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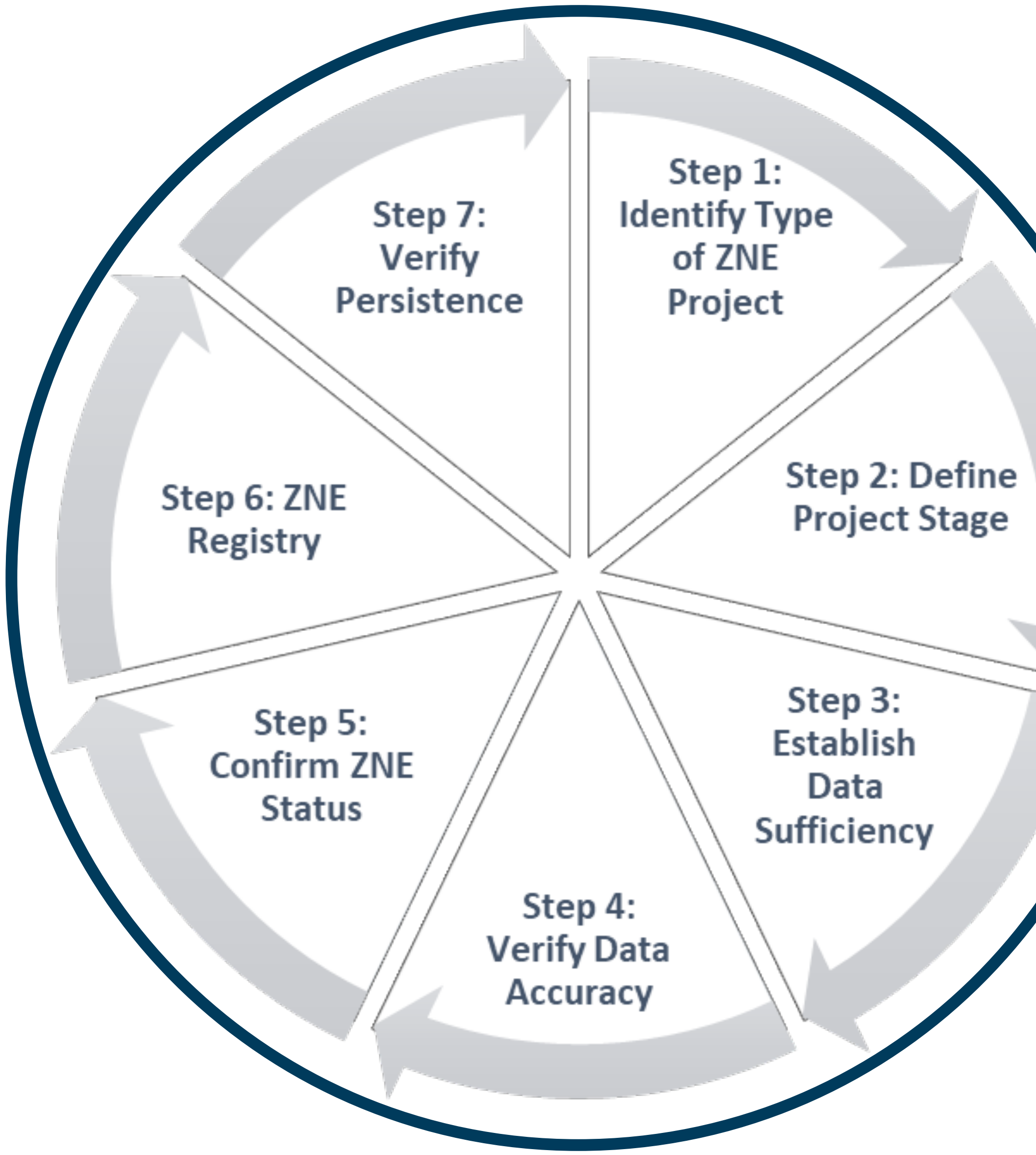
ZNE Verification Methodologies Phase 2

Final Report

December 17, 2018



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I. Acknowledgements

The California Investor Owned Utilities (IOUs) funded and supported the development of the Study. The Study has been carefully guided by Rachel Allen, the Pacific Gas & Electric (PG&E) project manager who provided oversight on this project. Michele Ortland, (PG&E), served as project manager while Rachel was out on leave. Dr. Carrie Brown, Vrushali Mendon and Anna LaRue of Resource Refocus LLC provided guidance to the TRC team on behalf of PG&E including reviewing technical content and deliverables.

Emrah Ozkaya, Lori Atwater, William Vicent, Southern California Edison (SCE); Lonnie Mansi, San Diego Gas & Electric Company (SDG&E); Michelle Sim, Southern California Gas Company (SoCalGas); provided guidance to the TRC team. The study research plan and draft report was posted on CPUC's basecamp site.

New Buildings Institute (NBI) provided data and insights on California commercial buildings that have targeted ZNE design and performance status, including summary of monitored and modeled energy use and generation from their 2018 Getting to Zero Status Update and Zero Energy Buildings List. Likewise, Edward Dean from Bernheim + Dean Associates provided data and insights on California commercial buildings. PG&E provided data on Prop 39 Schools and Residential Builder Demonstration Projects. Additional data on projects was provided by various design and engineering firms. These example projects were crucial in validating the verification methodologies and the study team would like to express our sincere appreciation.

The project study plan and draft findings were reviewed by numerous stakeholders through a public review process. Written comments and follow-up conversations that followed from that process assisted the study teams in their efforts. While not all comments were incorporated into the study, these comments nevertheless helped broaden the purview of the study which strengthened the study findings and recommendations.

The study team was led by Abhijeet Pande who provided research oversight and is the primary author of this report. David Douglass-Jaimes provided project management as well as analysis and reporting support. Rupam Singla provide data analysis and technical writing. Julianna (Yun) Wei led primary data collection through interviews. Parul Gulati and Avani Goyal provided technical analysis support.

2. Executive Summary

Pacific Gas & Electric (PG&E), on behalf of the joint California Investor Owned Utilities (IOUs) contracted with TRC to develop methodologies for verifying predicted or measured energy performance of Zero Net Energy (ZNE) buildings in California. This report represents the Phase 2 deliverable of this effort, which builds on the work of Phase 1 to develop verification methodologies for validating predicted and observed energy performance of ZNE buildings in California. A report for the Phase 1 study is posted on CALMAC at http://www.calmac.org/%5C/publications/ZNE_Evaluation_Methodologies_Final_Report_PGE0387.01.pdf

This report provides a deeper analysis of issues raised during Phase 1 and expands to consider issues for several building and project types including commercial buildings, multi-building projects, retrofits, and community scale ZNE projects.

2.1 Study Objectives

This report addresses the following study objectives:

- **Objective 1**: **Qualitative Analysis** - Assessment of key issues affecting ZNE verification including metrics, challenges with modeling ZNE buildings, challenges with field data collection and entities for tracking ZNE performance.
- **Objective 2**: **Quantitative Analysis** - Assessment of ZNE design and performance for a broad set of projects involving single family residential, multifamily and commercial buildings, ZNE retrofits and campus/community scale ZNE. The quantitative analysis conducted deeper dive on persistence of savings, impacts of the changes in Time Dependent Valuation (TDV, defined in section Key ZNE Terminology) values between 2013, 2016 and 2019 on ZNE design/performance and the cross-walk between these TDV values and site energy performance. The report addresses the differences between ZNE Code, ZNE Site/Source and Zero Net Carbon metrics.

Research questions to be addressed within these study objectives are outlined in Section 3.1.

2.2 Potential Use Cases for ZNE Verification Methods

This report presents methodologies to address ZNE verification challenges for a variety of potential use cases and applications, as illustrated in Figure 6, including:

- Codes and Standards Savings Claims
- Savings Claims for Above Code Programs Targeting ZNE
- Voluntary ZNE efforts

Note that the verification methods are intended for individual projects and not for programmatic evaluations conducted under the auspices of the CPUC as outlined in Section Limitations of Project Scope. This study envisions a wide range of user groups for the various ZNE verification stages, as shown in Figure 57, including homeowners, residential builders, commercial developers, designers and MEP firms, local building code officials, program implementers, and the CPUC. For example, homeowners and developers are most likely to be interested in ZNE Design or ZNE Performance Monitoring stages, whereas the CPUC is likely to be focused on the ZNE Performance Verified stage for the disbursement of ratepayer funds. Stakeholders like designers and MEP firms are likely to have an interest in all three stages.

2.3 Methodology and Approach

2.3.1 Review ZNE Tracking Databases and Reports

To supplement the literature review conducted as part of the Phase 1 report, the TRC team reviewed several additional sources in relation to the Phase 2 study objectives:

- Net-Zero Energy Coalition's *To Zero and Beyond: Zero Energy Residential Buildings Study*[1]
- NBI 2018 Getting to Zero Status Update and Zero Energy Buildings List[2]
- *Zero Net Energy Case Study Buildings, Volumes 1, 2, and 3*[3]
- California Department of General Services ZNE Initiative[4]
- CPUC ZNE Residential Stakeholder Group Basecamp Site[5]
- Projects referred to TRC by various stakeholders interviewed for this Phase II study

2.3.2 Interviews with ZNE Stakeholders

TRC conducted interviews with nine ZNE leaders that have experience with multiple ZNE projects including building designers, energy modelers, utility staff, and state policymakers. To allow interviewees to be as forthcoming as possible, interviewees were promised anonymity and results are presented in this report in a combined summary format.

Though the interviewee group represents a range of industry perspectives, interview responses addressed many of the same themes. Key findings from these interviews are outlined in the discussion below.

- A major sticking point for several stakeholders was inflexibility in simulation and compliance tools for modeling innovative solutions and strategies, or in adjusting standard assumptions.
- Stakeholders are seeing significant differences between modeled and monitored performance in ZNE buildings. Many stakeholders specifically mentioned difficulties with accurately predicting plug-loads, which have become a larger share of building energy use as other systems become more efficient. Several stakeholders noted that overestimated energy use has led to inefficiently oversized PV systems.
- Designers expressed concerns over design-build contracts that mandate performance targets that architects, and engineers have little or no control over once a building is operational.
- Multiple stakeholders brought up questions about how electric vehicle charging or battery storage systems should be considered in ZNE definitions and strategies.

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[1] Retrieved from: https://netzeroenergycoalition.com/wp-content/uploads/2017/06/2017-06-14_NetZeroEnergy17001_zero-energy-homes-booklet_a01_fnl_screen-1.pdf

[2] Retrieved from: https://newbuildings.org/resource/2018-getting-zero-status-update/

[3] Volume 3 is available here: https://www.amazon.com/Zero-Energy-Case-Study-Buildings/dp/1724455842. TRC also reviewed Volumes 1 and 2 for the Phase 1 report, and this report builds on the findings from those volumes included in the Phase 1 report. Volume 1 is available here: https://energydesignresources.com/media/19864463/zne_case_study_buildings-11.pdf and Volume 2 is available here: http://www.resourcerefocus.com/blog/2017/6/15/volume-2-of-zne-case-study-buildings-now-available

[4] Retrieved from: https://www.dgs.ca.gov/dgs/Sustainability/ZeroNetEnergy.aspx

[5] Retrieved from: https://basecamp.com/2039351/projects/2533572

- All interviewees emphasized the importance of communicating the fact that ZNE does not mean "zero energy bill" or "zero energy cost" to their customers.
- Some stakeholders noted a sales advantage related to ZNE and high-performance buildings. One homebuilder noted high demand for their ZNE homes, and the ability to charge a premium for high performance homes. One engineer also noted that developers realize they can charge a premium for high performance buildings, often keeping the profits rather than passing any energy savings on to their tenants.
- Stakeholders identified the difficulty of ongoing performance verification. As the utility representative noted, ZNE really needs to be about ongoing performance, which comes down to occupant behaviors and how buildings are used. But many stakeholders reported challenges in monitoring or collecting the data to understand ongoing performance.
- Many stakeholders noted that ongoing energy monitoring is usually out of the hands of the building design team. Even for many of the green building rating systems, providing performance data is usually the responsibility of the building owner.
- One engineer also noted that most buildings don't have the resources, and clients are not being trained to effectively operate ZNE buildings. They recommended the need for a new type of role that manages the ZNE needs of a building across both the design and operation sides of the process, a sort of "ZNE Integrator" role.

