the state.

7.3 Develop Standardized Registries for ZNE Buildings

Related to above, there is a need to develop a standardized tracking platform that tracks ZNE Design and ZNE Performance across buildings. Currently, there is no one place where this information is tracked.

NBI is tracking commercial buildings nationally through their efforts with various grants and sponsors as well as in greater depth in California through their efforts with the CPUC. On the residential side, the IOUs completed a ZNE Market Characterization study that identified ZNE buildings in the state, but that was a one-time activity. The Net-Zero Energy Coalition[1] as well as RESNET are both tracking ZNE buildings across

[1] http://netzeroenergycoalition.com/wp-content/uploads/2015/04/20150105_nzec_zero_energy_homes_report_booklet_fnl_02.pdf

the country – but they use differing definitions. Note that these efforts are reliant on self-reporting by building owners and operators of their predicted and actual energy use/energy generation onsite.

7.4 Develop Rulesets for ZNE Code - Design Nonresidential Modeling

There are several aspects of the ZNE Code - Design Nonresidential analysis, documentation and verification that are currently unknown. There are no procedures within the compliance tools to address onsite renewable generation, no procedures to calculate the Energy Design Rating and no nonresidential HERS Raters or data registries that can verify and track nonresidential building ZNE Code status.

7.5 Develop Verification Methodologies for ZNE Retrofits in Existing Buildings

The verification methodologies proposed in this document are applicable to new construction ZNE buildings only. The methodologies for ZNE performance validation may be applicable to retrofit situations but this study has not conducted detailed analysis of the suitability of the proposed verification methodologies for retrofits. The study team therefore recommends a follow-up study to review ZNE retrofit projects and identify retrofit specific verification methodologies.

8. Appendix A: ZNE Building Data Review

8.1 Review of ZNE Building Data

Below is a summary of the ZNE verification performed on twelve ZNE buildings located in five climate zones in California. The name, location, size and other details of these buildings have been kept confidential for this study. The study team was able to examine if the different buildings met the ZNE Performance status on an annual site or source performance metric, but it was not able to identify the reasons in cases the ZNE status was not successfully achieved by any building.

8.1.1 Building No. 1

Building 1 is an all-electric commercial office building located in climate zone 4, with the stated intention of being a ZNE Site - Performance building. The study team received data on the building' modeled (predicted) energy use developed by the project team using energy simulation analysis. The study team also received energy performance monitoring over a 12-month consecutive period for the building energy use and onsite PV energy generation. The modeled PV generation metrics, TDV values were not available for this verification. The monthly monitored end use data reported HVAC (heating, cooling and ventilation combined), plug loads and lighting consumption. The building meets ZNE Performance based on the site energy consumption metrics (kWh, kWh/sf and kBtu/sf) and source energy consumption (kBtu/sf).

Building Type	Commercial Office
Building Size	31,759
Climate Zone	4
ZNE Goal Targeted	ZNE Site - Performance
Data Available/Provided	Monthly energy consumption by end use (modeled and monitored) and PV generation data. End use data summarized by HVAC, lighting and plug loads.
Data Gaps	Modeled PV generation; TDV values

	Site Energy					Source Energy
	kWh	therm	kWh/sf	therm/sf	kBtu/sf	kBtu/sf
Modeled Energy Use	197,010	-	6.20	-	21.17	66.46
Modeled Energy Generation	Not Available					
Monitored Energy Use	250,049	-	7.87	-	26.86	84.35
Monitored Energy Generation	266,453	-	8.39	-	28.63	89.89
Monitored Net Energy Use	**(16,404)**	**-**	**(0.52)**	**-**	**(1.76)**	**(5.53)**

Figure 37: Annual Energy Performance Summary for Building 1

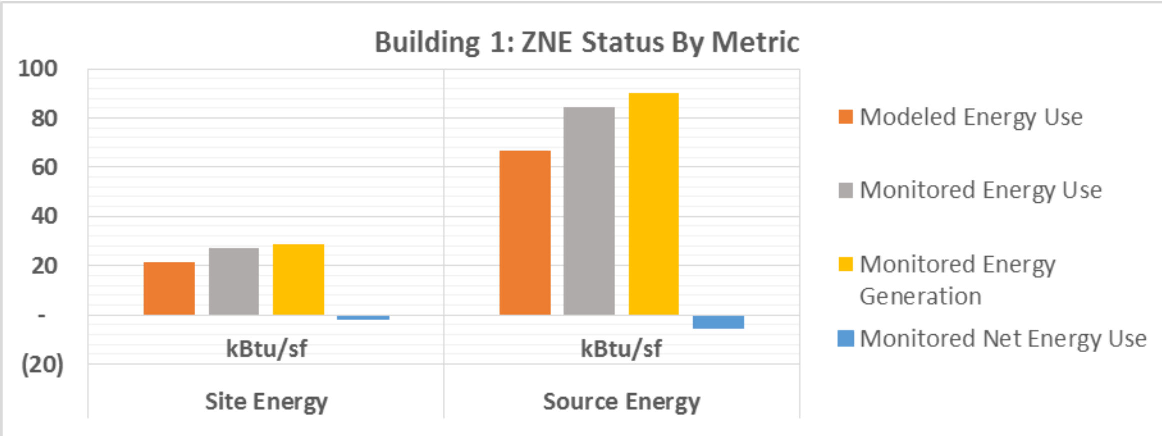

Figure 38: Annual Energy Use Profile for Building I

Annual Energy Performance:

As seen in Figure 37 and Figure 38, on an annual basis, the building uses approximately 27 percent more energy in operation than predicted. However, the building still meets the ZNE Performance based on both site and source EUIs since the building is a net energy producer on an annual basis. The annual onsite PV system generation onsite is greater than the monitored and modeled energy use for the building. This indicates that the PV system was either intentionally or unintentionally over-designed compared to the predicted energy use or that the PV system in operation is performing above and beyond what was predicted. The lack of availability of modeled energy generation data did not allow us to learn more about the intended performance of the PV system.

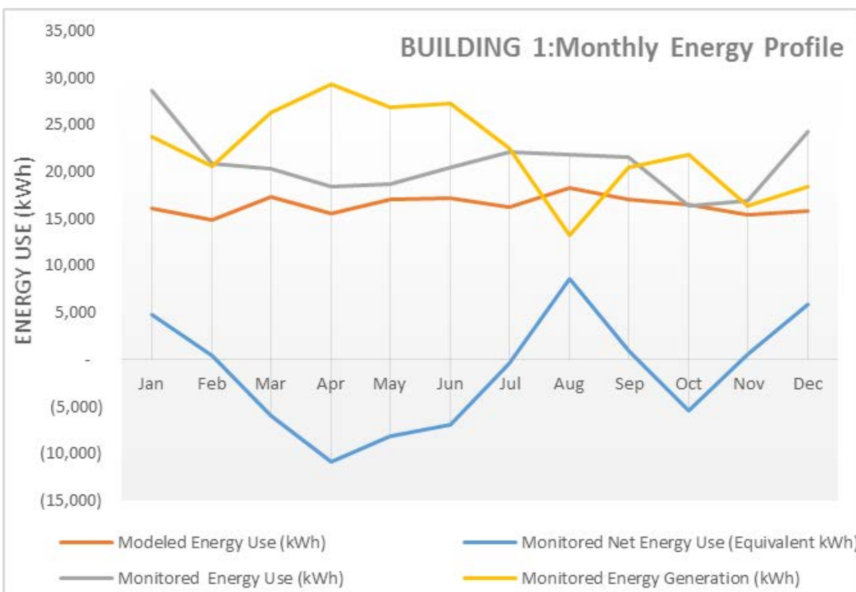

Figure 39: Monthly Energy Profile for Building I

Monthly Energy Performance:

Figure 39 shows the energy use and generation breakdown by month and it shows that the building is a net energy user during the summer cooling and winter heating seasons but that it is a net energy producer for the rest of the six months of the year. Note that there was an unusual drop in the energy generation in August, and the cause of that remains unknown to the study team.

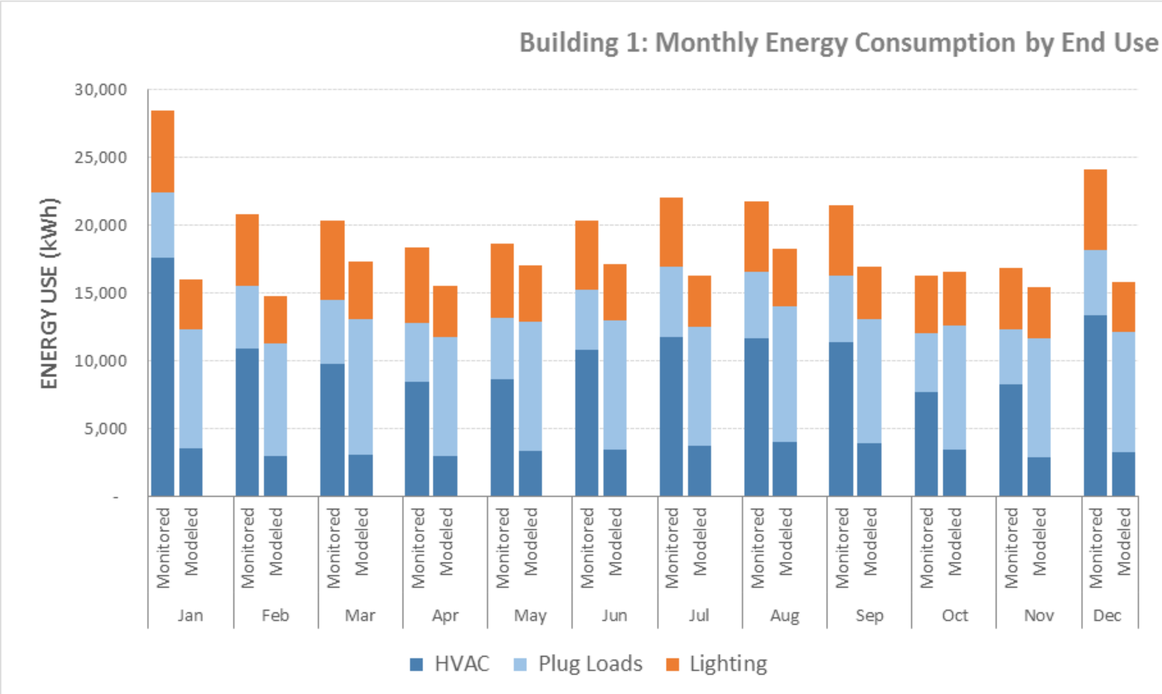

Figure 40: Monthly Energy Consumption by End Use for Building 1

Figure 40 shows that the building consistently uses more energy on HVAC and Lighting than predicted but lower energy for plug loads than predicted for all months of the year. This indicates that the predicted plug load usage was erroneously high, perhaps because the building does not have as many plug loads in practice as predicted during the design phase.

8.1.2 Building No. 2

Building 2 is an all-electric commercial office building located in climate zone 3 and has a goal of achieving ZNE Site - Performance. The study team received data on the building' monthly modeled and monitored energy use data along with the monthly modeled PV generation data. The modeled PV generation metrics, TDV values were not available for this verification. The monthly monitored end use data was summarized by HVAC (heating, cooling and ventilation combined), plug loads and lighting loads. The building meets ZNE Performance based on the site energy consumption (kWh, kWh/sf and kBtu/sf) and source energy consumption (kBtu/sf) metrics.

Building Type	Commercial Office
Building Size	20,020
Climate Zone	3
ZNE Goal Targeted	ZNE Site - Performance
Data Available/Provided	Monthly energy consumption by end use (modeled and monitored) and PV generation data. End use data summarized by HVAC, lighting and plug loads.
Data Gaps	Modeled PV generation; TDV values

	Site Energy					Source Energy
	kWh	Therm	kWh/sf	Therm/sf	kBtu/sf	kBtu/sf
Modeled Energy Use	151,237	-	7.55	-	25.78	80.93
Modeled Energy Generation	Not Available					
Monitored Energy Use	131,615	-	6.57	-	22.43	70.43
Monitored Energy Generation	157,087	-	7.85	-	26.77	84.06
Monitored Net Energy Use	**(25,472)**	-	**(1.27)**	-	**(4.34)**	**(13.63)**

Figure 41: Annual Energy Performance Summary for Building 2

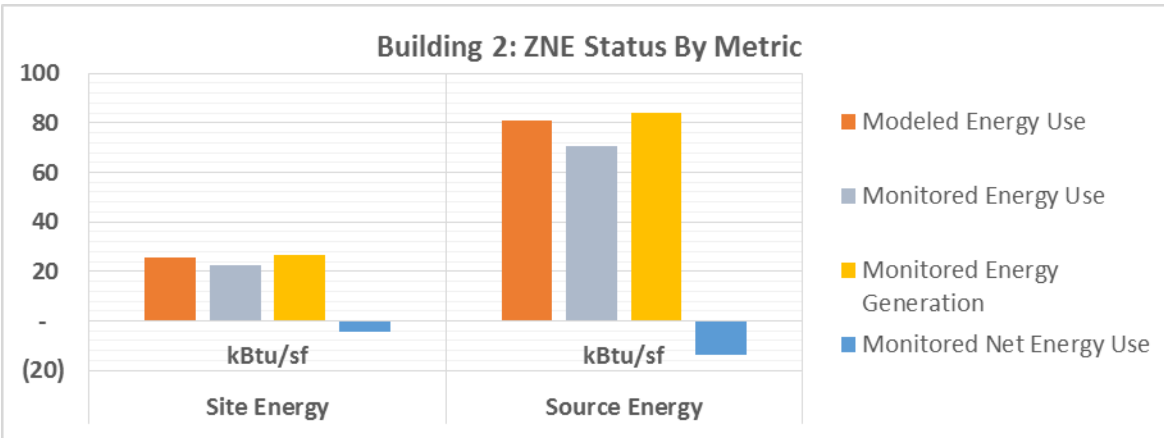

Figure 42: Annual Energy Profile for Building 2

<u>Annual Energy Performance:</u>

As seen in Figure 42 and Figure 43, this commercial office building uses 13 percent less energy in operation than predicted. The PV system seems to be sized according to the building's modeled performance and the building is a net energy producer on an annual basis.