2.3.3 ZNE Building Design and Performance Data

TRC gathered data on 94 buildings as described in Section 4.1. A summary of the buildings, including type, square footage, construction type, ZNE Stage, and ZNE Metric Targeted is given in **Some projects used multiple ZNE metrics, so the sum of numbers in parenthesis exceed the total number of buildings in the first column.*

Figure 10. Over one-third of buildings assessed were single-family residences, about a quarter were offices, one-fifth were schools, while the remaining buildings were a mix of libraries, multi-family buildings, museums, and other building types. TRC obtained data from the following sources:

- NBI provided a list of 43 California buildings from their Getting to Zero Database through 2017.
- Resource Refocus provided information on six residential ZNE model homes, and six school projects currently in progress under the Prop 39 pilot program.
- Edward Dean, author of the ZNE case study reports described above, identified additional buildings for inclusion in this study, and provided available building performance data.
- Several interviewees identified additional buildings that were not previously included in the study and provided performance data and information where available.

In some cases, multiple sources provided information on the same projects, so there is some overlap between categories. All building data shared in this report has been anonymized to maintain confidentiality of the projects and the project teams.

The buildings contain a mix of New Construction and Renovated buildings, with the majority being New Construction projects. The renovation projects covered both deep retrofits of existing buildings that maintained their original end uses and occupants as well as gut rehabs where the building was repurposed for a different occupant/tenant. The buildings range considerably in size, from the smallest single-family home at 1,700 sqft, up to the largest correctional facility (included under 'Other') at 408,800 sqft. From the data submitted, the ZNE Stage was determined either to be ZNE Design or ZNE Performance. Where the stage was determined to be ZNE Performance, the building was also considered ZNE Design – but not vice versa. In some cases, not enough data was provided to indicate ZNE status one way or the other. The ZNE metric targeted is also included in the table, with Site being by far the most common, and with Source and TDV only having a handful of buildings each.

Building Type	Building Square Footage	Construction Type	ZNE Stage	ZNE Metric Targeted*
Library (3)	9,300 – 34,500 sqft	New (3), Renovation (0)	ZNE Design (0), ZNE Performance (2), Insufficient Data (1)	Site (3), Source (0), TDV (0)
Multi-family (4)	6,200 – 17,600 sqft	New (4), Renovation (0)	ZNE Design (0), ZNE Performance (2), Insufficient Data (2)	Site (4), Source (0), TDV (0)
Museum (3)	190,000 – 190,000 sqft	New (3), Renovation (0)	ZNE Design (0), ZNE Performance (3), Insufficient Data (0)	Site (3), Source (0), TDV (0)
Office (24)	4,500 – 88,800 sqft	New (11), Renovation (13)	ZNE Design (0), ZNE Performance (13), Insufficient Data (11)	Site (19), Source (1), TDV (0)
School (20)	6,300 – 141,800 sqft	New (12), Renovation (8)	ZNE Design (5), ZNE Performance (9), Insufficient Data (6)	Site (15), Source (5), TDV (2)
Single-family (31)	1,700 – 3,200 sqft	New (31), Renovation (0)	ZNE Design (7), ZNE Performance (22), Insufficient Data (2)	Site (25), Source (1), TDV (6)
Other (5)	5,600 – 408,800 sqft	New (4), Renovation (1)	ZNE Design (0), ZNE Performance (2), Insufficient Data (3)	Site (5), Source (0), TDV (0)
All (90)	1,700 – 408,800 sqft	New (68), Renovation (22)	ZNE Design (12), ZNE Performance (53), Insufficient Data (25)	Site (74), Source (7), TDV (8)

Figure 1. Summary of ZNE Buildings Reviewed

*note: some projects used multiple ZNE metrics, so the sum of numbers in parenthesis exceed the total number of buildings in the first column.

As seen in Figure 2 there were data gaps across all building types. Note that buildings without gas use reported contains both buildings with no on-site gas usage and those buildings which have on-site gas usage but did not report it or reported equivalent kWh.

Data Type	Metric	All (n=90)	Library	Multi-family	Museum	Office	School	Single-family	Other
ZNE Target	Site/Source/TDV	90	3	4	3	24	20	31	5
Modelled Energy Use	kWh	55	2	0	2	9	14	28	0
	Therms	29	0	0	0	0	4	25	0
	Site kBtu	46	2	0	2	8	11	23	0
	Source kBtu	46	2	0	2	8	11	23	0
Monitored Energy Use	kWh	58	3	2	3	15	10	22	3
	Therms	13	1	1	0	3	4	3	1
	Site kBtu	54	3	2	2	13	10	22	2
	Source kBtu	53	3	2	2	12	10	22	2
Modeled Energy Generation	kWh	40	1	0	2	4	8	25	0
	Site kBtu	31	1	0	2	3	5	20	0
	Source kBtu	31	1	0	2	3	5	20	0
Monitored Energy Generation	kWh	56	2	2	3	13	10	23	3
	Site kBtu	53	2	2	2	12	9	23	3
	Source kBtu	52	2	2	2	11	9	23	3
Commissioning Report Available	-	8	0	0	0	2	5	0	1

Figure 2. Number of Buildings for which Data is Available

2.4 Findings

2.4.1 ZNE Design and ZNE Performance Require Different Verification Methods

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.

2.4.2 Different Metrics Require Different Criteria and Data Sources

There are various ZNE metrics that are being used by entities in the state of California and across the country. The choice of metric also affects the choice of the verification method and the data relied upon for ZNE verification. Figure 49 outlines the differences in the criteria and data sources necessary to verify ZNE. As seen in the figure, and as outlined above, the design verification is based largely on energy simulation analysis, but the metric influences the choice of energy analysis tools as well as the outputs to be verified. For example, the TDV metric requires using a compliance tool (CBECC-Res/CBECC-Com) whereas the site energy metrics, other simulation tools may also be used.

2.4.3 Different Audiences May Have Different Verification Needs

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 Design or ZNE Performance metrics. Figure 50 outlines the current California initiatives and the ZNE metrics of interest as well as the verification criteria and approach.

2.4.4 ZNE Metrics are Still Evolving

ZNE remains a developing approach to building energy efficiency. As a result, definitions, strategies, and metrics are still evolving. One potential new approach, which is still in the early stages of development, is a metric based on carbon emissions or an equivalent. Because carbon metrics are still in the early stages of development TRC did not evaluate the project data in this report against any potential Zero Net Carbon metrics. It is likely that a carbon metric would require additional or different inputs from those described in this report. In addition, many of the inputs necessary for an accurate determination of Zero Net Carbon status, such as detailed information on utility generation fuel mix, is not yet readily available at a sufficient level of detail.

As metrics and standards for verifying ZNE status continue to develop and evolve over time, the details of the verification requirements will need to evolve alongside, but the overall approach and strategy recommended in this report will still be valid.

2.5 Proposed Verification Methods

TRC proposes the following verification methods based on the findings identified in the previous section and the analysis done for this project. The methods outline the process separately from the documentation requirements.

2.5.1 Proposed Verification Levels

We propose three levels of ZNE Verification and one level that is short of ZNE for those projects that don't quite meet the ZNE designation. These ZNE levels are designed for multiple use cases and differ in terms of the verification methods and the stringency of the data and verification process.

- **Ultra-Efficient** – projects that are not quite ZNE but have high levels of efficiency and some renewables

- **ZNE Design** – The ZNE Design designation is assigned to those buildings where there is demonstrated design intent to have a building/project to be ZNE. This designation by its nature is for those buildings that are in design or construction but not yet occupied or operated.
- **ZNE Performance Monitored** – The ZNE Performance Monitored designation is assigned to those ZNE projects where the building has been operational for at least 12 months and there is a credible claim for ZNE performance, but not enough data to validate that claim. This is a common occurrence based on the 94 buildings studied by TRC for this project.
- **ZNE Performance Verified** - ZNE Performance Verified is the highest level of ZNE designation awarded to those projects where the ZNE Performance claim is credible, backed by the right quality and quantity of data that is verified by an independent verifier. This level has the most degree of difficulty to achieve but the most guarantee of accuracy and verification of ZNE Performance. This level is appropriate where the ZNE performance is part of a contractual agreement or when ratepayer funds are being used to support the ZNE performance project.

2.5.2 Proposed Verification Process

TRC proposes the following decision-tree and process for ZNE verification.

Figure 3: Proposed 7-Step ZNE Verification Process

Detailed discussion of the proposed verification process is documented below in section 6, and documentation requirements are outlined in Figure 54, Figure 55, and Figure 56.

2.6 Recommendations

2.6.1 Proposed mapping of Use Cases and ZNE Verification Levels

As identified in Section 6, there are various potential end users for these verification methods and different levels of rigor that they are likely to need with ZNE verification. On one end of the spectrum are all the voluntary claims of ZNE design and performance that need to be credible but may not need independent verification, whereas on the other end of the spectrum, the verification activities need to be conducted by independent third parties subject to stringent requirements.

Figure 57 shows the proposed mapping of the intended users and the ZNE Verification Levels. As discussed above, the Verified designation is most useful to those users who need independent verification of ZNE claims to justify spending ratepayer funds (program implementers, CPUC) or meet contractual obligations (designers and MEP firms that have signed performance guarantees).

2.6.2 Need for ZNE Registry

TRC has developed comprehensive methods for verifying claims of ZNE Design and Performance based on extensive review of existing ZNE projects – a total of 90 projects were reviewed for this study. To date, this is the most comprehensive review of California ZNE buildings that included both quantitative (review of underlying energy use and generation data) as well as qualitative (degree of difficulty and accuracy of verification methods). However, this is still not likely an exhaustive list and with the expected increase in ZNE construction in the state, there is a need to conduct ongoing tracking of ZNE claims and verifications.

Ideally, the CPUC would work with its sister agencies (CEC, CARB) to develop such as registry or at least support the development of such a registry. The registry would allow for a transparent way to provide insights into ZNE growth, energy performance of ZNE buildings and challenges and opportunities for ZNE buildings.

2.6.3 ZNE Performance Verification is Not a One-time Activity

As outlined in Section 6.3, the status of ZNE Performance Monitored or ZNE Performance Verified should not be in perpetuity but rather a time-bound rating like how vehicles need to prove they are meeting emissions standards every few years. We recommend that buildings undergo ZNE performance verification every 3-5 years to get insights into whether/how ZNE buildings can maintain energy performance.

3. Introduction and Study Background

Pacific Gas & Electric (PG&E), on behalf of the joint California Investor Owned Utilities (IOUs) has contracted with TRC Energy Services (TRC) to continue to develop validation methods for confirming predicted energy performance of Zero Net Energy (ZNE) buildings in California.

This report represents the Phase 2 deliverable of this effort, which builds on the work of Phase 1 to develop verification methodologies for validating predicted and observed energy performance of ZNE buildings in California. A report for the Phase 1 study is posted on CALMAC at http://www.calmac.org/%5C/publications/ZNE_Evaluation_Methodologies_Final_Report_PGE0387.01.pdf

This Phase 2 report provides a deeper analysis of issues raised during Phase 1 and seeks to address some of the limitations of the Phase 1 study. In addition, Phase 2 expands on the residential focus of Phase 1 to consider issues for other building and project types including commercial buildings, multi-building projects, retrofits, and community scale ZNE projects.