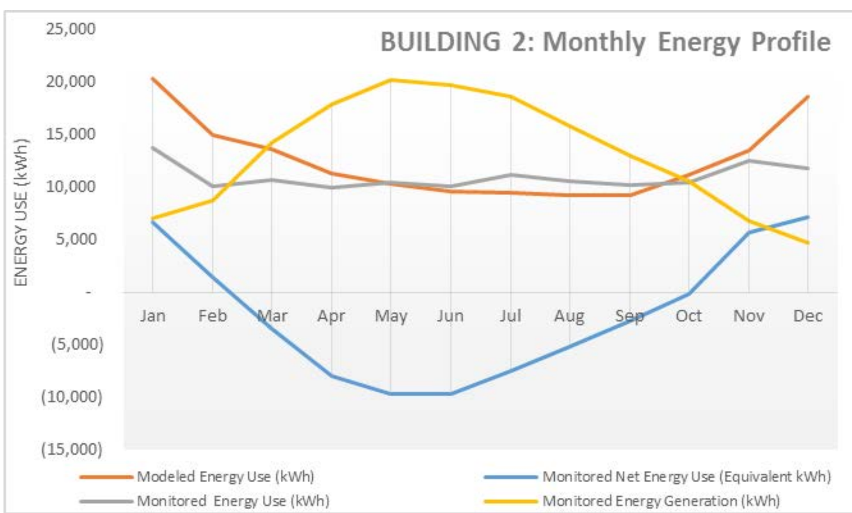

Figure 43: Monthly Energy Profile for Building 2

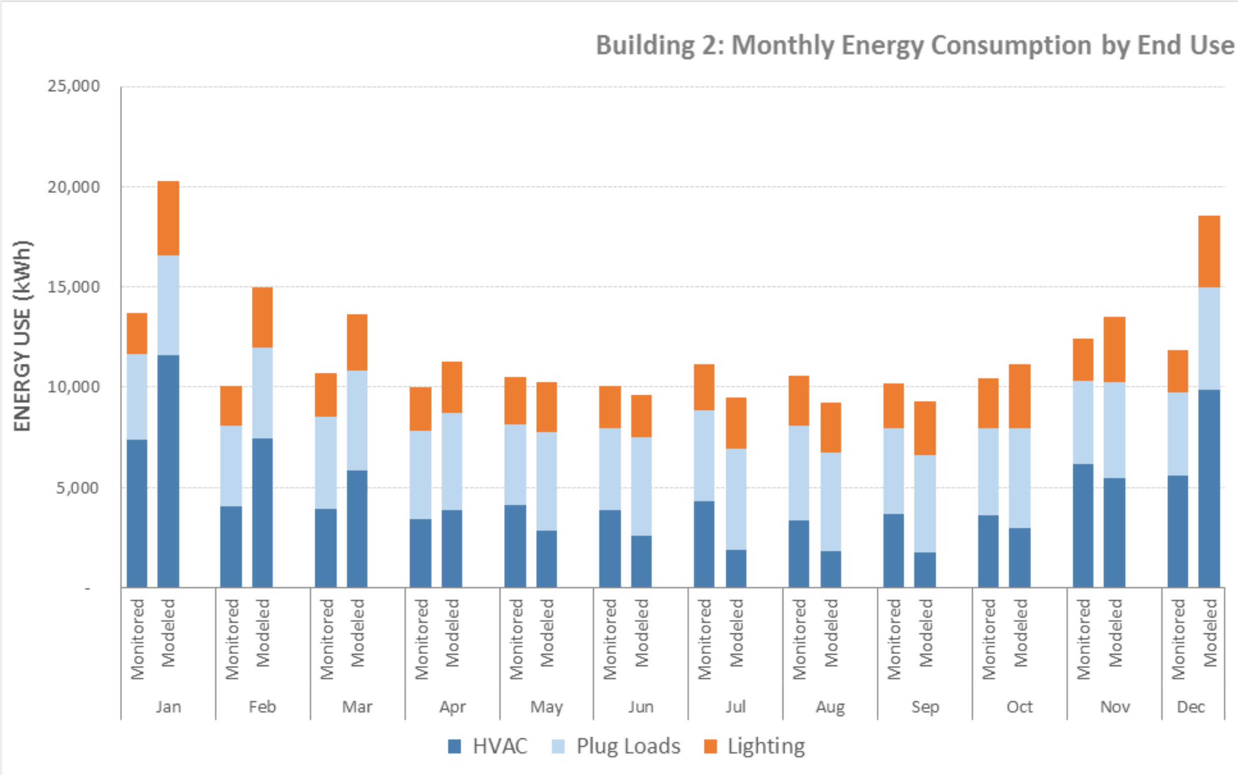

Figure 44: Monthly Energy Consumption by End Use for Building 2

<u>Monthly Energy Performance:</u>

Figure 43 shows the energy use and generation breakdown by month and it shows that the building is a net energy producer for nine months of the year, except for three winter months of the year. Figure 44 shows that the building consistently uses less energy than was predicted on a monthly basis. The HVAC loads were overestimated for the winter months and under predicted in the summer months.

8.1.3 Building No. 3

Building 3 is an all-electric museum building located in climate zone 3, with the stated intention of being a ZNE Site - Performance building. The study team received data on the building' modeled and monitored energy use and onsite PV energy generation. The modeled PV generation metrics, TDV values were not available for this verification. The monthly monitored end use data was summarized by HVAC (heating, cooling and ventilation combined), plug loads and lighting consumption. The verification results show that the building does not meet the ZNE Performance based on the site energy consumption (kWh, kWh/sf and kBtu/sf), or the source energy consumption (kBtu/sf) metrics.

Building Type	Museum
Building Size	190,000
Climate Zone	3
ZNE Goal Targeted	ZNE Site - Performance
Data Available/Provided	Monthly energy consumption by end use (modeled and monitored) and PV generation data; End use data summarized by HVAC, lighting and plug loads.
Data Gaps	Modeled PV generation; TDV values

	Site Energy					Source Energy
	kWh	therm	kWh/sf	therm/sf	kBtu/sf	kBtu/sf
Modeled Energy Use	2,668,019	-	14.04	-	47.91	150.44
Modeled Energy Generation	Not Available					
Monitored Energy Use	2,460,950	-	12.95	-	44.19	138.77
Monitored Energy Generation	1,988,839		10.47		35.72	112.15
Monitored Net Energy Use	472,110		2.48		8.48	26.62

Figure 45: Annual Energy Performance Summary for Building 3

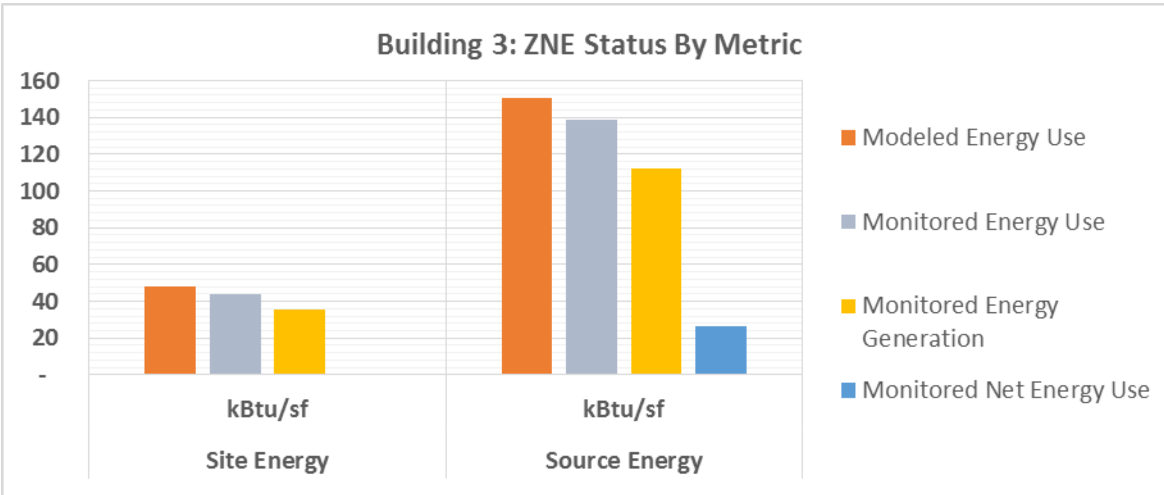

Figure 46: Annual Energy Profile for Building 3

Annual Energy Performance:

As seen in Figure 45 and Figure 46, this museum building in climate zone 3 is consuming approximately 8 percent less energy than was predicted. However, this building has a PV system that is under-sized for this building on an annual design and performance basis and the overall PV capacity in not adequate for the building to achieve ZNE Performance status. Upon review of the building energy modeling and notes from the building designer, the PV system was sized for portions of the museum that did not include a cafeteria and other process loads. These loads are not easily separated from the rest of the building energy use data and thus it is not possible to see whether the building would have met the ZNE Performance after removing these loads from its overall energy consumption. However, a partial building being ZNE does not meet the intent of any of the ZNE definitions being currently promoted in the state policy.

Monthly Energy Performance:

Figure 47 shows the energy use and generation breakdown by month and it shows that the building is a net energy user for majority of the year but a net producer during the peak summer months. Figure 48 shows that the modeled and monitored energy performance of the building are comparable for most of the year, and the reason for this building not being able to achieve ZNE status is mainly due to the sizing of the PV system.

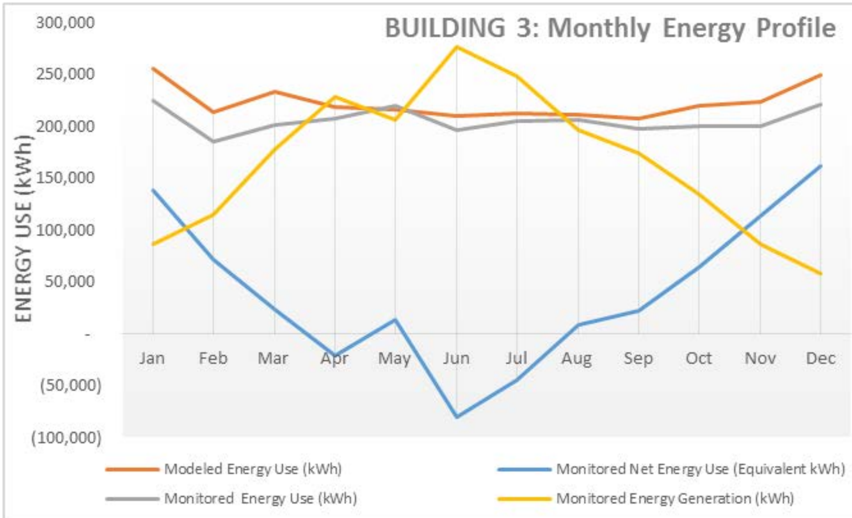

Figure 47: Monthly Energy Profile for Building 3

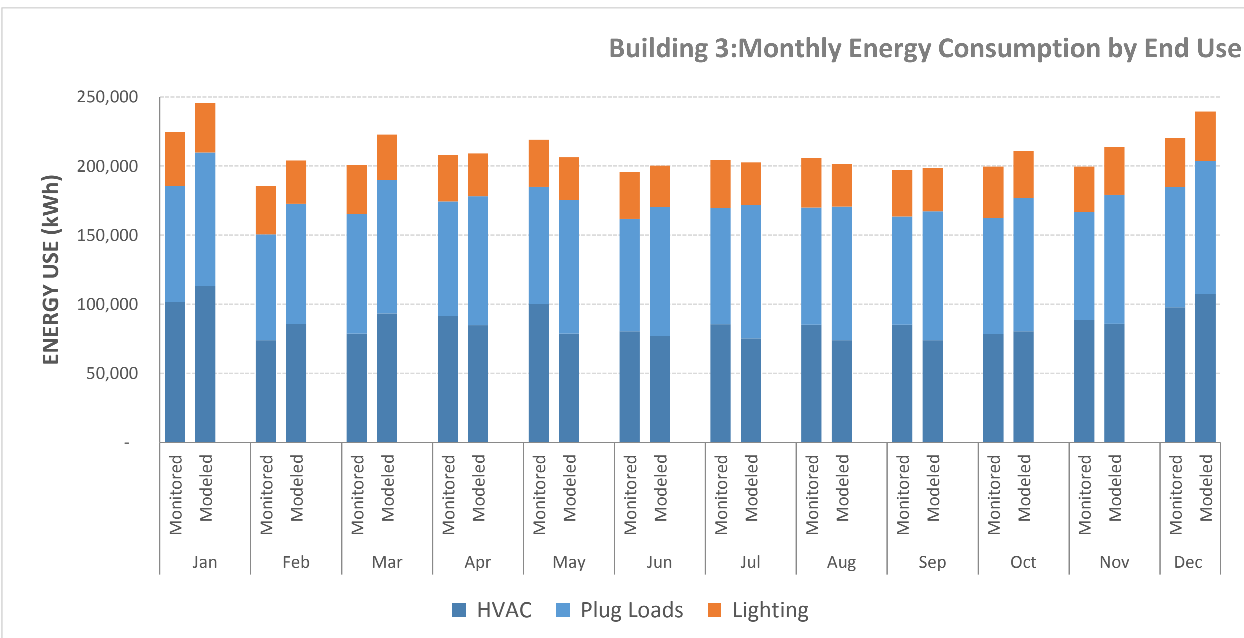

Figure 48: Monthly Energy Consumption by End Use for Building 3

8.1.4 Building No. 4

Building 4 is an all-electric building with a combination of commercial office and educational spaces. The building has stated intention of being a ZNE Site - Performance building. The study team received data on the building' modeled and monitored energy use along with onsite PV generation data for 12-months. The data gaps for this verification include modeled PV generation and TDV values, and the monthly monitored end use data was summarized by HVAC (heating, cooling and ventilation combined), plug loads and lighting consumption. The building meets ZNE Performance based on the site energy consumption (kWh, kWh/sf and kBtu/sf) and source energy consumption (kBtu/sf) metrics.

Building Type	Educational, Office
Building Size	45,001
Climate Zone	3
ZNE Goal Targeted	ZNE Site - Performance
Data Available/Provided	Monthly energy consumption by end use (modeled and monitored) and PV generation data; End use data summarized by HVAC, lighting and plug loads.
Data Gaps	Modeled PV generation; TDV values

	Site Energy					Source Energy
	kWh	therm	kWh/sf	therm/sf	kBtu/sf	kBtu/sf
Modeled Energy Use	237,570	-	5.28	-	18.01	56.56
Modeled Energy Generation	Not Available					
Monitored Energy Use	215,159	-	4.78	-	16.31	51.22
Monitored Energy Generation	267,556		5.95		20.29	63.70
Monitored Net Energy Use	(52,397)		(1.16)		(3.97)	(12.47)

Figure 49: Annual Energy Performance Summary for Building 4

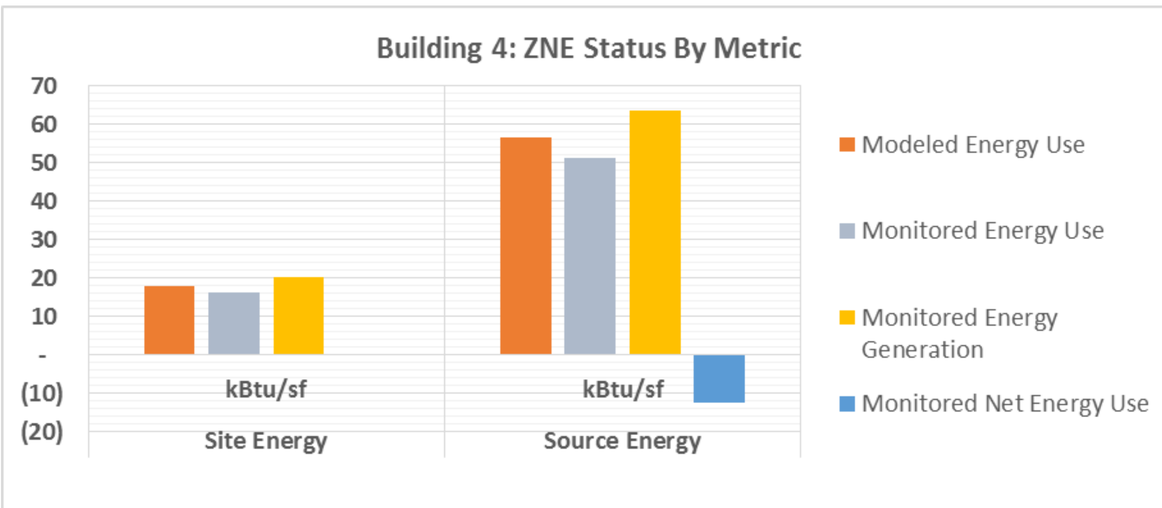

Figure 50: Annual Site Energy Profile for Building 4

Annual Energy Performance:

As seen in Figure 49 and Figure 50, this educational building in climate zone 3 achieves ZNE Performance status on an annual basis. The building uses approximately 9 percent less energy than predicted, and the PV generation is even higher than the modeled energy consumption for the building. The building meets ZNE Performance based on various metrics – kWh, kWh/sf, Site kBtu/sf and Source kBtu/sf.

Monthly Energy Performance:

Figure 51 shows that the building uses less energy than predicted for most of the year, except for three summer months. The predicted energy use from May-August are unusually low and indicates that the designers assumed the building to be not occupied at full capacity during summer months. In practice, the building seems to be occupied more than assumed and the energy use therefore is higher than predicted for those months. Figure 52 likewise shows that the modeled energy use for the summer months is negligible compared to the monitored energy use of the building.

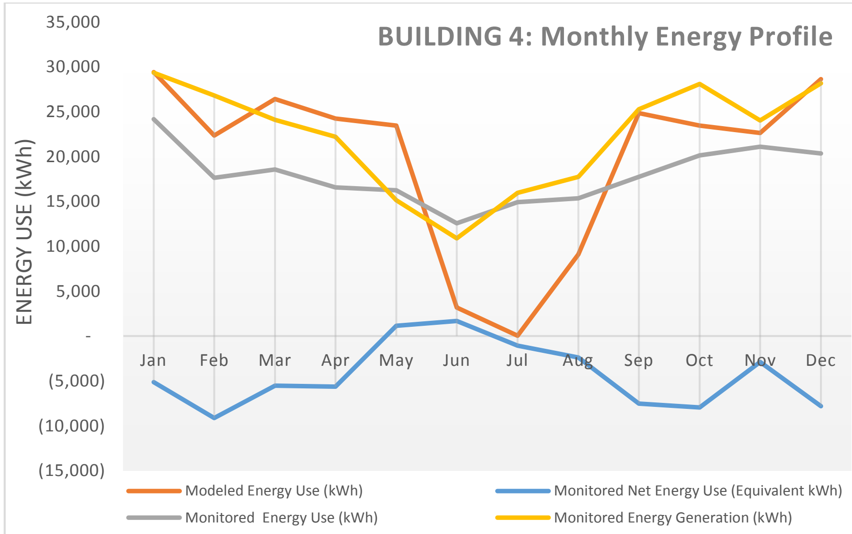

Figure 51: Monthly Energy Profile for Building 4

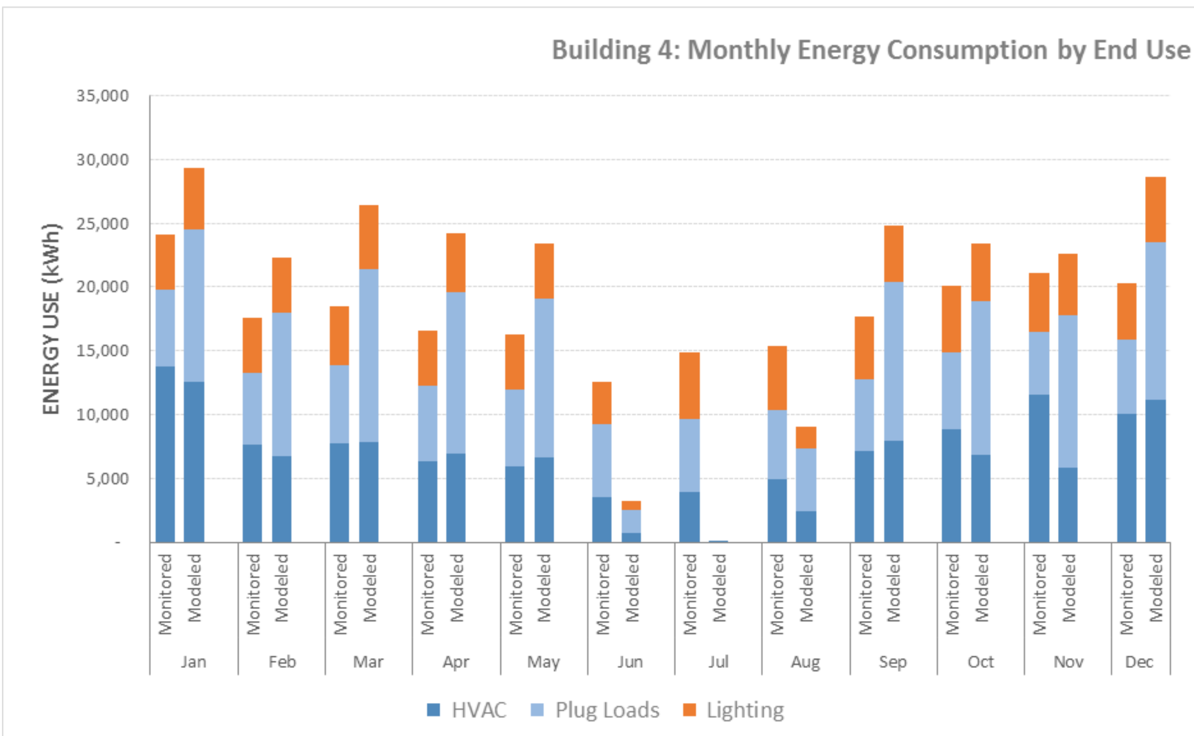

Figure 52: Monthly Energy Consumption by End Use for Building 4

8.1.5 Building No. 5

Building 5 is an all-electric commercial office building located in climate zone 4, with the stated intention of being a ZNE Site - Performance building. The data provided for this verification includes the buildings annual and monthly modeled and monitored energy use and PV generation data. The modeled PV generation metrics, TDV values were not available for this verification. The monthly monitored end use data was summarized for the HVAC (heating, cooling and ventilation combined), DHW, plug loads, lighting and process loads. The building meets ZNE Performance based on the site energy consumption (kWh, kWh/sf and kBtu/sf) and source energy consumption (kBtu/sf) metrics.

Building Type	Commercial Office
Building Size	6,557
Climate Zone	4
ZNE Goal Targeted	ZNE Site - Performance
Data Available/Provided	Monthly energy consumption by end use (modeled and monitored) and PV generation data
Data Gaps	Modeled PV generation; TDV values

	Site Energy					Source Energy
	kWh	therm	kWh/sf	therm/sf	kBtu/sf	kBtu/sf
Modeled Energy Use	47,720	-	7.28	-	24.83	77.97
Modeled Energy Generation	Not Available					
Monitored Energy Use	35,955	-	5.48	-	18.71	58.75
Monitored Energy Generation	40,431		6.17		21.04	66.06
Monitored Net Energy Use	(4,476)		(0.68)		(2.33)	(7.31)

Figure 53: Annual Energy Performance Summary for Building 5

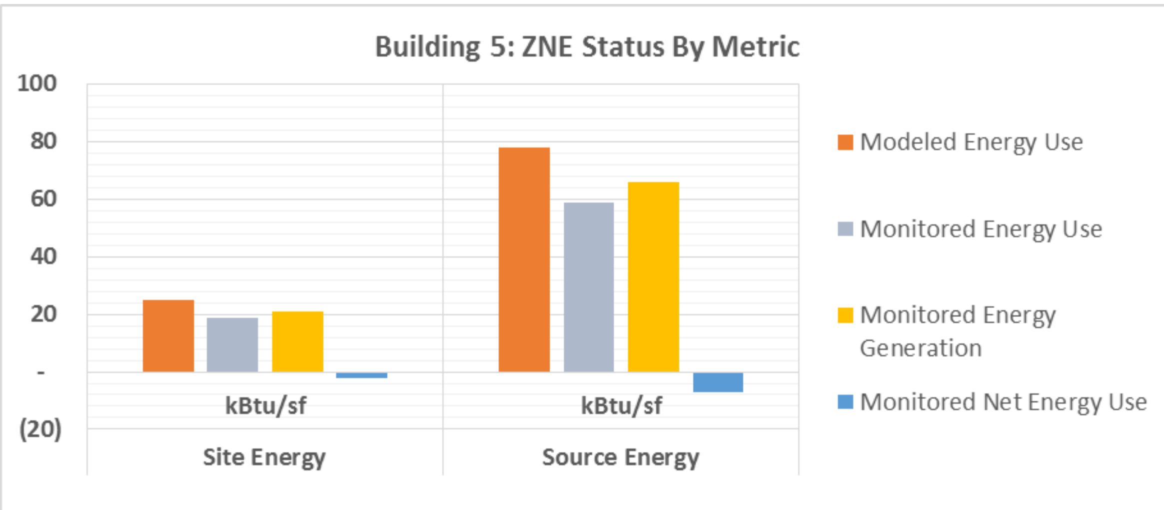

Figure 54: Annual Energy Profile for Building 5

Annual Energy Performance:

As seen in Figure 53 and Figure 54, this commercial office building in climate zone 4 achieves ZNE Performance status on an annual basis. The building uses approximately 25 percent less energy than was predicted, and the PV system is oversized compared to the modeled performance and the building produces more energy than it consumes on an annual basis.

Monthly Energy Performance:

Figure 55 shows that the building uses less energy than predicted all year round. The PV system however generates considerably more energy than the building consumes for eight months of the year. The building easily achieves ZNE Performance status for most months of the year. Figure 56 shows that the building consistently uses less energy on plug loads and lighting than predicted for all months of the year. Note that this small office building has a significant process load due to computer servers that use 9,000 of the total 36,000 kWh consumed by the entire building during the monitored period of 12 months.