3.1 Study Objectives and Research Questions

This report addresses the following study objectives:

- **Objective 1**: **Qualitative Analysis** - Assessment of the key issues affecting ZNE verification including metrics for commercial ZNE buildings, challenges with modeling ZNE buildings, challenges with field data collection and lack of dedicated entities for tracking ZNE performance.
- **Objective 2**: **Quantitative Analysis** - Assessment of ZNE design and performance for a broader set of buildings beyond those covered in Phase 1 including projects involving multiple ZNE buildings, ZNE retrofits, multifamily buildings and community scale ZNE. The quantitative analysis will also do a deeper dive on persistence of savings, impacts of the changes in Time Dependent Valuation (TDV, defined in section 3.2) values between 2013, 2016 and 2019 on ZNE design/performance and the cross-walk between these TDV values and site energy performance. The study will address the differences between IEPR ZNE Code, ZNE Site/Source and Zero Net Carbon metrics.

Research topics and questions for Objective 1, qualitative analysis, include but are not limited to:

1. **What is needed to support ZNE commercial building verification?**
2. **What are the modeling challenges?**
   a. How do challenges differ between compliance vs. other design models?
   b. What are the pros/cons to having more data vs. the time and expense to gather more data?
3. **Who is the target audience for verification methods?**
   a. Regulator/Utility vs. Owner, operator, occupant, and others?
   b. What do they know and what are they already doing?
   c. What else do they need?

Research topics and questions for Objective 2, quantitative analysis, include but are not limited to:

1. **Case Studies: Deeper analysis of the case studies of Phase 1 methods and projects**
   a. What are the replicable standard inputs for Site, Source, and TDV methods?
   b. What are some examples of how the Consultant applied the methodologies?
   c. What are the impacts to verification under the 3 current TDV releases?

d. How do fuel types impact the verification metrics?

2. **Crosswalk: Present a comparison table of calculations to translate verification method application outcomes across the various definitions of ZNE**
   a. How do compliance models compare to other energy models used in design?
   b. What is the quantitative difference between IEPR TDV ZNE vs. DOE/Governor's Office Source ZNE?
3. **Greenhouse Gases (GHG): Add GHG calculations, rather than only focusing on energy**
   a. How will fuel choice effects impact the calculations?
4. **Persistence of Performance**
   a. How does occupancy, behavior, degradation, etc. impact the verification calculations and outcomes?
   b. How do weather files used for code compliance compare to modeled weather that accounts for future shifts resulting from climate change?
   c. How can monitoring or verification methods provide actionable results to enhance the building's performance?
5. **Retrofits vs. New Construction**
   a. How can these methods be applied to retrofit projects?
   b. What are the barriers to retrofit project performance verification?

3.2 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 on site through renewable energy means. ZNE includes all energy end uses within the building (including process loads) but does not include electric vehicle (EV) 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 Performance Verified** – A ZNE Performance Verification designation denotes that the building has been verified to perform 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 like 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 given 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 DOE Common Definition for Zero Energy Buildings[1], EnergyStar and Portfolio Manager initiatives. This enables the values to be comparable across the various states and utility territories across the country.

- **IEPR ZNE Code** – This definition of ZNE is specific to California and is unlike the definitions of ZNE used elsewhere. ZNE Code is a design rating since it is based on predicted energy performance. Specifically, the ZNE Code definition is spelled out in the 2015 Integrated Energy Policy Report (2015 IEPR) as:

  A 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.

  Note that this definition includes all fuels consumed onsite. In addition, as part of the "best practices for highly efficient buildings", IEPR emphasizes that energy efficiency measures are to be installed first before renewables are considered.

- **2019 Title 24 ZNE Code** – This definition is specific to California and is a specific implementation of the IEPR ZNE Code and the EDR definitions. Currently in draft format and out for a required 45-day comment period, the 2019 Title 24 Standard Section 150.1(b) specifies the following:

  - Newly Constructed Buildings. The Energy Budget for newly constructed buildings is expressed in terms of the Energy Design Rating, which is based on TDV energy. The Energy Design Rating (EDR) has two components, the Energy Efficiency Design Rating, and the Solar Electric Generation and Demand Flexibility Design Rating. The Solar Electric Generation and Demand Flexibility Design Rating shall be subtracted from the Energy Efficiency Design Rating to determine the Total Energy Design Rating. The Proposed Building shall separately comply with the Energy Efficiency Design Rating and the Total Energy Design Rating.

    EXCEPTION to Section 150.1(b)1. A community shared solar electric generation system, or other renewable electric generation system, and/or community shared battery storage system, which provides dedicated power, utility energy reduction credits, or payments for energy bill reductions, to the permitted building and is approved by the Energy Commission as specified in Title 24, Part 1, Section 10-115, may offset part or all of the solar electric generation system Energy Design Rating required to comply with the Standards, as calculated according to methods established by the Commission in the Residential ACM Reference Manual.

  - Additions and Alterations to Existing Buildings. The Energy Budget for additions and alterations is expressed in terms of TDV energy.

[1] https://www.energy.gov/sites/prod/files/2015/09/f26/bto_common_definition_zero_energy_buildings_093015.pdf

- **Zero Net Carbon** – Zero Net Carbon (ZNC) focuses specifically on carbon emissions related to building energy use, rather than energy use alone. Architecture 2030 defines ZNC as a "building that produces on-site, or procures, enough carbon-free renewable energy to meet building operations energy consumption annually." This definition allows for procurement of energy from off-site non-carbon renewable sources to offset building energy, rather than requiring all energy to be produced on-site. Carbon emissions and carbon equivalents are measured in CO_2 lbs. There is no accepted definition for ZNC within California, though the California Energy Commission, California Air Resources Board and California Public Utilities Commission are all working on developing carbon metrics that can be used towards zero carbon buildings. These need to account for not only site energy use but also the fuel mix used for the energy generation (onsite and offsite) as well as account for seasonal and hourly variations based on location and utility.

- **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.

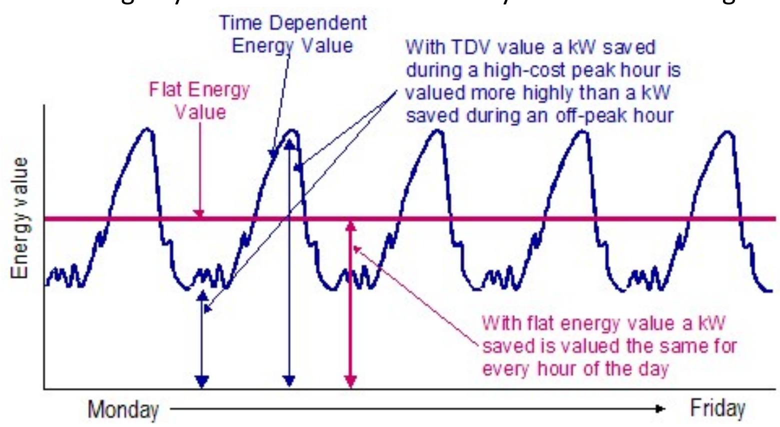

Figure 4: TDV Concept – "Flat" Valuation versus TDV for Electricity Use

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 air conditioning energy savings get higher benefit under TDV since air conditioning usage tends to coincide with current system peak and lighting savings get lesser benefits since they tend to occur outside the system peak.

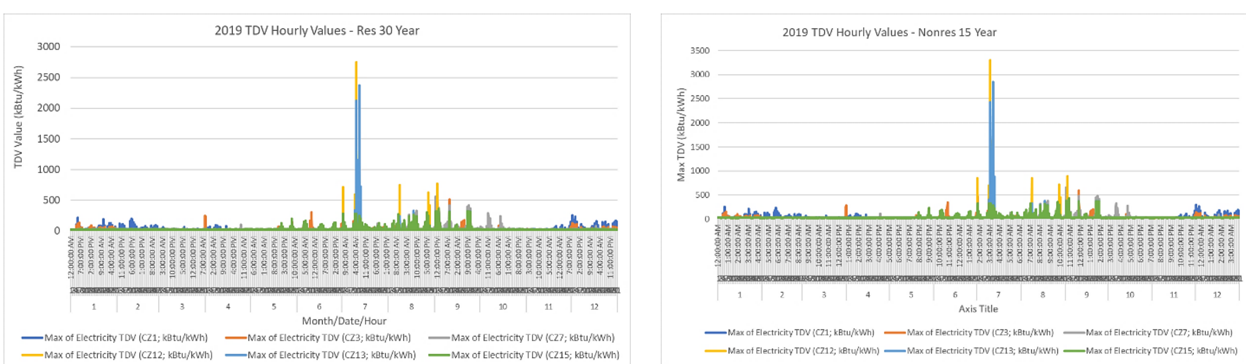

Figure 5: 2019 TDV Values Over the Year

- **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 2019 Title 24 ZNE Code definition. 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 IEPR ZNE Code - Design if the EDR equals 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). Standard 301 is under continuous maintenance and the most recent version being currently developed is 301-2019 and a draft version is currently out for public review. This draft version clarifies that the standard only applies to individual dwelling units and does not provide procedures for determining Energy Ratings for whole buildings containing more than one unit.
- **Energy Use Intensity (EUI)** - The EUI is expressed as kBtu/sf/yr. (site energy) and is a commonly used metric of a building's energy use or performance. It also allows benchmarking and comparisons of buildings. 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 Application Scenarios

This study aims to update verification methodologies to address ZNE verification challenges for the following programmatic and voluntary efforts:

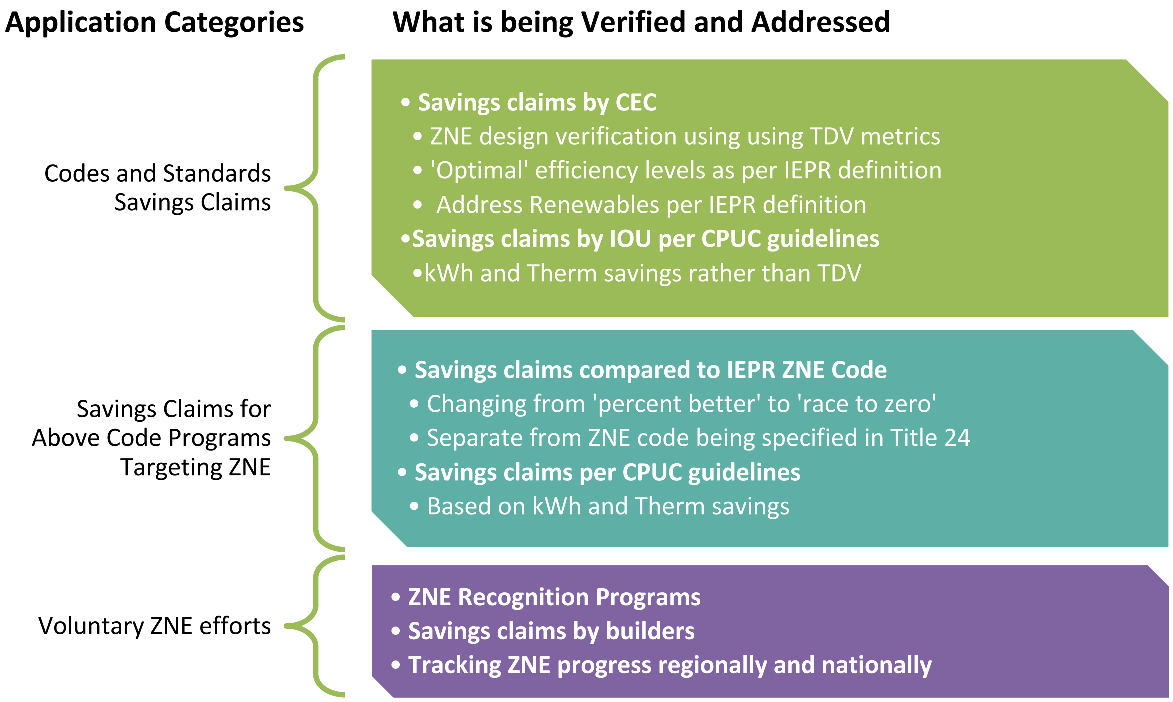

Figure 6: Application Scenarios for ZNE Verification

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

3.4 Limitations 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 individual building or project level 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 question that may arise during the study.
- This study focuses on the implications of potential policy choices regarding ZNE buildings. It does not presume policy choices as being preferable and presents the complexities or lack thereof for various policy choices. This study is not intended to make policy recommendations.
- 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 verification methodologies to a relatively small number of ZNE buildings in the state where energy performance data is available.
- 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 strategy incorporated into the building.
- This study is not an analysis of the cost effectiveness of specific measures used to achieve ZNE, or of ZNE buildings. Neither total construction costs, nor incremental costs of specific measures were considered as a part of this study.
- This study will not develop any new TDV values or other such primary data needed to evaluate ZNE buildings.