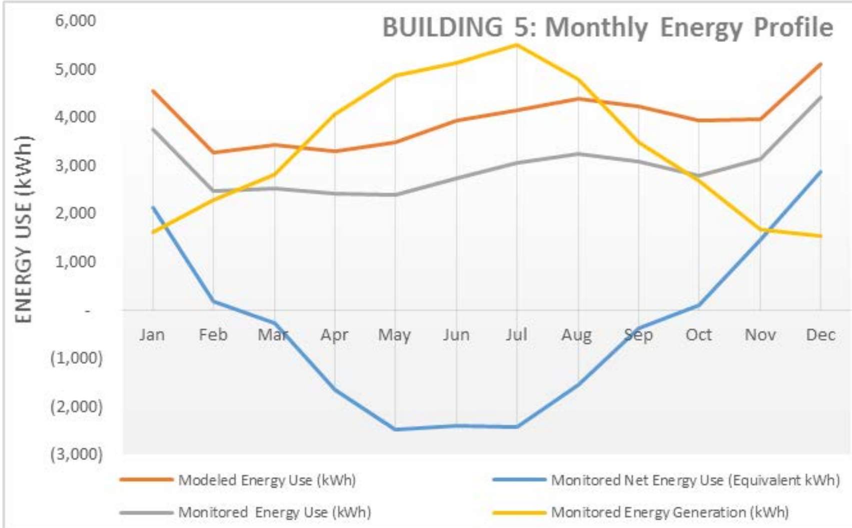

Figure 55: Monthly Energy Profile for Building 5

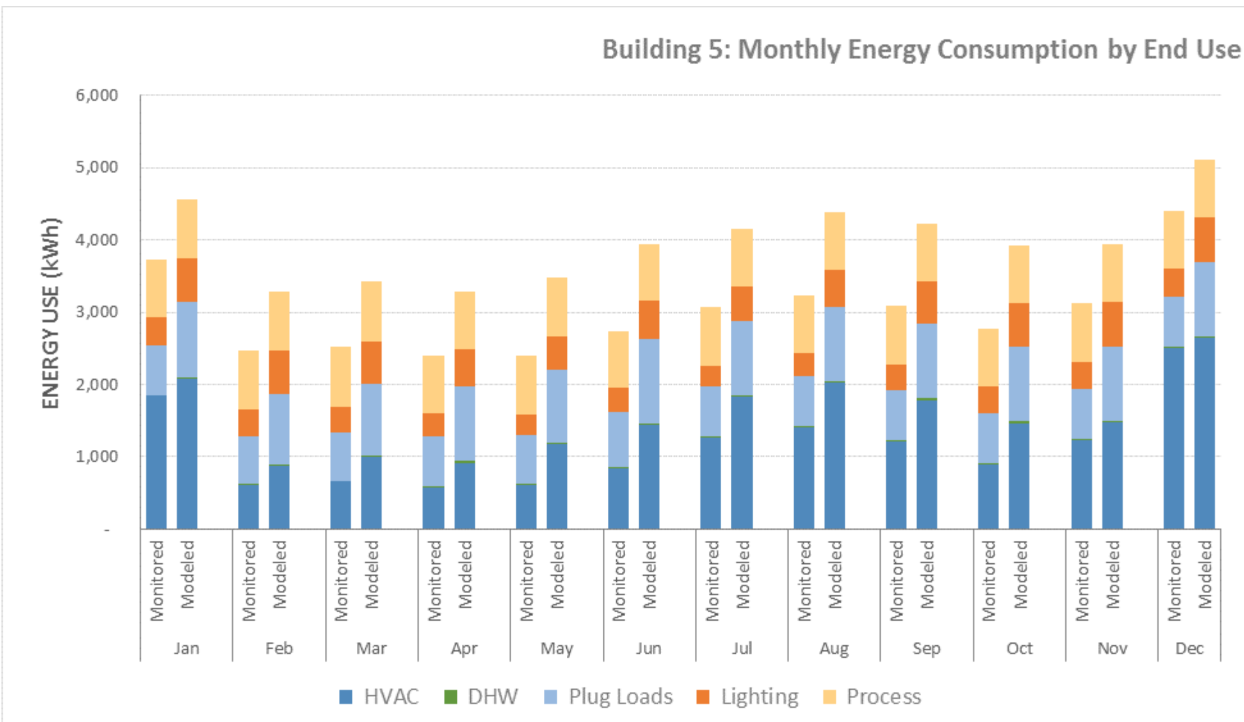

Figure 56: Monthly Energy Consumption by End Use for Building 5

8.1.6 Building No. 6

Building 6 is an all-electric commercial office building located in climate zone 4, with the stated intention of being a ZNE Site - Performance building. The study team received data on the building' modeled and monitored energy use, PV generation and all monthly end use consumption data. Two years of energy consumption data was available for this verification, but ZNE verification is limited to one year as the study team did not have the PV generation data for both years. Other data gaps included the modeled PV generation and TDV values for this building. The building meets ZNE Performance for year 1 based on the site energy consumption (kWh, kWh/sf and kBtu/sf) and source energy consumption (kBtu/sf) metrics. It is uncertain if the building maintained its ZNE status during its second year of operation also.

Building Type	Commercial Office
Building Size	49,000
Climate Zone	4
ZNE Goal Targeted	ZNE Site - Performance
Data Available/Provided	Monthly energy consumption by end use (modeled and monitored) and PV generation data
Data Gaps	Modeled PV generation; Monitored PV generation for year 2, End use consumption data for year 1 and TDV values

	Site Energy					Source Energy
	kWh	therm	kWh/sf	therm/sf	kBtu/sf	kBtu/sf
Modeled Energy Use	277,737	-	5.67	-	19.34	60.73
Modeled Energy Generation	Not Available					
Monitored Energy Use (Yr.1)	201,737	-	4.12	-	14.05	44.11
Monitored Energy Use (Yr.2)	297,248	-	6.07	-	20.70	64.99
Monitored Energy Generation (Yr. 1)	281,742		5.75		19.62	61.60
Monitored Net Energy Use (Yr. 1)	(80,005)		(1.63)		(5.57)	(17.49)

Figure 57: Annual Energy Performance Summary for Building 6

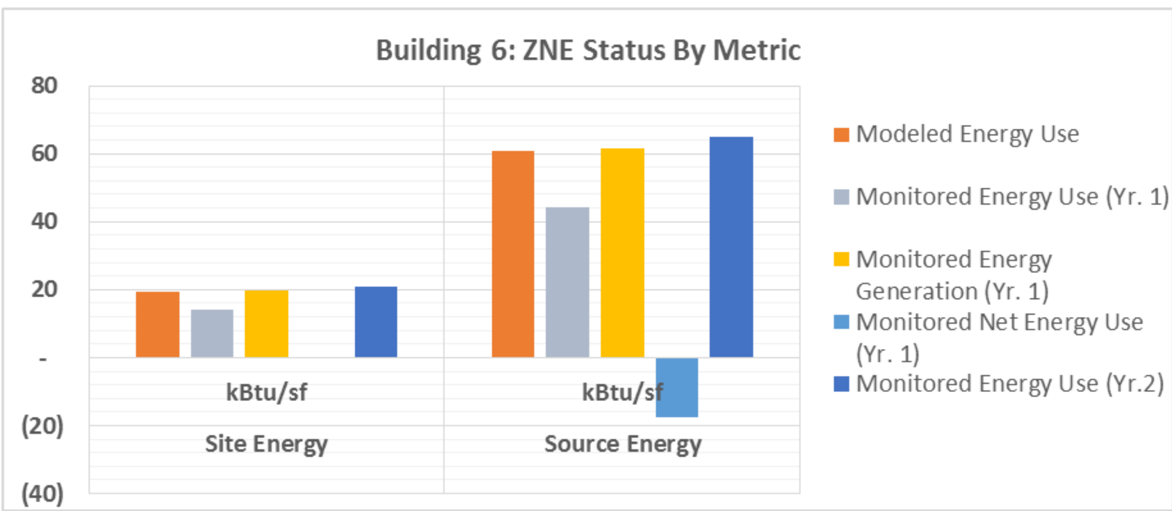

Figure 58: Annual Energy Profile for Building 6

<u>Annual Energy Performance:</u>

Figure 57 and Figure 58 show this commercial office building in climate zone 4 achieves ZNE Performance status on an annual basis. The building uses approximately 27 percent less energy than was predicted, and the PV system appears to be sized according to its modeled annual energy consumption.

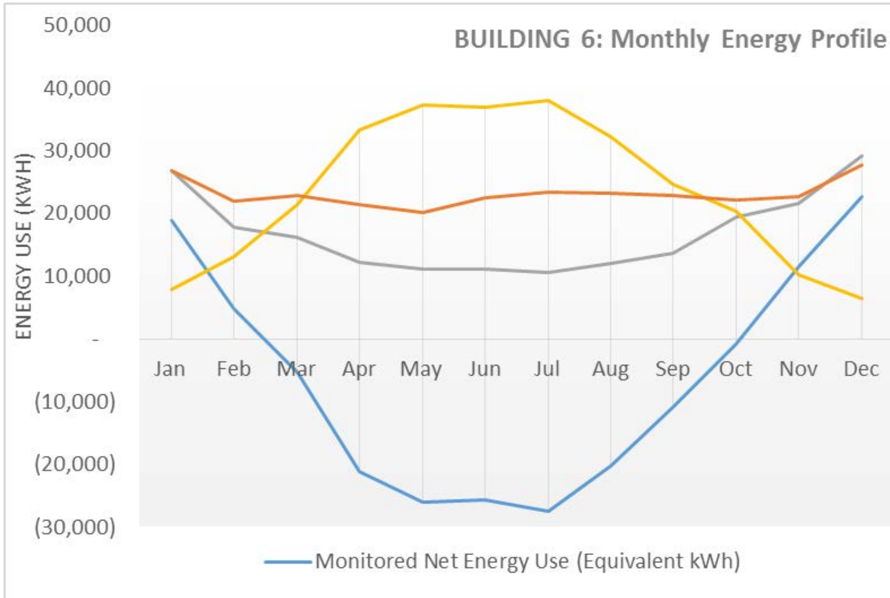

Figure 59: Monthly Energy Profile for Building 6

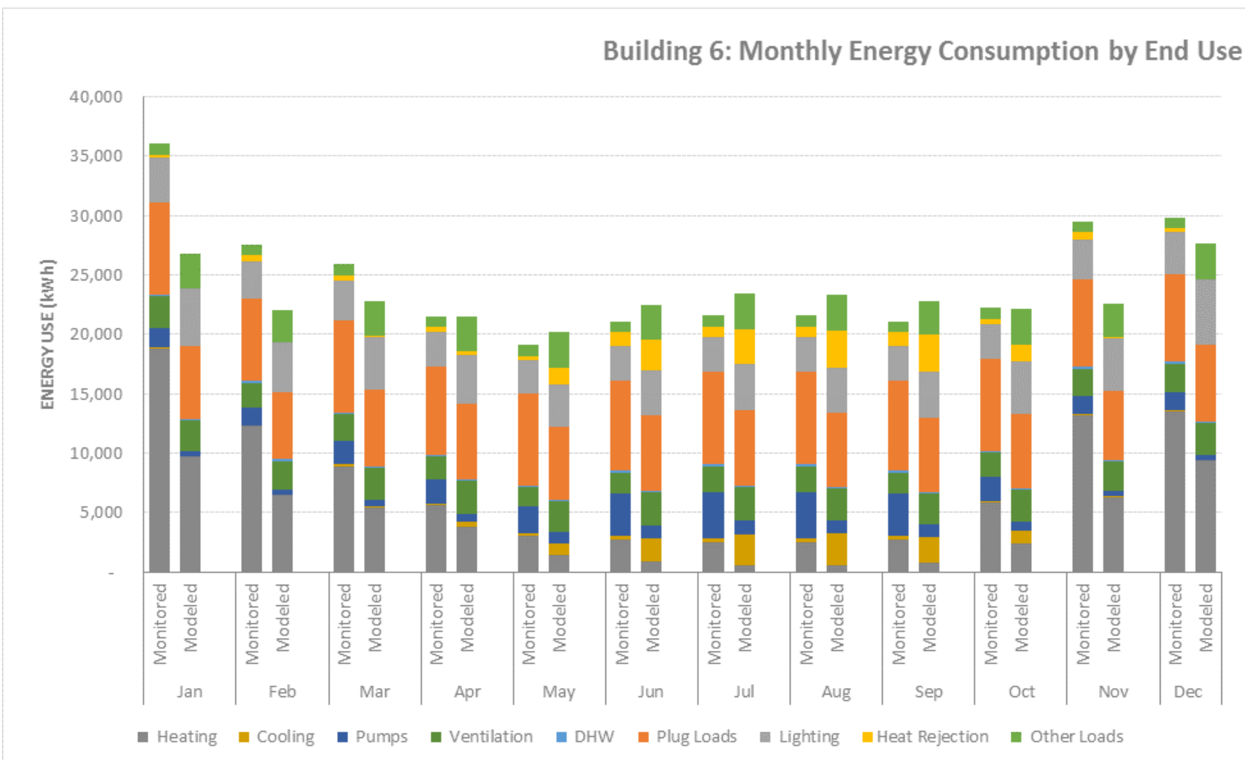

Figure 60: Monthly Energy Consumption by End Use for Building 6

Monthly Energy Performance:

Error! Reference source not found. shows that the building uses slightly less energy than predicted for most of the year. The building is a net energy generator for half of the year, but a net energy user for the rest of the year. It should be noted that the study team received billing data for an additional 12 months of building energy use data. This additional 12 month data is significantly higher than the data displayed in this section. However, the study team did not receive any PV generation data for this additional period so it is not possible for the study team to ascertain whether the building would have met its ZNE Performance goal for that additional year. This issue does highlight the potential for a building to be ZNE in one year and not be ZNE in another, raising important verification questions around persistence and which year should be used for ZNE Performance verification.

Figure 60 shows that the building using more energy for heating and plug loads for most of the year when compared to the modeled predictions. Note that the data for Figure 60 is from the second year of monitoring mentioned above – where the energy use is higher than the year used for the overall ZNE Performance validation, but where PV generation data is not available. This energy use breakdown was not available for buildings first year of operation.

8.1.7 Building No. 7

Building 7 is an all-electric library office building located in climate zone 4, with the stated intention of being a ZNE Site - Performance building. The buildings modeled and monitored energy consumption data, end use data and PV generation data was available for the verification. The data gaps included modeled PV generation and the TDV values for this building. The building meets ZNE Performance based on the site energy consumption (kWh, kWh/sf and kBtu/sf) and source energy consumption (kBtu/sf) metrics.

Building Type	Library
Building Size	6,300
Climate Zone	4
ZNE Goal Targeted	ZNE Site - Performance
Data Available/Provided	Monthly energy consumption by end use (modeled and monitored) and PV generation data
Data Gaps	Modeled PV generation; TDV values

	Site Energy					Source Energy
	kWh	therm	kWh/sf	therm/sf	kBtu/sf	kBtu/sf
Modeled Energy Use	50,292	-	7.98	-	27.24	85.53
Modeled Energy Generation	Not Available					
Monitored Energy Use	35,121	-	5.57	-	19.02	59.73
Monitored Energy Generation	53,730	-	8.53	-	29.10	91.37
Monitored Net Energy Use	(18,609)	-	(2.95)	-	(10.08)	(31.65)

Figure 61: Annual Energy Performance Summary for Building 7

<u>Annual Energy Performance:</u>

As seen in Figure 61 and Figure 62, this library building in climate zone 4 uses 30 percent less energy than was predicted. The PV system is probably sized according to the building's predicted energy performance and the building is a net energy generator on an annual basis. **Error! Reference source not found.** shows that the building uses less energy than predicted for almost all months of the year.

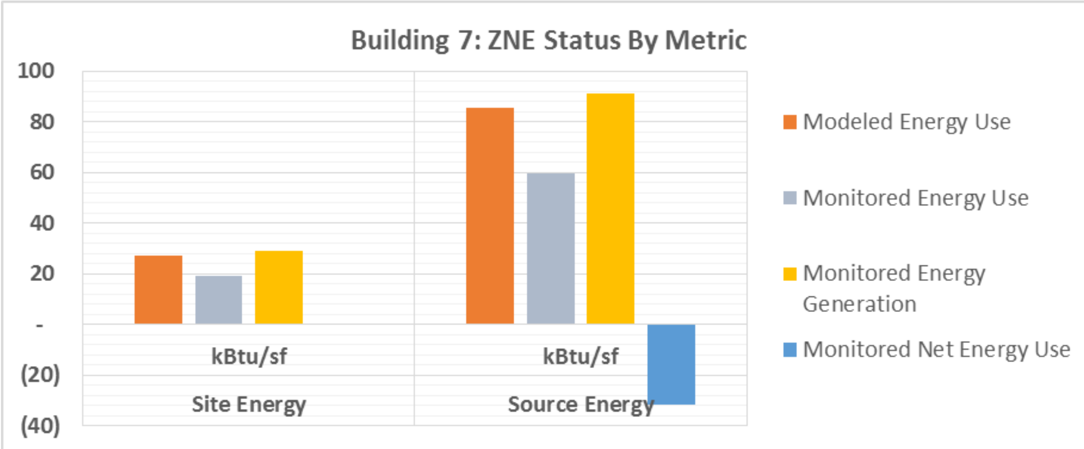

Figure 62: Annual Energy Profile for Building 7

<u>Monthly Energy Performance:</u>

The building is a net energy producer for eight months of the year and produces significantly more energy than it needs as shown in Figure 63. Figure 64 shows that the lighting, plug loads and DHW loads for the building were over predicted, but the heating and cooling loads were underestimated for this building.

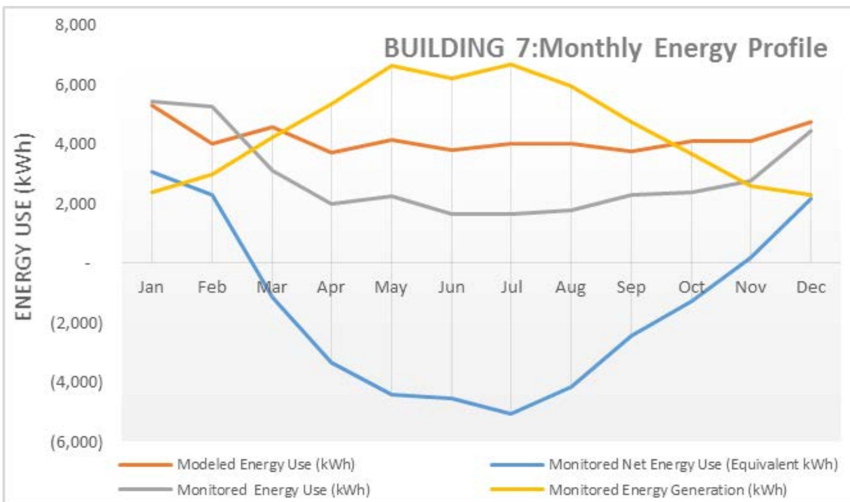

Figure 63: Monthly Energy Profile for Building 7

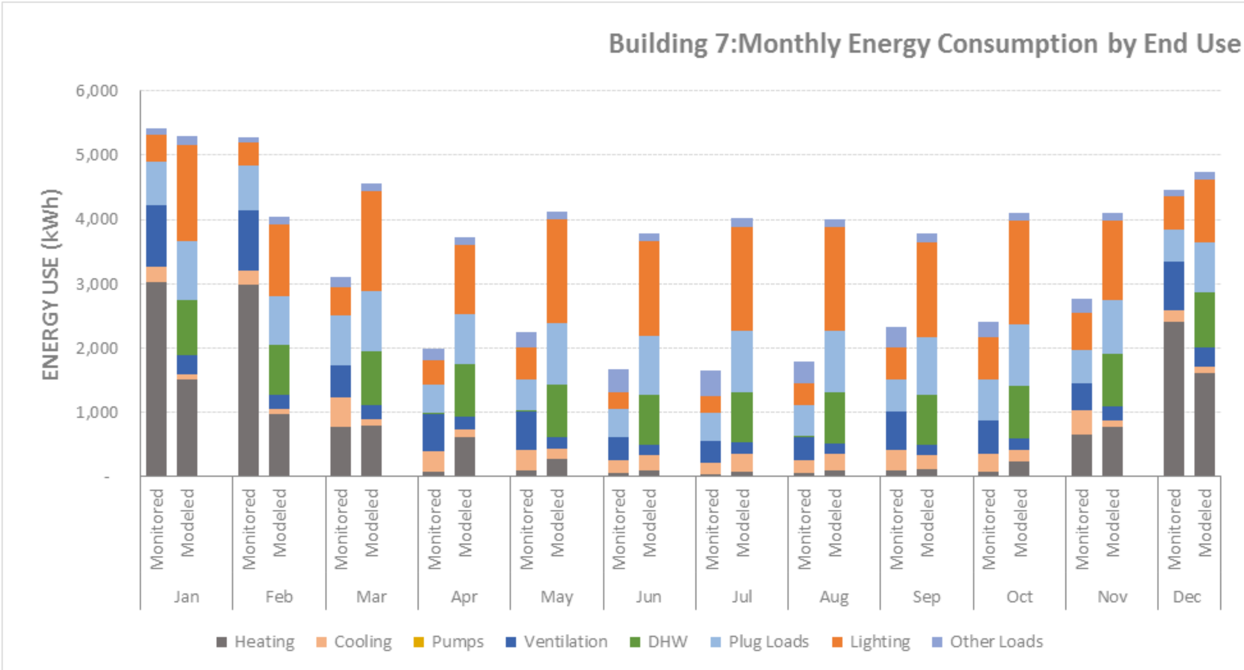

Figure 64: Monthly Energy Consumption by End Use for Building 7

8.1.8 Building No. 8

Building 8 is an all-electric library building located in climate zone 3, with the stated intention of being a ZNE Site - Performance building. The study team received data on the building' modeled and monitored energy use, PV generation data and end use consumption for the HVAC (heating, cooling and ventilation combined), plug loads and lighting consumption. The building meets ZNE Performance based on the site energy consumption (kWh, kWh/sf and kBtu/sf) and source energy consumption (kBtu/sf) metrics.

Building Type	Library
Building Size	9,300
Climate Zone	3
ZNE Goal Targeted	ZNE Site - Performance
Data Available/Provided	Monthly energy consumption by end use (modeled and monitored) and PV generation data
Data Gaps	Modeled PV generation; TDV values

	Site Energy					Source Energy
	kWh	therm	kWh/sf	therm/sf	kBtu/sf	kBtu/sf
Modeled Energy Use	47,711	-	5.13	-	17.50	54.96
Modeled Energy Generation	Not Available					
Monitored Energy Use	62,850	-	6.76	-	23.06	72.40
Monitored Energy Generation	75,353		8.10		27.65	86.81
Monitored Net Energy Use	(12,503)		(1.34)		(4.59)	(14.40)

Figure 65: Annual Energy Performance Summary for Building 8

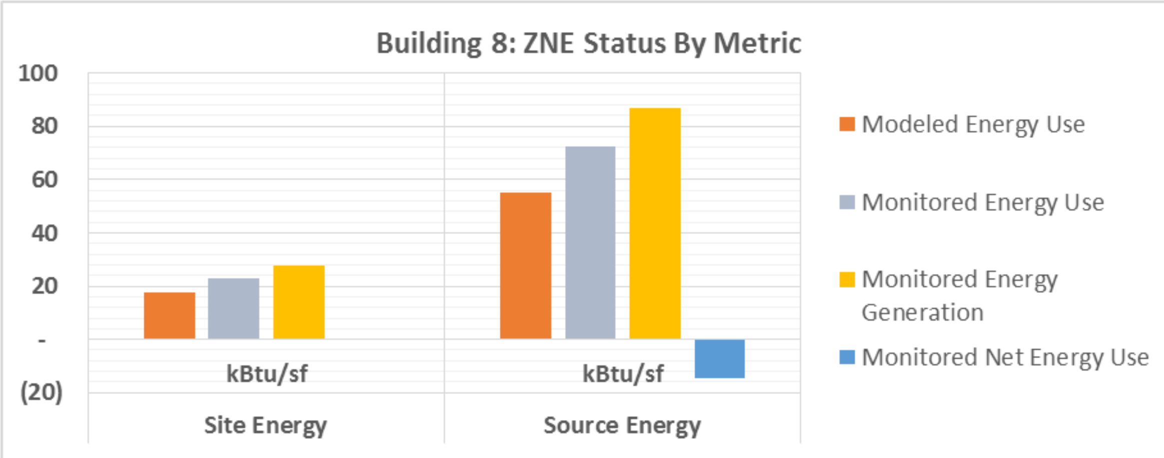

Figure 66: Annual Energy Profile for Building 8

Annual Energy Performance

As seen in Figure 65 and Figure 66, this library building in climate zone 4 uses almost 32 percent more energy than was predicted. The PV system appears to be sized much larger than the modeled energy consumption, and the building generates is a net energy generator on an annual basis.

Monthly Energy Performance:

Figure 67 shows that the building consistently uses more energy than predicted for all months of the year. However, for seven months (Mar-Aug) of the year the building produces significantly more energy than its needs. Figure 68 shows that the building consumes more energy for its lighting and HVAC than predicted, but less than predicted energy for its plug loads on a consistent basis.

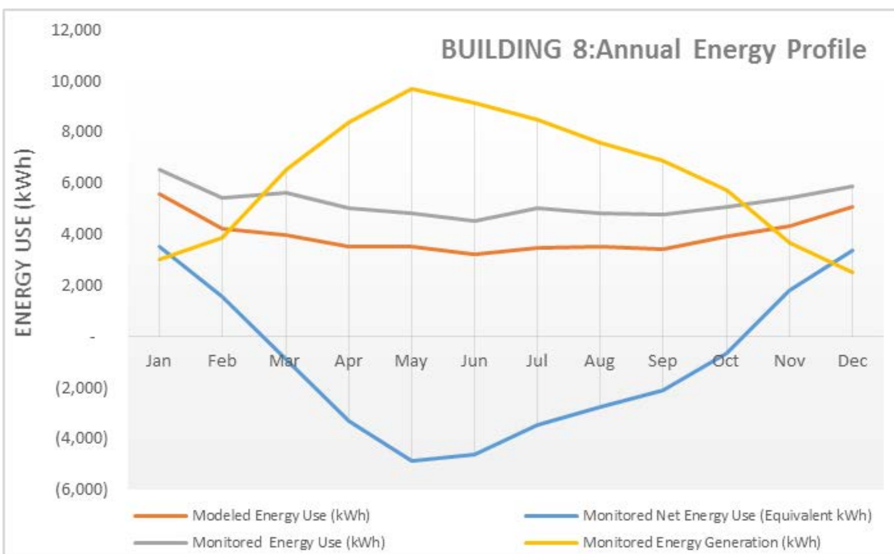

Figure 67: Monthly Energy Profile for Building 8

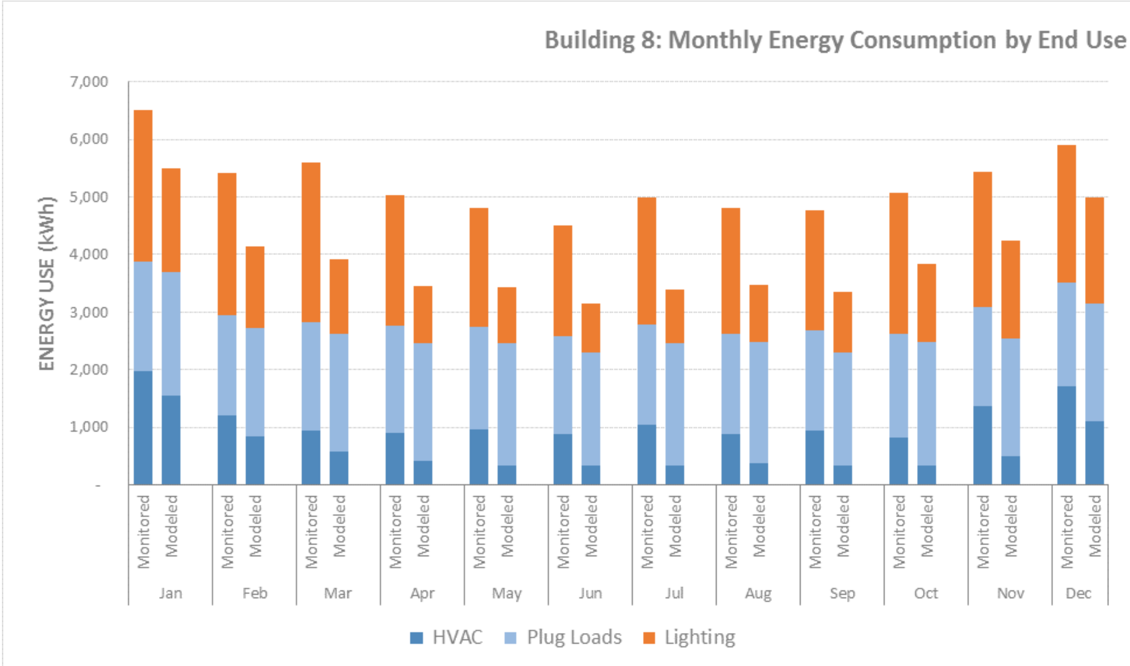

Figure 68: Monthly Energy Consumption by End Use for Building 8

8.1.9 Building No. 9

Building 9 is an all-electric single-family residential building located in climate zone 11, with the stated intention of being a ZNE Site - Performance building. The study team received total monthly monitored energy use and PV generation data. There was not modeled energy use or generation data available for this analysis. Additionally, the study team did not receive any TDV values or energy consumption data by end uses. The analysis shows that on an annual basis, this building meets the ZNE Performance based on the site energy and source energy metrics.