3.5 Methodology and Approach

TRC's general approach was to expand on the data collected and analyzed in Phase 1, collecting more detailed information on the buildings studied in Phase 1, and collecting information on new buildings where available, to provide a more complete understanding of how and why these buildings are performing as they are, and how that impacts the recommended documentation requirements. TRC also reexamined the Phase 1 recommendations considering newly implemented building energy standards, and the planned future updates to those standards. Based on this general approach, TRC pursued the following strategies:

- **Deeper exploration of Phase 1 buildings:** Data available in Phase 1 was largely limited to modeled energy use predictions and monitored post-occupancy energy use information, with limited supporting documentation. As a result, the report was not able to explain discrepancies between modeled and actual energy performance, or whether the monitored performance for each building would be predictive of continued ZNE performance. To provide a more complete understanding of these projects, TRC reached out to designers, engineers, developers, and other project stakeholders to obtain energy models, construction documents and conducted interviews with project stakeholders.
- **Expanded list of ZNE Buildings reviewed:** TRC sought additional buildings to expand the data set to include more examples of nonresidential and existing building retrofit projects that pursued ZNE. TRC coordinated with New Buildings Institute (NBI) on their ZNE tracking efforts to identify additional projects. TRC also developed a handout for distribution at industry events requesting ZNE building design and performance data (this handout is reproduced below in appendix section 8). TRC recruited additional projects through the interviews with project stakeholders described below. Through this process TRC obtained data on additional residential builder demonstration models and Prop 39 school projects, as well as information on an additional 41 nonresidential buildings from the NBI Getting to Zero Database.[1] TRC also reviewed additional documentation on the overall ZNE market, including the Zero Net Energy Coalition's 2016 building inventory.[2]
- **In-depth interviews with project decision-makers and industry stakeholders:** TRC interviewed designers, engineers, energy consultants, and utility representatives to gain additional insights into the specific buildings reviewed in the study, as well as the overall ZNE market and process. These interviews sought to provide greater details on the building designs, how predicted energy performance was

[1] https://newbuildings.org/resource/getting-to-zero-database/

[2] http://netzeroenergycoalition.com/2016-zero-energy-inventory/

modeled, any alterations to the project designs that could have impacted building performance, or any possible explanations for discrepancies between modeled and monitored energy performance for each building. These interviews also serve to inform a reexamination of the documentation recommendations from the Phase 1 report. Interviews addressed the feasibility of the various recommendations, barriers to achieving the recommendations, and potential strategies to resolve those barriers. TRC selected interviewees from the list of key decision-makers and stakeholders for the buildings included in this study, as well as other leading designers and experts on ZNE buildings in California.

- **Reexamination of recommended documentation requirements based on current and future energy standards:** Based on the findings and feedback from the project analysis and in-depth interviews, as well as newly available information about the forthcoming 2019 Title 24 Building Energy Efficiency Standards, and the energy modeling strategies and requirements that will accompany those standards, TRC reviewed the recommended documentation requirements from the Phase 1 report, and considered any opportunities to improve on those recommendations. As part of this process, TRC considered any potential challenges to meeting those requirements inherent in the plans for the 2019 Standards or modeling requirements. For any challenges, TRC considered if those conflicts can be addressed and resolved, or if the new Standards will fundamentally conflict with the recommended documentation requirements. TRC also considered how the documentation requirements may need to be revised or refined to correspond with the 2019 Standards.
- **Consideration of additional factors beyond the scope of the Phase 1 study:** Integral to the strategies detailed above, TRC considered additional factors of interest to the study, including:
  - Persistence of performance: How will ZNE performance be maintained over time? Will ZNE performance continue to be assessed after the first year, and if so how?
  - Existing buildings and retrofits: How do the findings of this study apply to existing buildings and retrofit projects seeking ZNE status? How will the documentation requirements differ from the recommendations for new construction projects, if at all?

4. Data Collection and Analysis

The following sections outline TRC's efforts to build on the findings of the Phase 1 study by reviewing existing efforts to verify and track ZNE buildings, expanding on the number of buildings reviewed and analyzed, and conducting in-depth interviews with ZNE industry stakeholders. The data and analysis described here informs the findings and recommendations outlined in sections 5, 6, and 7.

4.1 Review of ZNE Tracking Databases and Reports

To supplement the literature review conducted as part of the Phase 1 report, the TRC team reviewed several additional sources in relation to the Phase 2 study objectives:

- Net-Zero Energy Coalition's *To Zero and Beyond: Zero Energy Residential Buildings Study*[1]
- NBI 2018 Getting to Zero Status Update and Zero Energy Buildings List[2]
- *Zero Net Energy Case Study Buildings, Volumes 1, 2, and 3*[3]
- California Department of General Services ZNE Initiative[4]
- CPUC ZNE Residential Stakeholder Group Basecamp Site[5]

4.1.1 Net-Zero Energy Coalition's To Zero and Beyond: Zero Energy Residential Buildings Study

This report from the Net-Zero Energy Coalition provides a high-level summary and numerical totals for a range of high-performance residential buildings across the United States and Canada. Not all the buildings included in the report are "net zero" energy, strictly speaking, but rather fall into one of four categories:

- Net Producer – documentation shows that the renewable energy systems at the project supply 110% or more of the annual energy demand
- Zero Energy – documentation shows that the renewable energy systems at the project supply 100% or more of the annual energy demand
- Zero Energy Ready – documentation shows that the renewable energy systems supply 90% or more of the annual energy demand (or could if renewable energy systems are added or increased), OR if energy use data is not available
- Thousand Home Challenge – deep energy retrofits for existing homes that may or may not include renewable energy

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[1] Retrieved from: https://netzeroenergycoalition.com/wp-content/uploads/2017/06/2017-06-14_NetZeroEnergy17001_zero-energy-homes-booklet_a01_fnl_screen-1.pdf

[2] Retrieved from: https://newbuildings.org/resource/2018-getting-zero-status-update/

[3] Volume 3 is available here: https://www.amazon.com/Zero-Energy-Case-Study-Buildings/dp/1724455842. TRC also reviewed Volumes 1 and 2 for the Phase 1 report, and this report builds on the findings from those volumes included in the Phase 1 report. Volume 1 is available here: https://energydesignresources.com/media/19864463/zne_case_study_buildings-11.pdf and Volume 2 is available here: http://www.resourcerefocus.com/blog/2017/6/15/volume-2-of-zne-case-study-buildings-now-available

[4] Retrieved from: https://www.dgs.ca.gov/dgs/Sustainability/ZeroNetEnergy.aspx

[5] Retrieved from: https://basecamp.com/2039351/projects/2533572

For each of these categories, the Net-Zero Energy Coalition requires certification from one of several program options to be included in the inventory.

Across all four of these categories, the 2016 inventory found a total of 8,203 units, spread across 4,077 buildings, in 741 projects. These values represent a 33% increase in the total number of units tracked in the inventory in 2015. However, the bulk of these units (69.3%) fall into the "Zero Energy Ready" category. A further 7.7% of units were classified as Net Producers, and 22.6% qualified in the Zero Energy Category, with the final 0.4% of units listed under the Thousand Home Challenge category. California leads all other states in total number of units included in the inventory with 3,137, but the report does not provide a detailed breakdown of what portion of these units fall into each of the four categories.

4.1.2 NBI 2018 Getting to Zero Status Update and Zero Energy Building List

Like the Net-Zero Energy Coalition's residential inventory report, NBI's Getting to Zero Status Update compiles information on nearly 500 nonresidential building projects in the United States and Canada aiming for ZNE. The report also includes a complete list of all the buildings included in the report, with summary performance statistics where available. NBI divides the projects into two categories:

- Zero Energy Verified – projects that have either been certified under one of International Living Future Institute (ILFI) zero energy categories, or NBI has verified that performance data indicates the project has achieved at least one full year of zero energy status
- Zero Energy Emerging – projects that have a publicly stated goal of achieving zero energy status, but have not yet demonstrated that achievement, either because these buildings are still in planning or construction, have been fully occupied for less than a full year, do not have data available to document zero energy performance, or have performance data that does not demonstrate full zero energy performance

For 2018, NBI identified a total of 67 ZNE Verified project and 415 ZNE Emerging projects. The figure below illustrates the distribution of these projects across various building types, with "verified" projects shown in green, and "emerging" projects shown in blue.

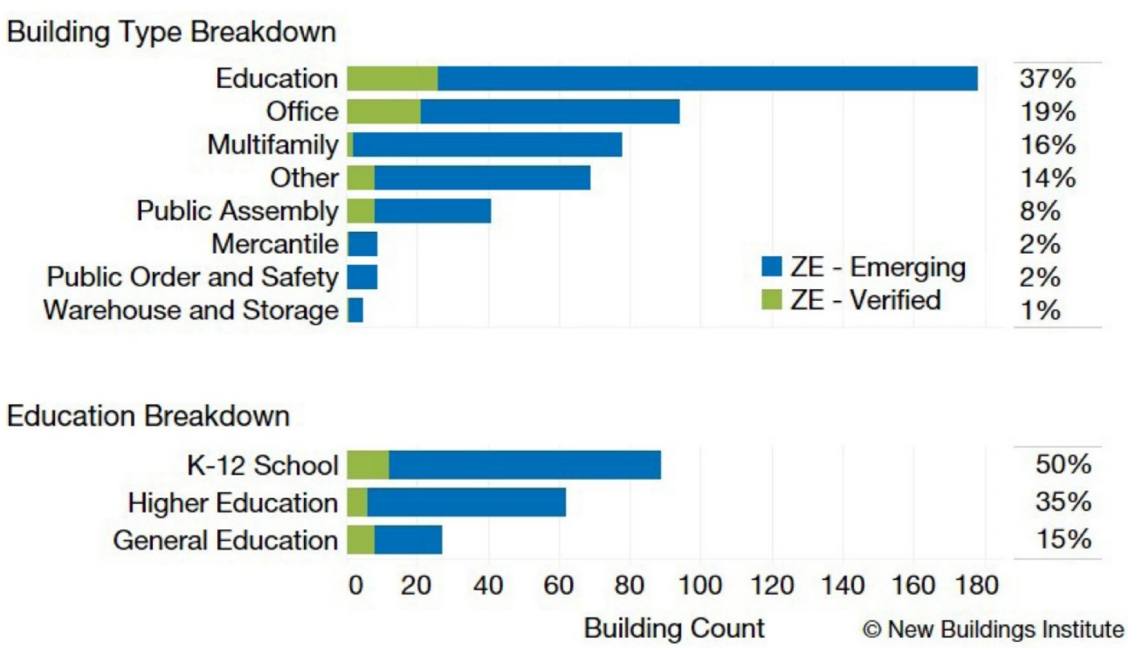

Figure 7: NBI 2018 Zero Energy Building Type Breakdown

NBI also provided available building and performance data for 43 California buildings included on the Zero Energy Building List for inclusion in this study, as described below. These 43 buildings fall into one of four categories:

- ZNE Verified – NBI has reviewed and verified data indicating ZNE Site performance for at least one full year
- ZNE Emerging – buildings that are targeting ZNE performance, but have not yet achieved it or do not have enough data to be verified
- Ultra-Low Energy Verified – buildings that have not invested in the on-site renewables to achieve ZNE, but have demonstrated progress towards energy use reduction, and NBI has reviewed and verified performance data to confirm ultra-low energy status
- Ultra-Low Energy Emerging – buildings that are targeting ultra-low energy status, but have not yet achieved it or do not have enough data to be verified

Project Status	Total Projects	Monthly Energy Use Data	Monitored Data	Data Partially Estimated
ZNE Verified	15	14	13	2
ZNE Emerging	21	8	8	0
Ultra-Low Verified	5	4	4	1
Ultra-Low Emerging	2	0	0	0
TOTAL	43	26	25	3

Figure 8: NBI Project Data Assessment

As Figure 8 shows, 15 of the 43 projects were categorized as ZNE verified. Of those 15 ZNE Verified projects, NBI had received monthly utility data for 14 projects for their review, while one building provided only annual energy use and generation totals. Two of those 15 buildings also included some portion of "estimated" data. NBI was able to confirm through follow-up and review that these buildings still met the threshold for ZNE Verified.