Building Type	Single family residential
Building Size	3,268
Climate Zone	11
ZNE Goal Targeted	ZNE Site - Performance
Data Available/Provided	Monthly monitored energy consumption, Monitored PV generation data
Data Gaps	Modeled energy consumption, Modeled PV generation, End use consumption and TDV values

	Site Energy					Source Energy
	kWh	therm	kWh/sf	therm/sf	kBtu/sf	kBtu/sf
Modeled Energy Use	Not Available					
Modeled Energy Generation						
Monitored Energy Use	11,460	-	3.51	-	11.96	37.57
Monitored Energy Generation	13,398	-	4.10	-	13.99	43.92
Monitored Net Energy Use	(1,938)	-	(0.59)	-	(2.02)	(6.35)

Figure 69: Annual Energy Performance Summary for Building 9

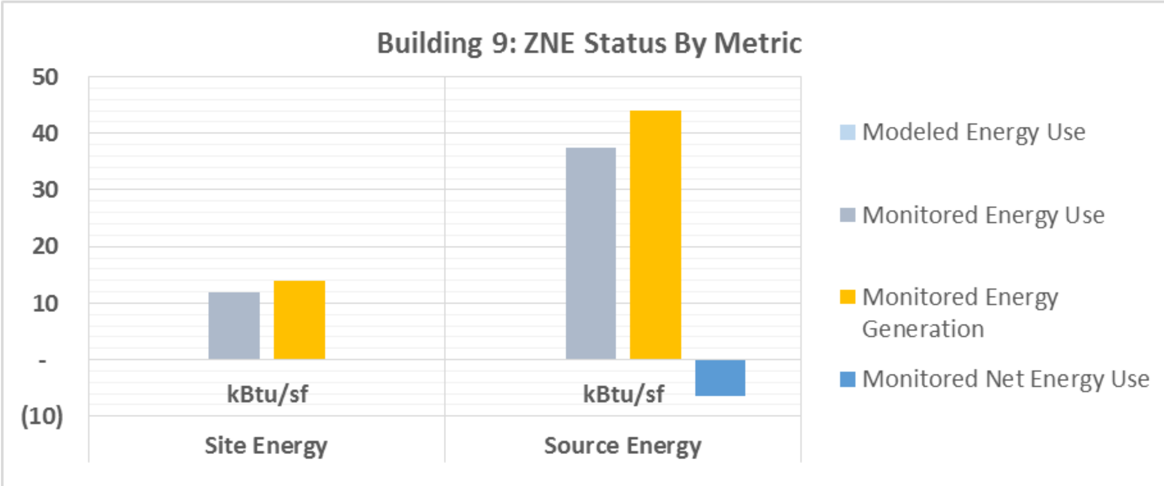

Figure 70: Annual Energy Profile for Building 9

<u>Annual Energy Performance</u>

As seen in Figure 69 and Figure 70 this single family home in climate zone11 is a net energy producer and generates almost 17 percent more energy than it consumes. On an annual basis and achieves its ZNE Site - Performance goals.

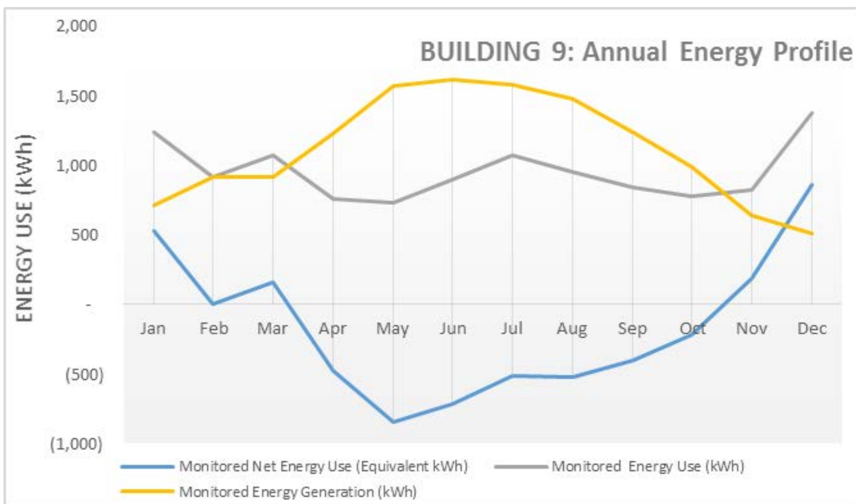

Figure 71: Monthly Energy Profile for Building 9

<u>Monthly Energy Performance:</u>

Figure 71 shows that the building generates more energy than it consumes for most months of the year.

8.1.10 Building No. 10

Building 10 is a single-family residential building located in climate zone 4, with the stated intention of being a ZNE Source - Performance building. The data provided to the study team for this verification included modeled and monitored monthly data for electricity and gas consumption and the PV generation data; and annual end use consumption data. The data gaps included the modeled PV generation, TDV values and a monthly breakdown of the building' energy consumption by end uses. The building does meet its goal of ZNE Performance based on the source energy consumption (kBtu/sf) metric, but fails to meet the other metrics of site energy consumption (kWh, kWh/sf and kBtu/sf).

Building Type	Single family residential
Building Size	3,170
Climate Zone	4
ZNE Goal Targeted	ZNE Source - Performance
Data Available/Provided	Monthly monitored energy consumption, PV generation data, Annual end use consumption
Data Gaps	Modeled PV generation, Monthly end use consumption, and TDV values

	Site Energy					Source Energy
	kWh	therm	kWh/sf	therm/sf	kBtu/sf	kBtu/sf
Modeled Energy Use	9,220	99	2.91	0.03	13.05	34.28
Modeled Energy Generation	Not Available					
Monitored Energy Use	9,357	65	2.95	0.02	12.12	33.78
Monitored Energy Generation	10,849		3.42		11.68	36.67
Monitored Net Energy Use	413		0.13		0.45	(2.89)

Figure 72: Annual Energy Performance Summary for Building 10

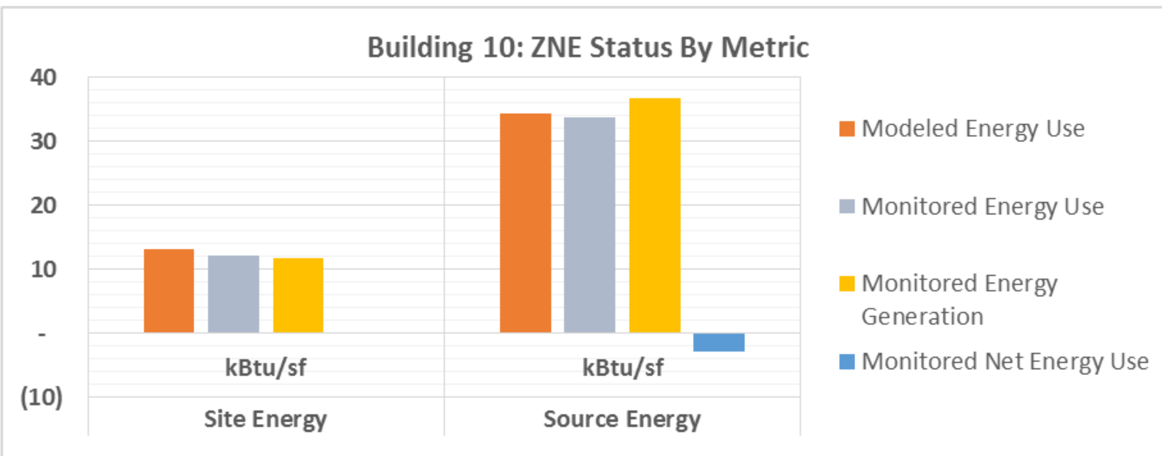

Figure 73: Annual Energy Profile for Building 10

<u>Annual Energy Performance</u>

As seen in Figure 72 and Figure 73 this single family home in climate zone 4 is a net energy producer on an annual basis using the source energy metric. The home offsets all of its electricity usage with onsite PV generation, but under the site metrics, the house does not meet ZNE Performance when the natural gas usage is converted to equivalent kWh and kWh/sf metrics. This is the first building in the dataset reviewed by the study team that had natural gas usage, and the impact of not adequately accounting for the onsite natural gas usage is clear in the impact of achieving ZNE Performance. This building demonstrates that the need for special attention in projects that use multiple fuels and the use of accurate accounting of all fuel types in order to estimate the overall renewable capacity needed to offset the building's total energy consumption. An important lesson learned from this project was that the choice of energy simulation software matters when it comes is an important factor in to predicting a home's building's ZNE Design. As seen in Figure 74, two different software tools (CBECC-Res and BEopt) were used by the design team to estimate the building energy use. While the electric usage is similar as a whole, there are substantial differences in the energy use by end use. Natural gas usage prediction is significantly different between the tools. For the analysis presented in Figure 75 use the Title 24 modeling as the 'real' predicted energy use for the building.

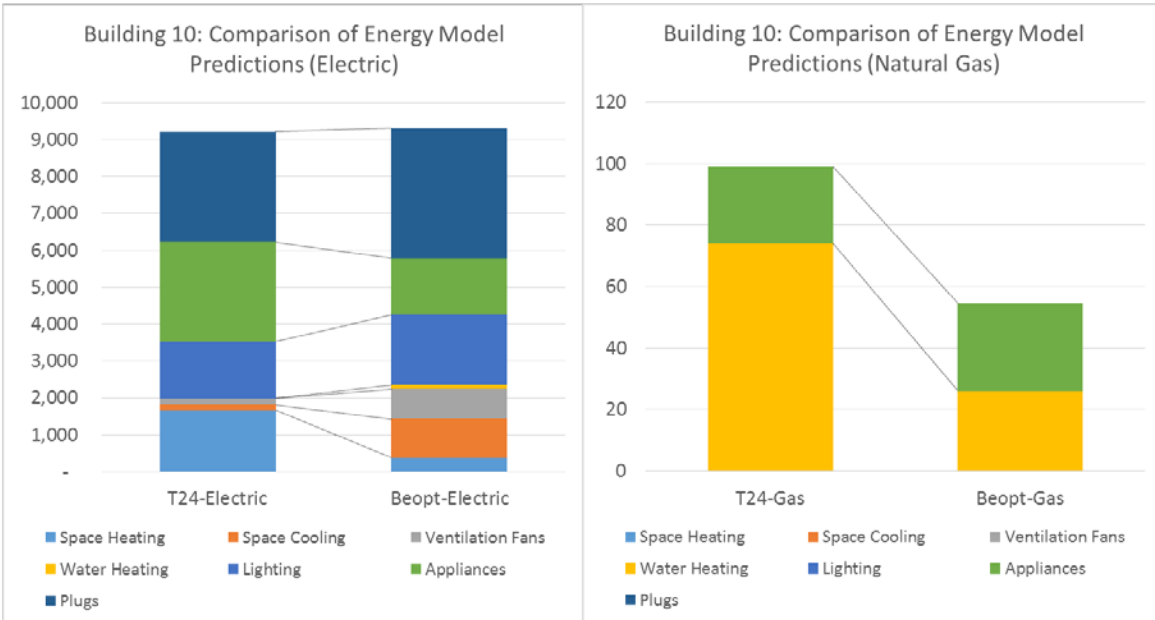

Figure 74: Comparison of Energy use Predictions for Building 10

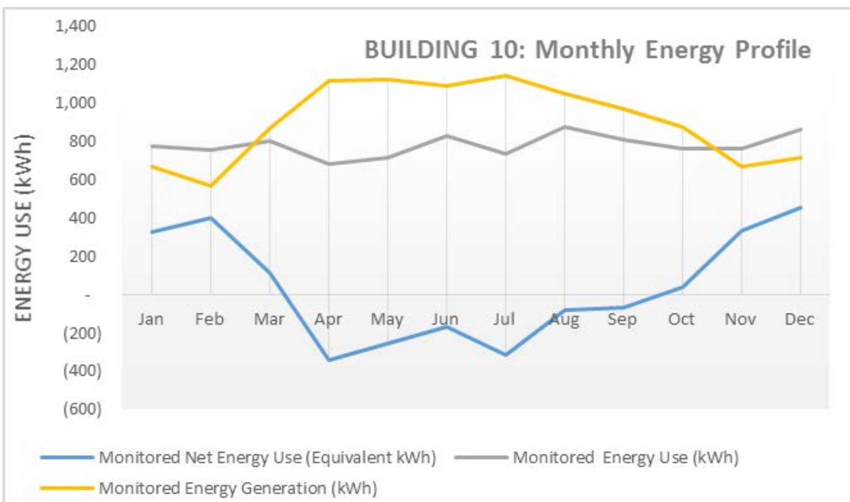

Figure 75: Monthly Energy Profile for Building 10

Monthly Energy Performance:

The monthly energy performance analysis is based only on monitored data as the monthly modelled energy consumption data was not available for this building. Figure 75 shows that the building is a net energy producer for five months of the year. The energy generation for the home is almost equal to the energy consumption for two months or the year and on an annual basis the home does achieve ZNE status.

It is important to note that the building PV system is also intended to offset some electric vehicle charging. However, it is not clear how much of the PV capacity is dedicated to the EV charging versus dedicated to the home energy use. The study team has not de-rated the PV system sizing to account for PV system capacity dedicated to offsetting home energy use due to lack of data. This building highlights the need for metering or verification methods which are capable of separating the impact of EV from the overall building's ZNE verification.

8.1.11 Building No. 11

Building 11 is a single-family residential building located in climate zone 13 with the stated intention of being a ZNE Code and Source Performance building. The modeled PV generation and TDV values were not available to the study team, so the study team could not determine if Building 11 met its ZNE Code goals. The modeled energy use and generation data was also not available for this verification. The building was evaluated using the available energy consumption and PV generation data only. The building does meet its goal of ZNE Performance based on the source energy consumption (kBtu/sf) metric, but fails to meet the other metrics of site energy consumption (kWh, kWh/sf and kBtu/sf).