This review of the data also indicated a wide range of sources for reported energy performance data, including utility bills, interval data from utility meters, building energy management system data (such as Lucid Dashboard), or other energy monitoring sources.

4.1.3 *Zero Net Energy Case Study Buildings, Volume 3*

To date, Edward Dean has published three volumes of case studies, in collaboration with PG&E, documenting ZNE nonresidential buildings in California. Each volume carefully documents the design of each building, as well as verifying energy use and generation for each project to confirm net zero status. The first two published volumes contain a total of eleven buildings, designed to be operating at zero net energy consumption or better for at least one year of occupancy (based on a Site ZNE metric). The Phase 1 report of this study included data and information related to the buildings included in the first two case study reports.

Mr. Dean recently completed the third volume of ZNE Case Study buildings with additional six nonresidential projects, including projects at university and school campuses that involve multiple buildings. TRC conducted two in-depth interviews with Mr. Dean and reviewed data for these projects to discuss the process of verifying building performance for the case studies (specifically campuses), identify key ZNE stakeholders and experts for further interviews and data requests, and to share data for inclusion in this study. All building performance data related to the case studies and shared with TRC has been anonymized in this study.

4.1.4 California Department of General Services ZNE Initiative

The State of California's Department of General Services (DGS) has established its own standards and deadlines for State buildings to achieve ZNE.[1] Several key segments of the Management Memo on Zero Net Energy for New and Existing State Buildings are reproduced below:

- "Purpose - This management memo (MM) provides state agencies and building professionals with the requirements for meeting zero net energy (ZNE), as well as the direction, strategies and procedures that will help them achieve ZNE for new building design and construction, and build-to-suit leases, as well as existing state-owned buildings.

  "This MM is part of a series of directives to state agencies designed to implement the Governor's Executive Order (EO) B-18-12 on energy and resource conservation in state buildings. See State Administrative Manual (SAM) Section 1815.31 for more details and guidance."

- "Policy - Executive Order B-18-12 requires the following actions to reduce the environmental impact of state facilities on climate change:
  - "All new State buildings and major renovations beginning design after 2025 shall be constructed as Zero Net Energy facilities.
  - "50% of new facilities beginning design after 2020 shall be Zero Net Energy.
  - "State agencies shall also take measures toward achieving Zero Net Energy for 50% of the square footage of existing State-owned building area by 2025.
  - "To facilitate achieving these goals the following shall apply:
    - "All new state buildings, major renovations, and build-to-suit leases beginning design after October 23, 2017, and as many as possible already begun, shall be designed and built following cost-effective energy efficiency strategies for achieving ZNE identified below.
    - "Departments shall work to improve energy efficiency in existing buildings in the most cost-effective manner to meet or exceed energy efficiency targets established in energy efficiency strategies for achieving ZNE identified below.
    - "Renewable energy generation shall be added to state facilities either onsite, and/or offsite to achieve EO B-18-12 targets by following renewable energy generation prioritization and strategies identified below."

- "Reporting Requirements - Energy use reporting is already required monthly into the ENERGY STAR Portfolio Manager database (see SAM chapter 1815.4). Departments should also provide status on compliance with this policy in their department *Sustainability Road Map*."

- "Definition of Zero Net Energy (ZNE) - Zero Net Energy means that a building or facility is energy efficient, meeting established energy efficiency targets, and consumes no more energy than it produces from clean, renewable resources over the course of a year. Renewable energy generation can occur onsite, and/or offsite, as outlined under "Renewable Energy Generation" below. In further defining ZNE

[1] More information on the DGS Zero Net Energy Program can be found here: https://www.dgs.ca.gov/dgs/Sustainability/ZeroNetEnergy.aspx

for state buildings, the California's governor's office approved the ZNE Source definition for ZNE on state buildings to comply with Executive Order B-18-12 as follows:

ZNE Source – Energy efficient building that produces as much clean renewable energy as it consumes over the course of a year, when accounted for at the energy generation source.

Source energy represents the total amount of raw fuel that is required to operate the building. It incorporates all fuel extraction, transmission, delivery, and production losses. By taking all energy use into account, the ZNE definition provides a complete assessment of energy used in buildings."

In addition to the standards, requirements, and definitions outlined above, the State of California has established energy efficiency targets, expressed as Source Energy Use Intensity (EUI) in kBtu/sf/year, for a range of building types in all 16 California Climate Zones, as described in Figure 9 below.

State Building Type	Source EUI Targets for State Climate Zones***																
	CA Ave	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Conversion Factors for Zones	1.00	0.99	1.01	0.92	0.97	0.95	0.94	0.90	0.95	0.97	0.99	1.06	1.02	1.05	1.06	1.09	1.12
Adult Education - CCC	54	53	55	50	52	51	51	49	51	52	53	57	55	57	57	59	60
College/University	142	141	143	131	138	135	133	128	135	138	141	151	145	149	151	155	159
Data Center	100	99	101	92	97	95	94	90	95	97	99	106	102	105	106	109	112
Fire Station - CALFIRE	65	64	66	60	63	62	61	59	62	63	64	69	66	68	69	71	73
K-12 School	85	84	86	78	82	81	80	77	81	82	84	90	87	89	90	93	95
Laboratory	261	259	264	240	254	248	246	235	248	254	259	277	267	274	277	285	293
Library	114	113	115	105	111	108	107	103	108	111	113	121	116	120	121	124	128
Mixed Use Property (CALFIRE)	49	48	49	45	47	46	46	44	46	47	48	52	50	51	52	53	55
Multi-family Housing	133	132	134	122	129	126	125	120	126	129	132	141	136	140	141	145	149
Non-Refrig. Warehouse	37	37	37	34	36	35	35	33	35	36	37	39	38	39	39	40	41
Office - Average All Types	81	81	82	75	79	77	77	73	77	79	81	86	83	85	86	89	91
Office - Large >50K sq. ft.	128	127	129	118	124	122	120	115	122	124	127	136	131	134	136	140	143
Office - Small <50K sq. ft. - CHP	201	199	203	185	195	191	189	181	191	195	199	213	205	211	213	219	225
Office - Small <50K sq. ft. - CMD	30	30	30	28	29	29	28	27	29	29	30	32	31	32	32	33	34
Office - Small <50K sq. ft. - DMV	162	160	164	149	157	154	152	146	154	157	160	172	165	170	172	177	181
Office - Small <50K sq. ft. - EDD	132	131	133	121	128	125	124	119	125	128	131	140	135	139	140	144	148
Office - Small <50K sq. ft. - Others	114	113	115	105	111	108	107	103	108	111	113	121	116	120	121	124	128
Other - Maintenance DOT/DWR	71	70	72	65	69	67	67	64	67	69	70	75	72	75	75	77	80
Other - Caltrans TMC	567	561	573	522	550	539	533	510	539	550	561	601	578	595	601	618	635
Other - CDFA	249	247	252	229	242	237	234	224	237	242	247	264	254	262	264	272	279
Other - CDFW ecolog. reserve	22	22	22	20	21	21	21	20	21	21	22	23	22	23	23	24	25
Other - CDFW fish hatchery	118	117	119	109	114	112	111	106	112	114	117	125	120	124	125	129	132
Other - CDFW wildlife area	55	54	56	51	53	52	52	50	52	53	54	58	56	58	58	60	62
Other - DPR park structures	27	27	27	25	26	26	25	24	26	26	27	29	28	28	29	29	30
Other - HCD migrant centers	30	30	30	28	29	29	28	27	29	29	30	32	31	32	32	33	34
Other - Education	54	53	55	50	52	51	51	49	51	52	53	57	55	57	57	59	60
Other - Entertainment public	17	17	17	16	16	16	16	15	16	16	17	18	17	18	18	19	19
Other - Lodging/Residential	189	187	191	174	183	180	178	170	180	183	187	200	193	198	200	206	212
Other - Specialty Hospital (DSH)	426	422	430	392	413	405	400	383	405	413	422	452	435	447	452	464	477
Outpatient Rehab/Phys - (DSH)	113	112	114	104	110	107	106	102	107	110	112	120	115	119	120	123	127
Prison/Incarceration - CDCR	187	185	189	172	181	178	176	168	178	181	185	198	191	196	198	204	209
Residence Hall/dorm - CALFIRE	112	111	113	103	109	106	105	101	106	109	111	119	114	118	119	122	125
Senior Care Facility – CalVet	161	159	163	148	156	153	151	145	153	156	159	171	164	169	171	175	180

Figure 9: DGS EUI Targets for Existing State Buildings Pursuing ZNE

4.1.5 CPUC ZNE Residential Stakeholder Group Basecamp Site

The TRC team posted a request for project information on the CPUC's ZNE Residential Stakeholder Group Basecamp site. In addition to additional project information, this request prompted a wide-ranging discussion among the group about strategies and challenges related to designing and building ZNE residential buildings. Topics included energy modeling issues, how to communicate the meaning and value of ZNE to customers, and how ZNE is defined.

Energy modeling was one of the main topics of discussion, with stakeholders noting a variety of challenges and caveats to accurately modeling residential energy use. Because of the nature of residential energy use, and its dependence on the number of occupants, use of various plug loads, and a variety of other factors, actual energy use tends to vary widely from modeled predictions at the level of an individual home. However, as one stakeholder noted, despite limited accuracy at the individual home level, energy modeling can accurately predict performance across larger groups of homes or in multifamily scenarios. Another stakeholder brought up community solar and distributed generation scenarios, where the performance of an individual home would be less important than the performance of the overall community in determining ZNE. A representative from a utility also pointed out that beyond predicting whole-home energy use, models can help to identify problems with individual systems when actual performance differs widely from modeled predictions, if appropriate information is available and included in the model. One stakeholder noted that it is unrealistic to expect energy models to accurately predict individual home performance in the first place. Rather, they suggested that modeling should be focused on the relative effects of different variables and efficiency measures on overall performance. Since occupants and behaviors change over time, buildings (and modeling) should be designed to accommodate that change and perform well under a variety of circumstances. Another stakeholder noted the importance of considering how thermostat setpoint assumptions can impact modeling outcomes, as these can have even greater impacts on energy performance than plug load or occupancy variations.

Another significant topic in the discussion thread related to how to communicate the meaning and value of ZNE homes to customers. Several stakeholders expressed caution in how ZNE is described to customers, emphasizing phrasing such as "zero energy ready" and the importance of refraining from making any promises in regarding energy bills and actual energy performance. On the other hand, one builder emphasized the importance of the realized energy savings for customers, even going so far as to show customers his own personal energy bills as an example of the performance they might expect. A separate builder also indicated that his company has guaranteed zero power usage bills for three years (not including utility fees, and based only on currently installed appliances), and will pay any difference for their customers. Another builder noted that his company emphasizes non-energy benefits such as improved comfort and health, as well as lower energy bills compared to other new homes. Other stakeholders discussed the importance of distinguishing between ZNE as a design rating and actual ZNE performance. Along those same lines, one builder suggested that the CEC should not be using the phrase "Zero Net Energy" for their definition because it is based on TDV. On the other hand, another stakeholder noted that as the Title 24 Energy Standards move closer to ZNE, the burden to “sell” ZNE is reduced because it’s already required in code.

4.2 ZNE Building Design and Performance Data

To supplement the twelve buildings analyzed in the Phase 1 study, TRC obtained additional data on a range of building projects targeting ZNE.

- New Buildings Institute provided a list of 43 California buildings from their Getting to Zero Database through 2017.
- Resource Refocus provided information on six residential ZNE model homes, and six school projects currently in progress under the Prop 39 pilot program.
- Edward Dean, author of the ZNE case study reports described above, identified additional buildings for inclusion in this study, and provided available building performance data.
- Several interviewees identified additional buildings that were not previously included in the study and provided performance data and information where available.

In some cases, multiple sources provided information on the same projects, so there is some overlap between categories. All building data shared in this report has been anonymized.

4.2.1 Overall Findings

TRC gathered data on 94 buildings that are ZNE under various metrics based on the data collection activities described in Section 4.1. A summary of the buildings, including type, square footage, construction type, ZNE Stage, and ZNE Metric Targeted is given in **Some projects used multiple ZNE metrics, so the sum of numbers in parenthesis exceed the total number of buildings in the first column.*

Figure 10 below. Over one-third of buildings assessed were single-family residences, about a quarter were offices, one-fifth were schools, while the remaining buildings were a mix of libraries, multi-family buildings, museums, and other building types.

The buildings contain a mix of New Construction and Renovated buildings, with the majority being New Construction projects. The renovation projects covered both deep retrofits of existing buildings that maintained their original end uses and occupants as well as gut rehabs where the building was repurposed for a different occupant/tenant. The buildings range considerably in size, from the smallest single-family home at 1,200 sqft, up to the largest correctional facility (included under 'Other') at 408,800 sqft. From the data submitted, the ZNE Stage was determined either to be ZNE Design or ZNE Performance. Where the stage was determined to be ZNE Performance, the building was also considered ZNE Design – but not vice versa. In some cases, not enough data was provided to indicate ZNE status one way or the other. The ZNE metric targeted is also included in the table, with site energy the most common, while Source and TDV having a handful of buildings each.

Building Type	Building Square Footage	Construction Type	ZNE Stage	ZNE Metric Targeted*
Library (3)	9,300 – 34,500 sqft	New (3), Renovation (0)	ZNE Design (0), ZNE Performance (2), Insufficient Data (1)	Site (3), Source (0), TDV (0)
Multifamily (4)	6,240 – 19,900 sqft	New (4), Renovation (0)	ZNE Design (1), ZNE Performance (2), Insufficient Data (1)	Site (4), Source (0), TDV (0)
Museum (2)	8,500 – 190,000 sqft	New (2), Renovation (0)	ZNE Design (0), ZNE Performance (2), Insufficient Data (0)	Site (2), Source (0), TDV (0)
Office (23)	4,500 – 88,800 sqft	New (10), Renovation (13)	ZNE Design (2), ZNE Performance (12), Insufficient Data (9)	Site (18), Source (1), TDV (0)
School (22)	2,400 - 141,800 sqft	New (14), Renovation (8)	ZNE Design (5), ZNE Performance (9), Insufficient Data (8)	Site (15), Source (5), TDV (2)
Single family (31)	1,200 – 3,200 sqft	New (31), Renovation (0)	ZNE Design (7), ZNE Performance (22), Insufficient Data (2)	Site (25), Source (1), TDV (6)
Other (9)	3,500 – 408,800 sqft	New (8), Renovation (1)	ZNE Design (0), ZNE Performance (2), Insufficient Data (7)	Site (5), Source (0), TDV (0)
All (94)	1,200 – 408,800 sqft	New (72), Renovation (22)	ZNE Design (15), ZNE Performance (51), Insufficient Data (28)	Site (72), Source (7), TDV (8)

**Some projects used multiple ZNE metrics, so the sum of numbers in parenthesis exceed the total number of buildings in the first column.*

Figure 10. Summary of Overall Findings

4.2.2 Summary of Data Availability by ZNE Type

A summary of the data available is shown in Figure 11 for buildings in the Design Phase and in Figure 12 for buildings in the Performance Phase shows that the majority of buildings assessed do not actually perform as

ZNE, but do have ultra-efficient performance, or are near-ZNE. For most of these buildings, third-party data (i.e. utility bills) was not available, instead data was mostly self-reported in the form of spreadsheets.

ZNE Type	Annual Simulation Results	Hourly/ Monthly Simulation Results	Solar PV Generation/ Estimation
Ultra-Efficient Design	4	3	4
ZNE Design	11	10	11

Figure 11. Summary of data available for buildings in Design Phase

ZNE Type	Annual Energy Use	Monthly Bills	Summary Spreadsheets of Data Only	Building Commissioning/ Occupancy
Ultra-Efficient Performance	35	5	30	0
ZNE Performance	16	12	4	0

Figure 12. Summary of data available for buildings in Performance Phase

4.2.3 Summary of Missing Data

Figure 13 shows the number of buildings for which data is available, separated by Building Type. As seen in the figure, there were data gaps across all building types. Commissioning reports are lacking for almost every building assessed. Note that buildings without gas use reported contains both buildings with no on-site gas usage and those buildings which have on-site gas usage but did not report it or reported equivalent kWh

Data Type	Metric	All (n=94)	Library	Multi-family	Museum	Office	School	Single-family	Other
ZNE Target	Site/Source/TDV	94	3	4	2	23	22	31	9
Modelled Energy Use	kWh	58	2	3	1	11	13	28	0
	Therms	31	0	2	0	1	3	25	0
	Site kBtu	50	2	3	1	11	10	23	0
	Source kBtu	49	2	3	1	10	10	23	0
Monitored Energy Use	kWh	56	3	2	2	14	10	22	3
	Therms	13	1	1	0	3	4	3	1
	Site kBtu	57	3	2	2	12	10	22	6
	Source kBtu	52	3	2	2	12	9	22	2
Modeled Energy Generation	kWh	43	1	2	1	6	8	25	0
	Site kBtu	41	1	2	1	7	5	25	0
	Source kBtu	40	1	2	1	6	5	25	0
Monitored Energy Generation	kWh	54	2	2	2	12	10	23	3
	Site kBtu	57	2	2	2	11	10	23	7
	Source kBtu	52	2	2	2	11	9	23	3
Commissioning Report Available	-	8	0	0	0	2	5	0	1

Figure 13. Number of Buildings for which Data is Available

4.2.4 Retrofit Project Energy Analysis for ZNE

PG&E and Resource Refocus provided information on six school projects participating in the Prop 39 pilot program, pursuing efficiency measures in preparation for potential ZNE retrofits. Based on initial reports for each of the projects, four of the schools are targeting a Source ZNE metric, and two are targeting a 2013 TDV metric and Site electric ZNE.

As with the residential projects described below in section 4.2.1, TRC conducted an analysis comparing Site ZNE and TDV ZNE. As of this writing, models were only available for three of the six projects. The graphs below in Figure 14 show the results for those three projects, including the baseline building in dark blue, the proposed efficiency measures in light blue, and the proposed PV generation in green. The proposed PV generation shown in the graphs below reflects the best information available in the initial draft reports for these projects, which may be based on assessment of potential roof area available for a PV array, and may not reflect the actual PV generation needs for the project. Schools 1 and 3 are targeting a Source ZNE metric, while School 2 is targeting a TDV ZNE metric, as well as Site Electric ZNE. As the graphs below illustrate, the proposed design for School 2 does not meet the Site kBtu metric but does meet the TDV metric for all three versions. Schools 1 and 3 meet both the Site metric and all three TDV metrics as well.

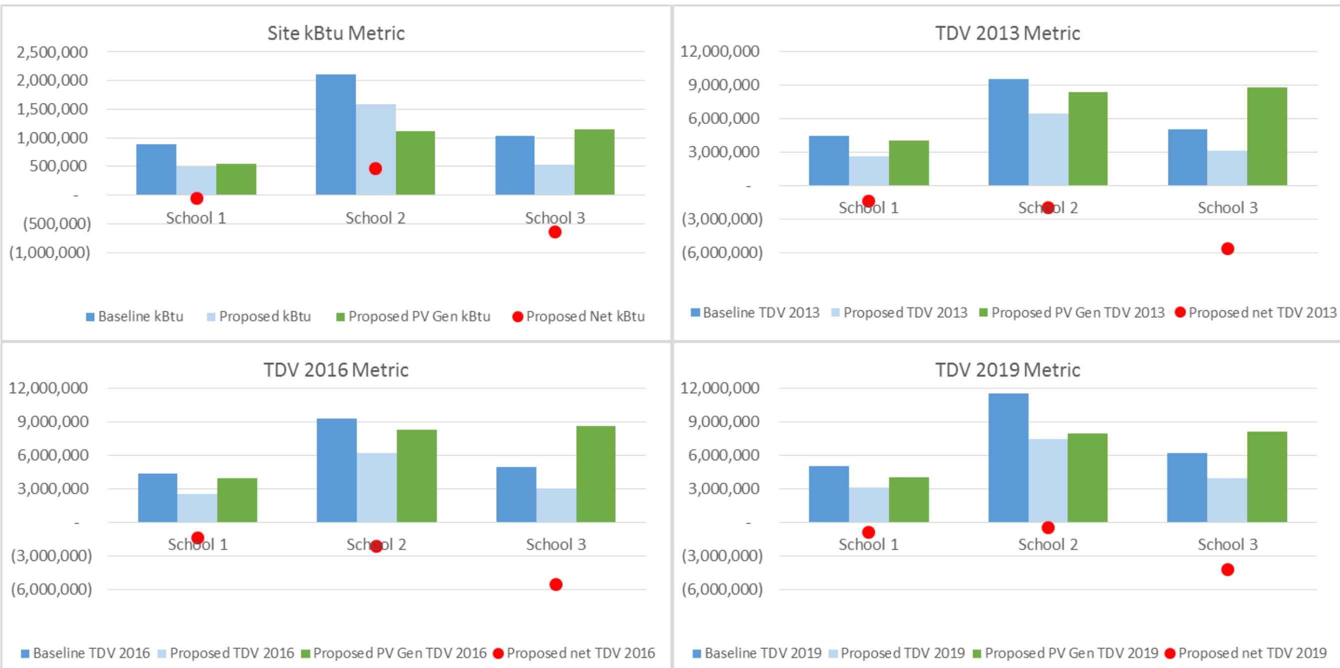

Figure 14: Prop 39 Projects TDV Metric Analysis Results Graphs

The graphs below in Figure 15 compare the Site ZNE and Source ZNE metrics, as well as showing the relative electricity and natural gas use at each site. As noted above, Schools 1 and 3 are targeting a Source ZNE metric, and as these graphs show, both buildings achieve ZNE using both the Site and Source metrics. By contrast, School 2 is targeting a TDV metric, as well as Site Electric ZNE. As Figure 15 shows, School 2's PV generation does exceed the site electricity use, meeting the Site Electric ZNE goal. However, School 2 also meets a Source ZNE metric as shown below.