Building Type	Single family residential
Building Size	2,064
Climate Zone	13
ZNE Goal Targeted	ZNE Source, ZNE Code
Data Available/Provided	Monthly monitored energy consumption, Monitored PV generation data
Data Gaps	Monthly monitored end use data, Modeled energy consumption, Modeled PV generation, End use consumption and TDV values

	Site Energy					Source Energy
	kWh	therm	kWh/sf	therm/sf	kBtu/sf	kBtu/sf
Modeled Energy Use	Not Available					
Modeled Energy Generation						
Monitored Energy Use	6,629	192	3.21	0.09	20.26	44.18
Monitored Energy Generation	9,590		4.65		15.85	49.78
Monitored Net Energy Use	2666		1.29		4.41	(5.60)

Figure 76: Annual Energy Performance Summary for Building 11

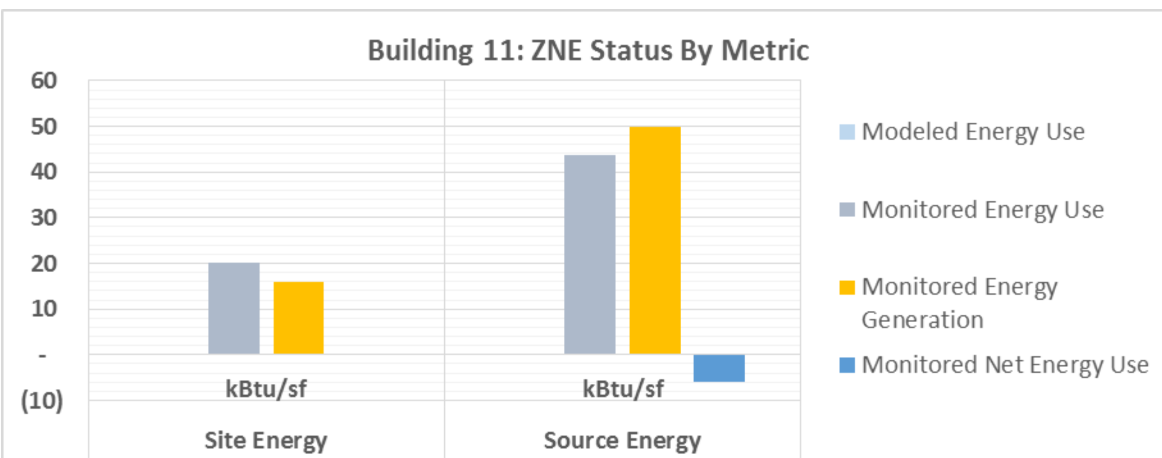

Figure 77: Annual Energy Profile for Building 11

<u>Annual Energy Performance:</u>

Figure 76 and Figure 77 show that this single family home in climate zone 13 is a net energy producer on an annual basis using the source energy metrics. The building produces almost 45 percent more energy than it consumes. As with building, 10, this building does not meet the site ZNE Performance metrics when the natural gas usage is converted to equivalent kWh and kWh/sf. Similarly the building does not meet ZNE site using the kBtu/sf metric either. However the building meets its ZNE Performance goals based on Source kBtu/sf.

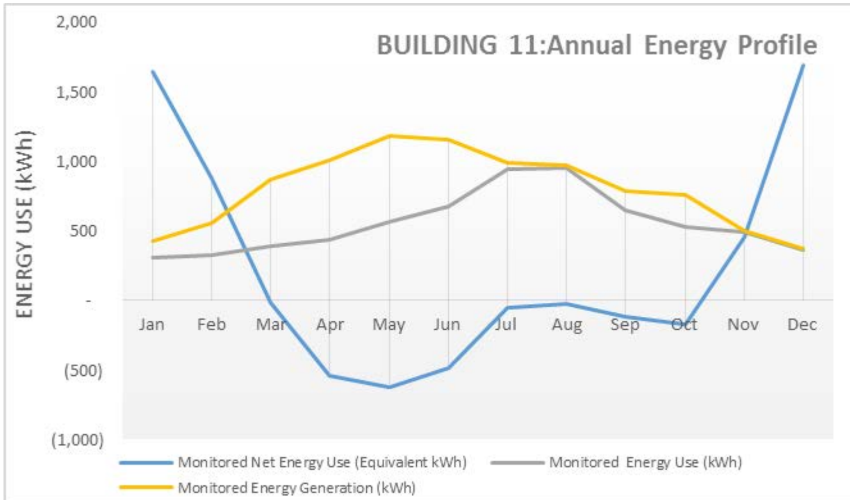

Figure 78: Monthly Energy Profile for Building 11

Monthly Energy Performance

Figure 78 shows that the building is a net energy producer for the entire year. The PV system' generation is considerably higher for the first six months of the year after which it tapers off and is closer to the actual energy consumption in the home.

8.1.12 Building No. 12

Building 12 is an all-electric single family residential building located in climate zone 12, with the stated intention of being a ZNE Performance building. The study team conducted this verification based on the building' modeled annual energy consumption, monitored annual onsite PV generation data and nine months of monitored energy consumption data (April – December). The modeled PV generation metrics, TDV values were not available for this verification. The monthly monitored end use data included consumption for the HVAC (heating, cooling and ventilation combined), plug loads, lighting, DHW and 'other loads'. For the nine-months of performance monitored, this building meets ZNE Performance based on the site energy consumption metrics (kWh, kWh/sf and kBtu/sf) and source energy consumption (kBtu/sf).

Building Type	Single family residential
Building Size	2,032
Climate Zone	12
ZNE Goal Targeted	ZNE Site - Performance
Data Available/Provided	Monthly modeled energy consumption and partial monitored energy consumption and PV generation data
Data Gaps	Monitored energy use data for Jan-Mar, Modeled PV generation and TDV values.

	Site Energy					Source Energy
	kWh	therm	kWh/sf	therm/sf	kBtu/sf	kBtu/sf
Modeled Energy Use	6,424	-	3.16	-	10.79	33.87
Modeled Energy Generation	Not Available					
Monitored Energy Use	8,147	-	4.01	-	13.68	42.96
Monitored Energy Generation	9,406	-	4.63	-	15.79	49.59
Monitored Net Energy Use	(1,259)		(0.62)		(2.11)	(6.64)

Figure 79: Nine Months Energy Performance Summary for Building 12

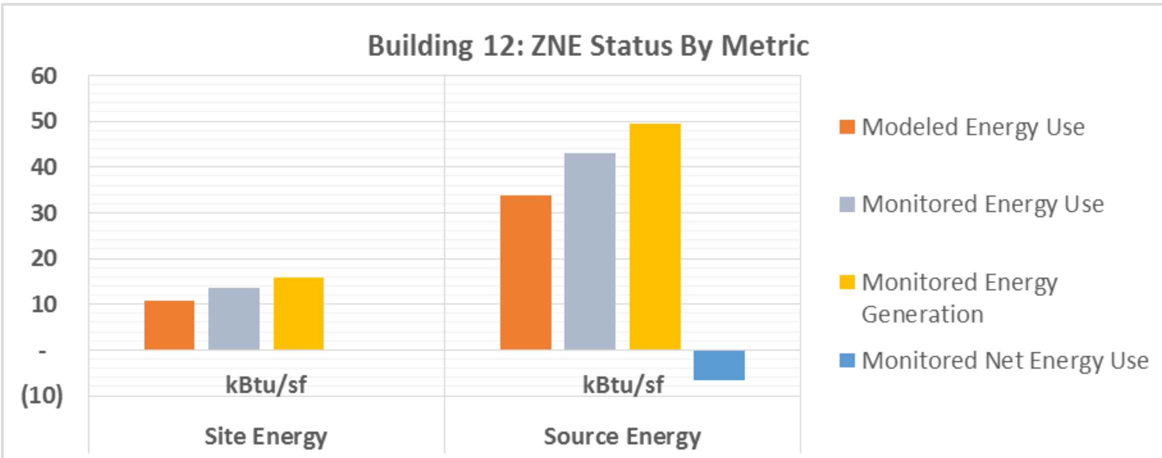

Figure 80: Nine Months Energy Profile for Building 12

<u>Annual Energy Performance</u>

This building is currently being monitored and only nine months of monitored data was available for this study. Figure 81 shows that the nine month consumption for the building is almost 27 percent more than the annual modeled energy use. However, the PV system is adequately sized to meet the predicted needs and possibly even the actual energy use for this home. Figure 82 demonstrates that this building is a net energy producer based on the partial monitored data available for this building.

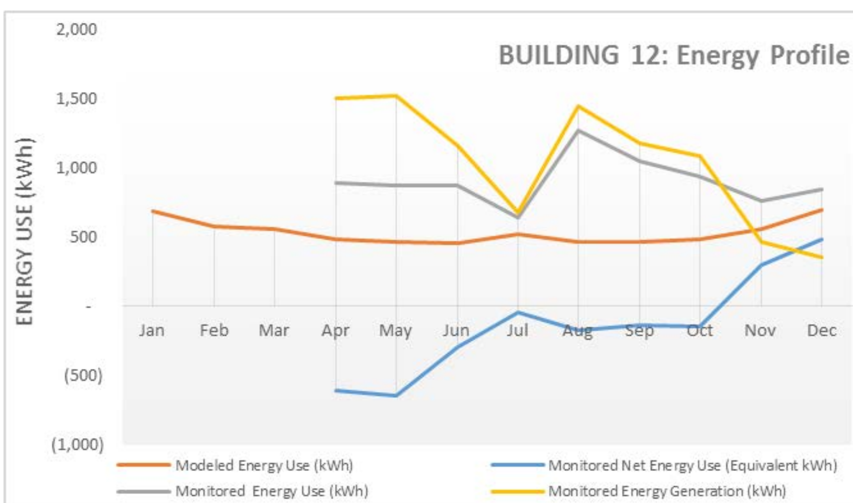

Figure 81: Monthly Energy Profile for Building 12

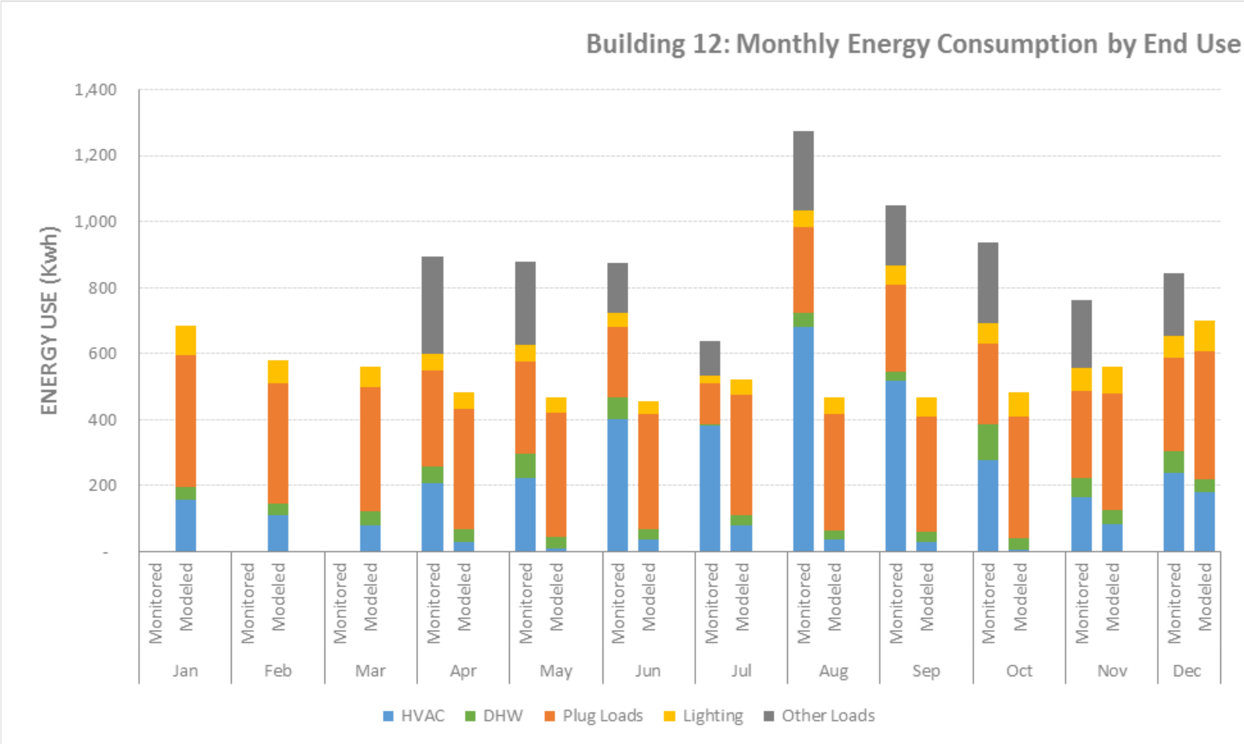

Figure 82: Monthly Energy Consumption by End Use for Building 12

Monthly Energy Performance:

Figure 81 shows that the building consumes more energy than predicted, but the energy generation for this building is even higher than its consumption needs. The building is a net energy producer during the months of April-June. As seen in Figure 82, based on the nine months of data available it is clear that the building is using more energy than predicted for HVAC and other loads, which are a significant factor for this building. The other loads consist of garage mechanical system, home energy monitoring system, data acquisition system, and energy storage system.

8.2 ZNE Building Data Analysis Summary

As shown in the summary in Figure 83 below, most of the twelve building evaluated by the study team were successfully able to achieve their designed ZNE goals. The only exception was Building 3 which failed to achieve the ZNE Performance metrics on the site or source energy level. Buildings 10 and 11 successfully met their goals of being ZNE Performance at a source energy metric, but failed to meet the ZNE Performance criteria a site energy level. The lack of availability of TDV values for these projects limited the study team' ability to examine if these projects met the ZNE code metrics or not.

	Net Site Energy			Net Source Energy
	kWh	kWh/sf	kBtu/sf	kBtu/sf
BUILDING 1	(16,404)	(0.52)	(1.76)	(5.53)
BUILDING 2	(25,472)	(1.27)	(4.34)	(13.63)
BUILDING 3	**472,110**	**2.48**	**8.48**	**26.62**
BUILDING 4	(52,397)	(1.16)	(3.97)	(12.47)
BUILDING 5	(4,476)	(0.68)	(2.33)	(7.31)
BUILDING 6 (Yr. 1)	(80,005)	(1.63)	(5.57)	(17.49)
BUILDING 7	(18,609)	(2.95)	(10.08)	(31.65)
BUILDING 8	(12,503)	(1.34)	(4.59)	(14.40)

	Net Site Energy			Net Source Energy
	kWh	kWh/sf	kBtu/sf	kBtu/sf
BUILDING 9	(1,938)	(0.59)	(2.02)	(6.35)
BUILDING 10	521	0.16	0.56	(2.63)
BUILDING 11	2,666	1.29	4.41	(6.07)
BUILDING 12	(1,259)	(0.62)	(2.11)	(6.64)

Figure 83: Summary of ZNE Evaluation of Representative Projects

Thus, it is important that the desired ZNE status for the building needs to be determined early on in the design process, and the ZNE performance verification needs to be conducted keeping in mind the desired ZNE goals for the building.