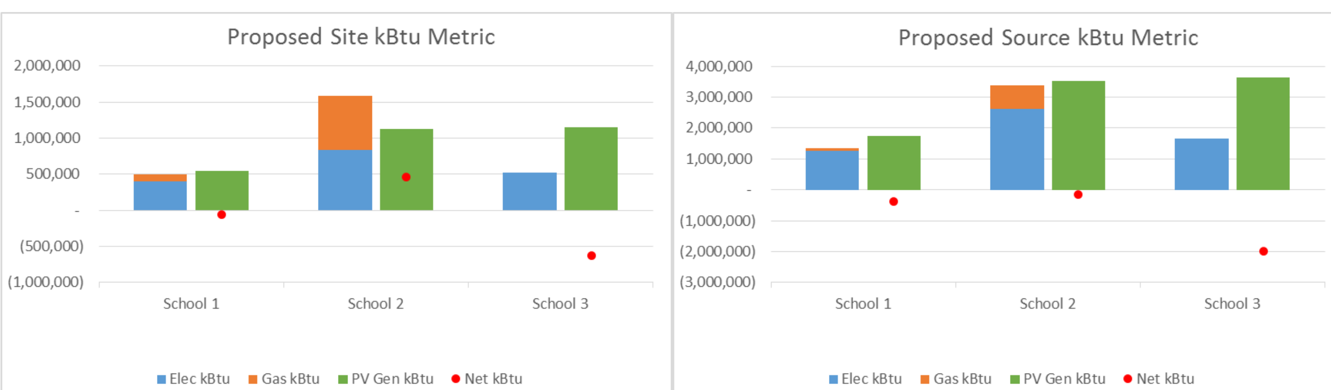

Figure 15: Prop 39 Projects Site versus Source Metrics

4.2.5 ZNE Design - Difference between Energy Use and Energy Generation

TRC analyzed the difference between Modeled Energy Use and Modeled Energy Generation as determined in the Design Phase. Figure 16 presents modeled energy generation versus modeled energy use, with different colors to distinguish Building Type. Values above the solid line indicate that the modeled energy generation is greater than the modeled energy use.

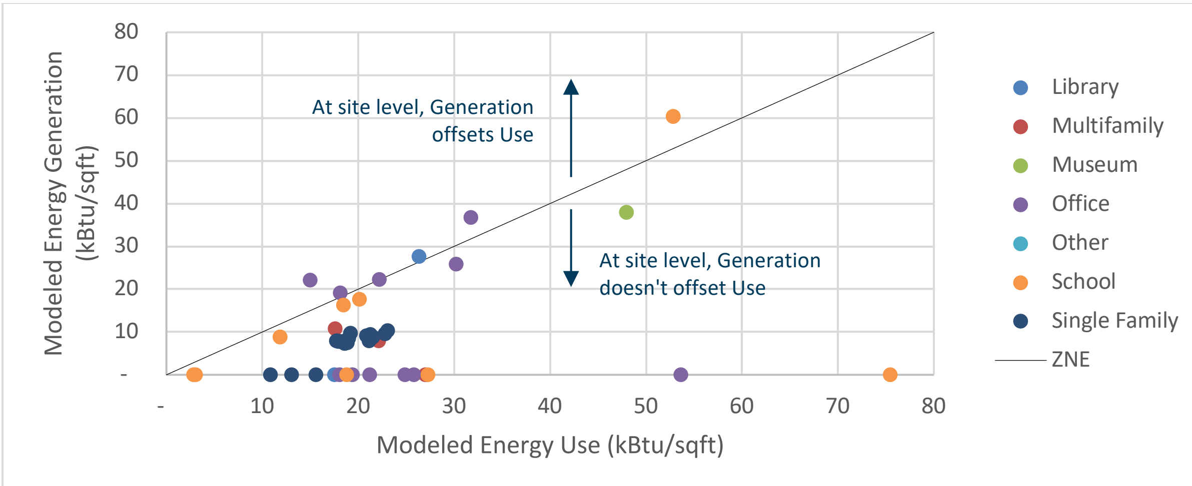

Figure 16. Modeled energy generation versus modeled energy use

Considering the magnitude of the modeled energy, Figure 17 presents the percentage difference between the modeled energy use and modeled energy generation, plotted against the modeled energy use, with different colors to distinguish Building Type. A positive value on the y-axis indicates that the modeled energy use is greater than the modeled energy generation. Figure 18 is a similar chart, with a close-up of buildings with low annual energy usage, which are primarily single-family. Most of the single-family homes often have modeled energy use that is higher than modeled energy generation, whereas for larger buildings the opposite is generally true.

This does not necessarily mean that the residential buildings are not ZNE, but rather that the choice of ZNE metrics such as TDV or source result in energy generation systems that do not offset the total modeled energy use at the site kWh level. One other factor is that TRC did not receive independent confirmation of the PV system size for these building designs and had to rely on the PV size modeled in the energy analysis or mentioned as a recommendation on a consultant report.

On the other hand, most larger buildings are designed with site energy in mind and tend to oversize the renewable systems to accommodate potential energy uses in operation that may not have been anticipated at the design stage. The one notable exception is the museum which is one of the largest buildings that did not size the photovoltaic system to offset the entire facility energy use.

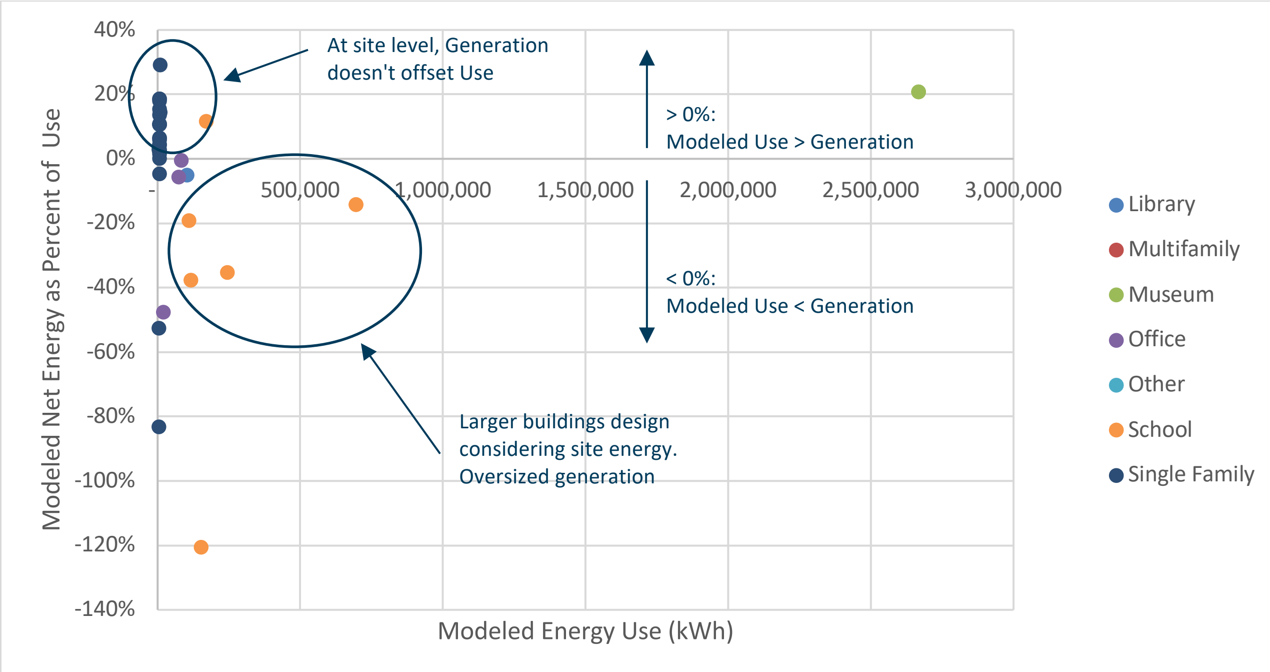

Figure 17. Modeled Net Energy as a Percent of Energy Use Versus Modeled Energy Use

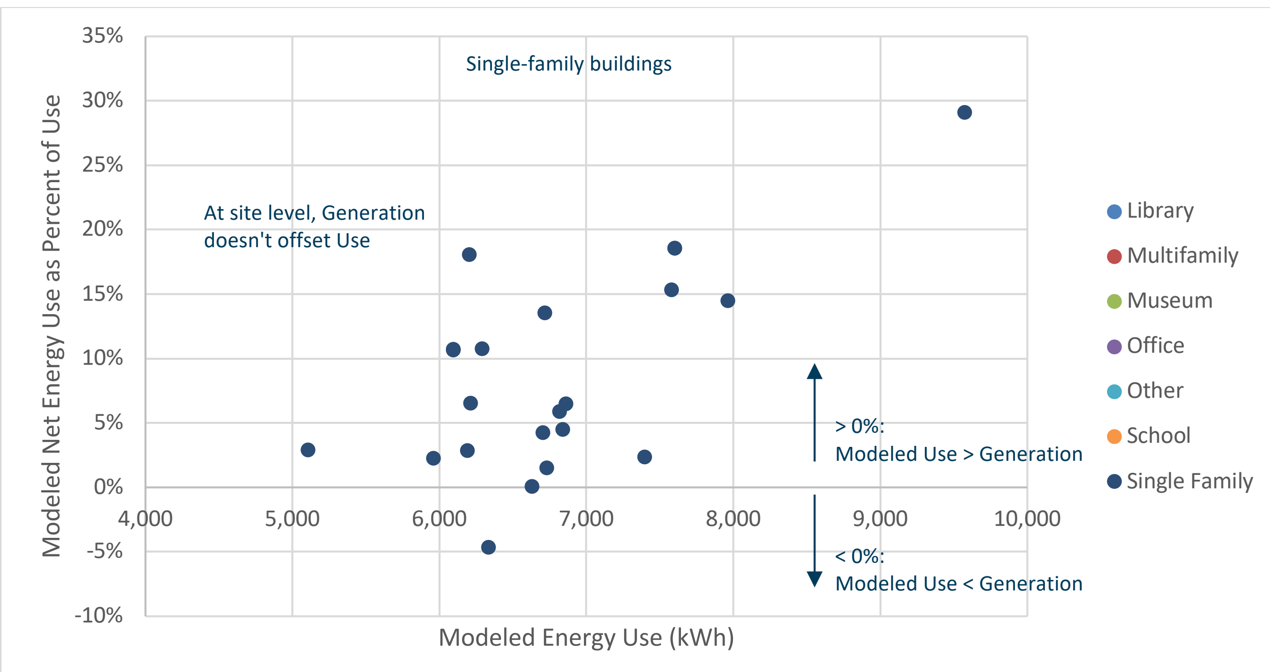

Figure 18. Modeled Net Energy as a Percent of Energy Use Versus Modeled Energy Use, Focus on Single-family Homes

Figure 19 shows the average percent difference between modeled energy use and modeled energy generation, separated by Building Type as well as by modeled annual energy usage. Schools and Offices have the largest spread of Annual Energy use, as well as the largest spread of the difference between modeled energy use and modeled energy generation.

		Average % Difference Between Modeled Energy Use and Modeled Energy Generation						
Annual Energy Use (kWh)	# Buildings	Library	Multi-family	Museum	Office	Other	School	Single- family
1,000 – 9,999	29	-	-	-	-	-	-	-

10,000 – 99,999	11	0%	-	-	-11%	-	0%	-
100,000 – 999,999	17	-5%	-	-	0%	-	-23%	-
1,000,000 +	3	-	-	21%	-	-	0%	-

Figure 19. Average % difference between modeled energy use and modeled energy generation

As seen in Figure 17, there are some buildings for which the modeled energy generation is significantly higher than the modeled energy use, particularly in larger buildings. These buildings can be considered to have PV systems that are 'oversized'. Figure 20 shows the average percent difference between modeled energy use and modeled energy generation for only buildings with oversized PV systems.