The projects represented locations from five of the sixteen climate zones in California, which limits our understanding of how ZNE buildings might perform in other climate zones. The monitored energy performance for most of the buildings deviated significantly from the modeled or predicted energy consumption. This highlights the critical need for more accurate energy performance modeling of ZNE projects, as it impacts the sizing of the PV systems, overall ZNE performance and has financial implications for the project.

9. Appendix B: Measuring ZNE Performance for Buildings Using the TDV Metric

As California looks ahead to implementing a Zero Net Energy (ZNE) building energy standard for residential buildings in the 2019 Title 24 code cycle, it is worth considering how to measure, verify, and communicate the performance of ZNE buildings once constructed and occupied. In the IEPR, the CEC has indicated that it intends to use time-dependent valuation (TDV) to measure compliance for new construction buildings; just as has been done since the 2005 Title 24 Update went into effect. Compliance testing is done before the building is constructed. Compliance is measured either against a set of prescriptive energy efficiency packages or more commonly, based on a simulation of the proposed building's energy usage.

There are a number of reasons why measurement of a building's actual (as opposed to simulated) energy performance is important. These include (a) determining the effect of the new standard for attribution of energy efficiency savings to utility programs, (b) evaluating what could further be improved in buildings, and (c) communicating to building owners what they can expect in terms of energy consumption in a building built to ZNE code.

The challenge of evaluating ZNE building performance in buildings that were designed based on the CEC's TDV definition, is that there is not a straightforward way to perform this verification. This section briefly discusses why the TDV definition of ZNE buildings does not lend itself easily to Performance performance-based verification, and presents three alternative options for evaluating ZNE Performance, based on the TDV definition of ZNE.

9.1 Multiplying the TDV Factors Used For Compliance by Measured Energy Usage Will Not Provide Meaningful Results

The TDV factors reflect a lifecycle value of energy for each hour of a 'typical' year, and are based on 15-year or 30-year long term forecasts of energy and capacity costs of the grid over the life of the building. Figure 84 below illustrates the components of the TDV factors, which vary over the course of a 24 hour period as demand on the electricity grid peaks in the late afternoon.

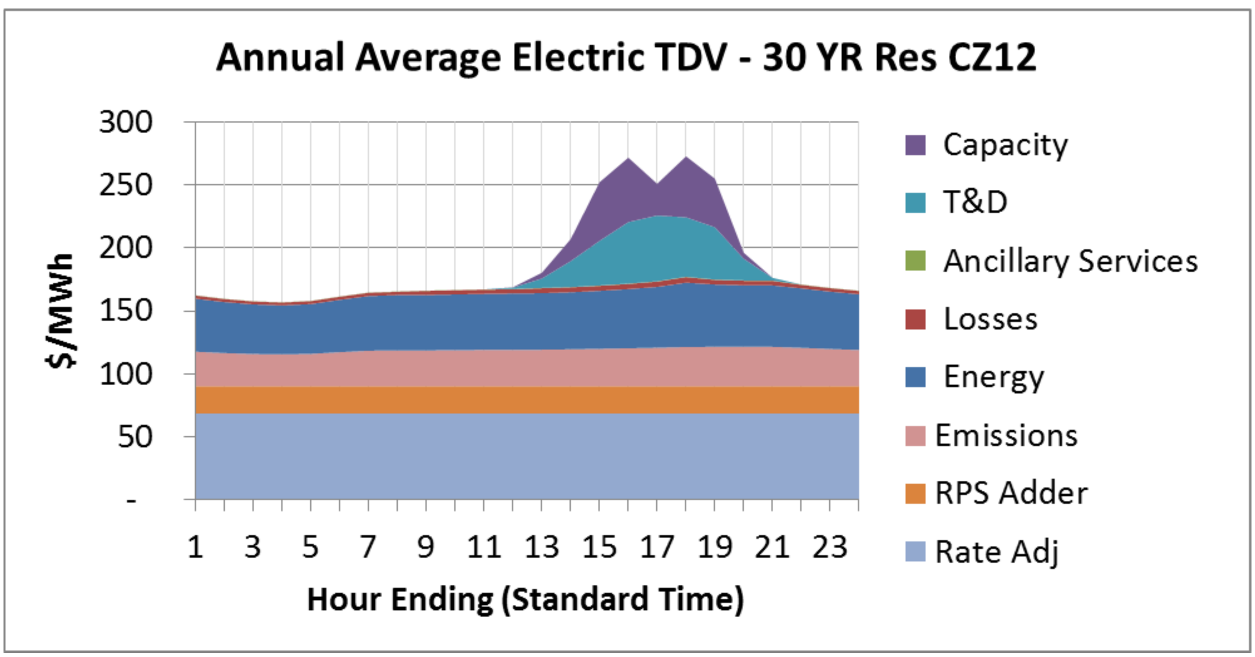

Figure 84: 30 Year Levelized TDV values averaged over a 24 hour period (Climate Zone 12)

The TDV factors are first calculated as a $/MWh value of electricity generation on the grid (grossed up for fixed costs to maintain and operate the grid through the "rate adjustment" factor) and as $/therm value of natural gas and propane usage in the building. These energy costs are then converted into kBtu/kWh and kBtu/therm values using a standard conversion factor, so that the TDV factors can be used in building simulation tools. This methodology is discussed in more detail in the 2016 TDV Methodology Report.[1]

The TDV factors for each hour deviate from actual observations concerning grid operations in two important ways.

1. **Weather:** First, the 'typical' weather pattern that is modeled in the TDV calculations will not be identical to actual observed weather patterns in any given year. For example, on a particular day in the summer perhaps the TDV factors were developed assuming it was going to be an average high temperature of 100 degrees. In reality, on that particular day it may have been cooler - an average high temperature of 88 degrees. The degree to which the forecast TDVs align on an hourly basis with actual weather patterns is effectively random since the TDVs are based on statewide weather trends that affect the entire grid, rather than the observed temperatures at a given location.
2. **Lifecycle value vs. single year observations:** Second, the TDV values are lifecycle values, that reflect a 15-year or 30-year forecast of future grid conditions. They include an underlying retail rate escalation rate assumption, which tends to increase the value of energy efficiency savings relative to today's energy value. In addition, the TDV factors include assumptions about future renewable development on the grid to meet Renewable Portfolio Standard (RPS) requirements. For example, the 33% RPS requirement by 2020, and now the 50% RPS requirement by 2030, will impact the value of and timing of capacity need over time. In addition, the TDV factors include a future natural gas price forecast, and changes in net system load patterns with increasing renewable penetrations over time. The TDV factors do not reflect grid conditions or weather in any particular year, but are a time weighted averages over the 30 year assumed life of a building.

9.2 Alternative Approaches to Evaluating "TDV Building Performance"

The answers to the question - Did the building achieve ZNE in performance, based on a building designed to the TDV definition of ZNE? - depends on a number of factors including:

- Did the building simulation tool accurately model the building as it was built?
- Were assumptions about the home or building occupancy correct?
- How accurately were non-regulated loads estimated?
- How different were actual weather patterns from simulated weather?
- How close was the forecast of future energy prices compared to actual prices, taking into account changes in natural gas prices, RPS policy, etc.

To answer this question, the study team presents three options in the figure below. For reasons outlined below the graphic, the study team recommends Option #3 to answer the question above.

[1] Horri, B.; Cutter, E. et al. "Time Dependent Valuation of Energy for Developing Building Efficiency Standards: 2016 Time Dependent Valuation (TDV) Data Sources and Inputs", (2014) available at: http://www.energy.ca.gov/title24/2016standards/prerulemaking/documents/2014-07-09_workshop/2017_TDV_Documents/

Analysis Component/ Analysis Option	Time dependent valuation (TDV)	Ex-post TDVs, full update (Option #1)	Ex-post TDVs, weather update only (Option #2)	Energy Consumption Comparison Only (Option #3)
Building performance	Simulated	Actual	Actual	Actual
Weather	Simulated	Actual	Actual	Actual
Grid performance • Generation • Capacity • Ancillary services • Transmission and distribution • GHG emissions	Simulated, 30 year net present value	Actual, single historical year, estimated using market price data	Simulated using actual weather (could apply a day matching approach or load regression approach to update TDVs based on actual weather)	N/A
Natural gas prices	Forecast, 30-year net present value	Actual, single historical year	Forecast, 30-year net present value	N/A
RPS policy and adder	Forecast, 30-year net present value	Actual, single historical year	Forecast, 30-year net present value	N/A
Retail rates	Forecast, 30-year net present value	Actual, single historical year	Forecast, 30-year net present value	N/A
Notes	*TDVs guide building design and code compliance, but simulated conditions are not the same as actual conditions*	*A full TDV update is labor and data intensive, would not reflect lifetime value of energy efficiency savings, actual grid conditions are largely outside of building occupant's control*	*A partial update of TDVs based on historical weather conditions controls for the weather uncertainty when comparing actual performance to TDVs. Davis Energy Group (2014) used a day matching approach to apply this method.*[1] *A more sophisticated version of this approach would use a load regression such as*	*In this approach the building's simulated energy consumption is compared to actual energy consumption (calibrated for weather differences), and excludes any ex-post analysis of TDV factors. It is the simplest of the approaches, and only requires comparing simulated energy demand (for a building that is*

[1] Davis Energy Group (2014) "Cottle Zero Net Energy Home Monitoring Performance Evaluation Report, 12 Months of Occupancy", Pacific Gas and Electric Company's Emerging Technologies Program, *ET Project Number: ET13PGE1011*

Analysis Component/ Analysis Option	Time dependent valuation (TDV)	Ex-post TDVs, full update (Option #1)	Ex-post TDVs, weather update only (Option #2)	Energy Consumption Comparison Only (Option #3)
			the one E3 uses to develop the TDVs.	*deemed to be ZNE compliant) to actual energy demand.*

Figure 85: Comparison of Building Simulation and Building Performance Metrics, Pros and Cons of Each Approach

9.2.1 Option #1 Ex-Post TDV – Full Update

In this approach, the following methodology is used (see Option#1 in Figure 85):

- Use the building's actual energy consumption, (which reflects actual weather, actual occupancy, actual plug load usage, etc.) in place of simulated energy consumption. Multiply actual energy use by:
- Ex-post TDV factors: Construct new ex-post TDV factors based on actual weather and historically observed costs of energy supply, reflecting actual grid conditions.

The appeal of this approach is that it is a comprehensive update of the TDVs, so would seem to be most reflective of actual conditions experienced by the building. The downside of this approach is that it is labor and data intensive to develop and maintain updated ex-post TDV factors, and would only reflect historical grid conditions for the period the building was monitored. As a result, it would likely underestimate the lifetime value of energy efficiency savings in a building, which would be expected to last over a 15 to 30 year timeframe. Furthermore, it would result in different TDV values that are beyond the control of the building developer, owner or occupant, such as unexpected changes in natural gas prices. For these reasons the study team does not advocate this approach.

9.2.2 Option # 2 Ex-post TDV - Weather Update Only

In this approach, ex-post TDV factors are created that align with the historical weather, but use the prior forecasted inputs, and then multiply by actual energy use (kWh and therms). This approach is less data intensive, reflects the lifecycle costs and benefits of energy efficiency and ZNE compliance and is not affected by factors that have little to do with actual building performance. This second approach answers a slightly different question than the one posed at the start of Section 9.2.2:

<u>Did the building achieve ZNE (according to the TDV definition of ZNE), given actual weather conditions, assuming that the original TDV forecasts were accurate?</u>

This research question removes the forecast error in the underlying TDV value and focuses on building performance and consumer behavior. This test is unaffected, for example, if the state is achieving more rapid progress towards its RPS than was originally forecast, or if retail electricity rates increased faster than expected. This approach however shares the same downsides as the option #1 in terms of the labor and data intensive analysis that requires specialized skills above and beyond traditional energy modeling or performance validation. For this reason, the study team does not advocate this approach.

9.2.3 Option #3 Energy Consumption Comparison only

In this option, the approach is to compare the actual and simulated energy usage for the building, by hour, by time period, or by year, to see if the building is in line with expectations. Comparable metrics include: kWh/sf, therms/sf, kBtu/sf. This third approach is the simplest and most transparent approach and answers the question:

How did the building's actual energy performance compare to the energy consumption estimated by the building simulation analysis?

To answer this question, a simple comparison of simulated to actual energy use by time of use (TOU) period or annually could be performed.

9.3 Temporal Scale of Comparison between Options

	Hourly energy use	Time of Use Period (TOU) energy use	Annual energy use
Ex-post TDVs, full update (Option #1)	X		
Ex-post TDVs, weather update only (Option #2)	X	X	
Energy Consumption Comparison Only (Option #3)		X	X

Figure 86: ZNE Performance Evaluation Options, Classified by the Recommended Type of Temporal Resolution for Evaluating Performance

An additional consideration for measurement of performance is the temporal scale of comparison: hourly, by TOU period (e.g. peak, off-peak, etc.), or annually. The additional temporal detail adds complexity to the analysis, but is also more reflective of the actual TDV factors, which are hourly, and building performance which is more broadly seasonal and time of use.

Of the three ZNE verification metrics discussed in this section, each approach lends itself to a different level of temporal resolution, as shown in Figure 86. For Option #1, the full update of the TDVs based on ex-post data, it makes sense to pursue a fully hourly verification, given that it will be necessary to collect hourly data anyway to perform the TDV update.

For Option #2, which only updates the weather assumptions in the development of the TDVs, either an hourly or a TOU period verification could be performed. For Option #3, the energy consumption analysis comparison lends itself best to a TOU or even an annual energy use verification. Note that under option #3, the verification is not whether the buildings is TDV zero but rather an verification of whether the actual net site energy use matches the predicted net site energy use.

This approach would allow the development of standardized energy consumption metrics that could be compared across many ZNE buildings within a climate zone, such as kWh/sf. and kBtu/sf.