		Average % Difference Between Modeled Energy Use and Modeled Energy Generation						
Annual Energy Use (kWh)	# Buildings	Library	Multi-family	Museum	Office	Other	School	Single-family
1,000 – 9,999	3	-	-	-	-	-	-	-47%
10,000 – 99,999	3	-	-	-	-18%	-	-	-
100,000 – 999,999	7	-5%	-	-	-	-	-40%	-

Figure 20. Average % difference: modeled energy use vs. generation, buildings with oversized PV only

Summary statistics of modeled energy use, modeled energy generation, and net energy use were calculated to determine the spread of values, and are represented in Figure 21. Minimum values, maximum values, and average values are shown, separated by Building Type. As noted above, Schools and Offices have the largest spread of values.

	Modeled Energy Use			**Modeled Energy Generation**			**Net Energy Use**		
	Min	Max	Average	Min	Max	Average	Min	Max	Average
Library	47,711	104,000	75,855	109,200	109,200	109,200	(5,200)	(5,200)	(1,733)
Multi-family	5,806	52,206	35,787	40,740	62,870	51,805	(57,064)	11,466	(11,400)
Museum	2,668,019	2,668,019	2,668,019	2,113,713	2,113,713	2,113,713	554,306	554,306	369,537
Office	19,624	825,204	202,748	28,980	954,800	214,823	(129,596)	(367)	(6,595)
Other	-	-	-	-	-	-	-	-	-
School	47,711	1,549,210	371,160	131,499	794,890	343,962	(185,122)	69,658	(17,048)
Single-family	3,910	9,574	6,679	4,960	7,221	6,167	(3,250)	2,786	305
All	3,910	2,668,019	220,143	4,960	2,113,713	199,533	(185,122)	554,306	5,940

Figure 21. Summary modeled energy use, energy generation, and net energy use

4.2.6 ZNE Performance - Difference between Energy Use and Energy Generation

TRC evaluated the difference between monitored energy use and monitored energy generation determined in the Performance phase. Figure 22 presents the percentage difference between the monitored energy use and monitored energy generation, plotted against the monitored energy use, with different colors to distinguish Building Type. A positive value on the y-axis indicates that the monitored energy use is greater than the monitored energy generation. Figure 23 is a similar chart, with a close-up of buildings with lower annual energy usage. From the figures it is clear that there is a large spread in the difference between monitored energy use and monitored energy generation, larger than that seen from the modeling results presented in Figure 17 and Figure 18.

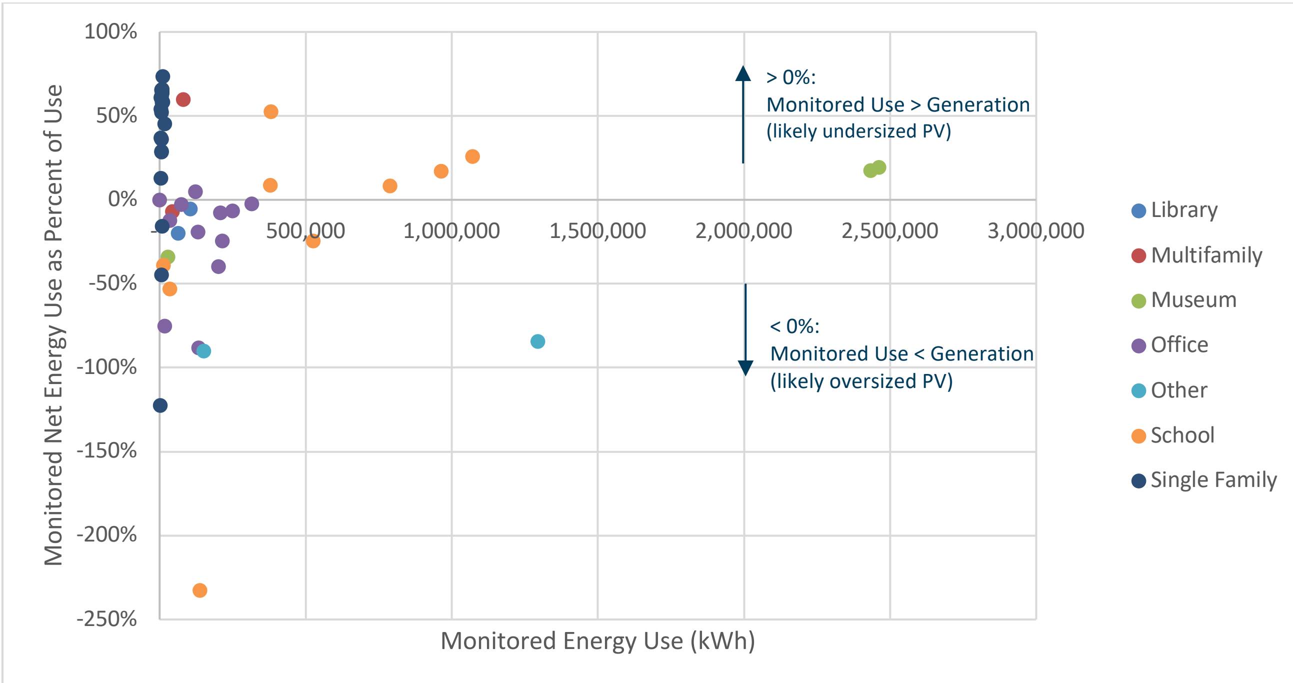

Figure 22. Monitored Net Energy as a Percent of Energy Use Versus Modeled Energy Use

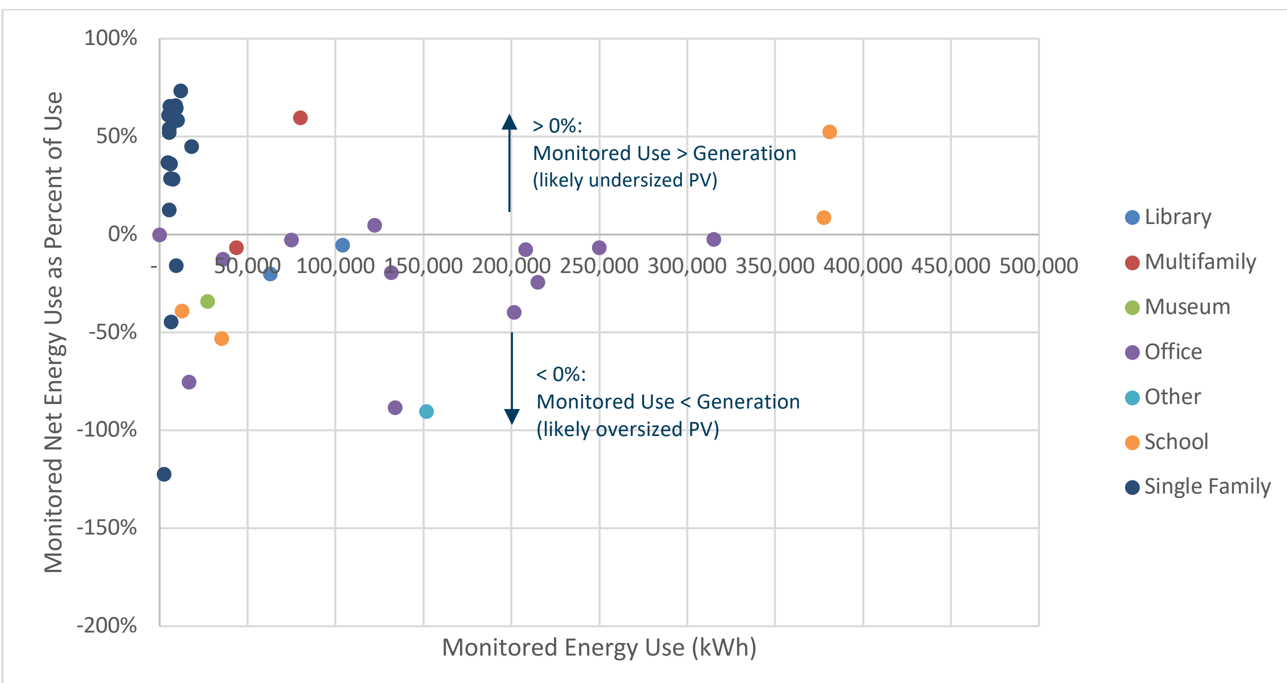

Figure 23. Monitored Net Energy as a Percent of Energy Use Versus Modeled Energy Use, Focus on Smaller-load Buildings

Figure 24 shows the average percent difference between monitored energy use and monitored energy generation, separated by Building Type as well as by monitored annual energy usage. All building types have a large spread of the difference between monitored energy use and monitored energy generation.

		Average % Difference Between Monitored Energy Use and Monitored Energy Generation						
Annual Energy Use (kWh)	# Buildings	Library	Multi-family	Museum	Office	Other	School	Single-family
1,000 – 9,999	20	-	-	-	-	0%	-	30%
10,000 – 99,999	14	-20%	26%	-34%	-18%	-	-46%	59%
100,000 – 999,999	21	-3%	-	-	-20%	-90%	-19%	-
1,000,000 +	4	-	-	18%	-	-85%	26%	-

Figure 24. Average percent difference between monitored energy use and monitored energy generation

Summary statistics of monitored energy use, monitored energy generation, and net energy use were calculated to determine the spread of values, and are represented in Figure 25. Minimum values, maximum values, and average values are shown, separated by Building Type.

	Monitored Energy Use			Monitored Energy Generation			Net Energy Use		
	Min	Max	Average	Min	Max	Average	Min	Max	Average
Library	62,850	418,869	195,306	75,353	109,900	92,627	(12,503)	(5,700)	(6,068)
Multi-family	43,806	79,926	61,866	32,328	46,788	39,558	(2,982)	47,598	11,154
Museum	27,341	2,460,950	1,640,614	36,700	2,006,611	1,344,050	(9,359)	472,110	296,563
Office	16,705	315,066	147,760	29,275	322,994	175,964	(118,213)	15,538	(13,642)
Other	6,632	1,295,204	484,486	14,648	2,389,738	897,609	(1,094,534)	(136,819)	(246,271)
School	12,869	1,071,237	491,372	17,890	799,390	423,578	(321,760)	365,238	42,451
Single-family	2,558	18,116	7,617	1,918	10,849	4,643	(3,129)	8,766	2,115
All	2,558	2,460,950	257,926	4,960	2,113,713	199,533	(185,122)	554,306	5,940

Figure 25. Summary statistics on monitored energy use, energy generation and net energy use

4.2.7 ZNE Performance – Difference between Energy Use Predicted versus Actual

The Phase 1 report for this project had highlighted the fact that the predicted/modeled energy use of the building may or may not match the actual/monitored energy use of the building. In Phase 2, TRC expanded on this analysis by looking in detail at various building types where TRC collected both the predicted and actual energy use of the building. Note that this sub-section only deals with the building energy use without accounting for any of the energy generated or exported from the building site to the grid.

Figure 26 shows a scatter plot of the measured EUI versus the modeled EUI for the building summarized above separated by the building types – Residential Single Family, Residential Multifamily, Office, Library, Museum, Schools and Other. As seen in the plot, there is no direct correlation between measured versus predicted energy use for almost all the building types. Energy use is either higher or lower than predicted for each building and building type, the reasons for which are varied and are outlined in the Findings section of this report.

Figure 27 presents the percentage difference between the monitored energy use and modeled energy use, plotted against the monitored energy use, with different colors to distinguish building type. A positive value on the y-axis indicates that the monitored energy use is greater than the modeled energy use (building uses more energy than expected). Figure 28 is a similar chart, with a close-up of buildings with low annual energy usage, which are primarily single-family. For the buildings with low annual energy usage, the difference between monitored energy use and modeled energy use tends to increase with increasing annual energy usage.

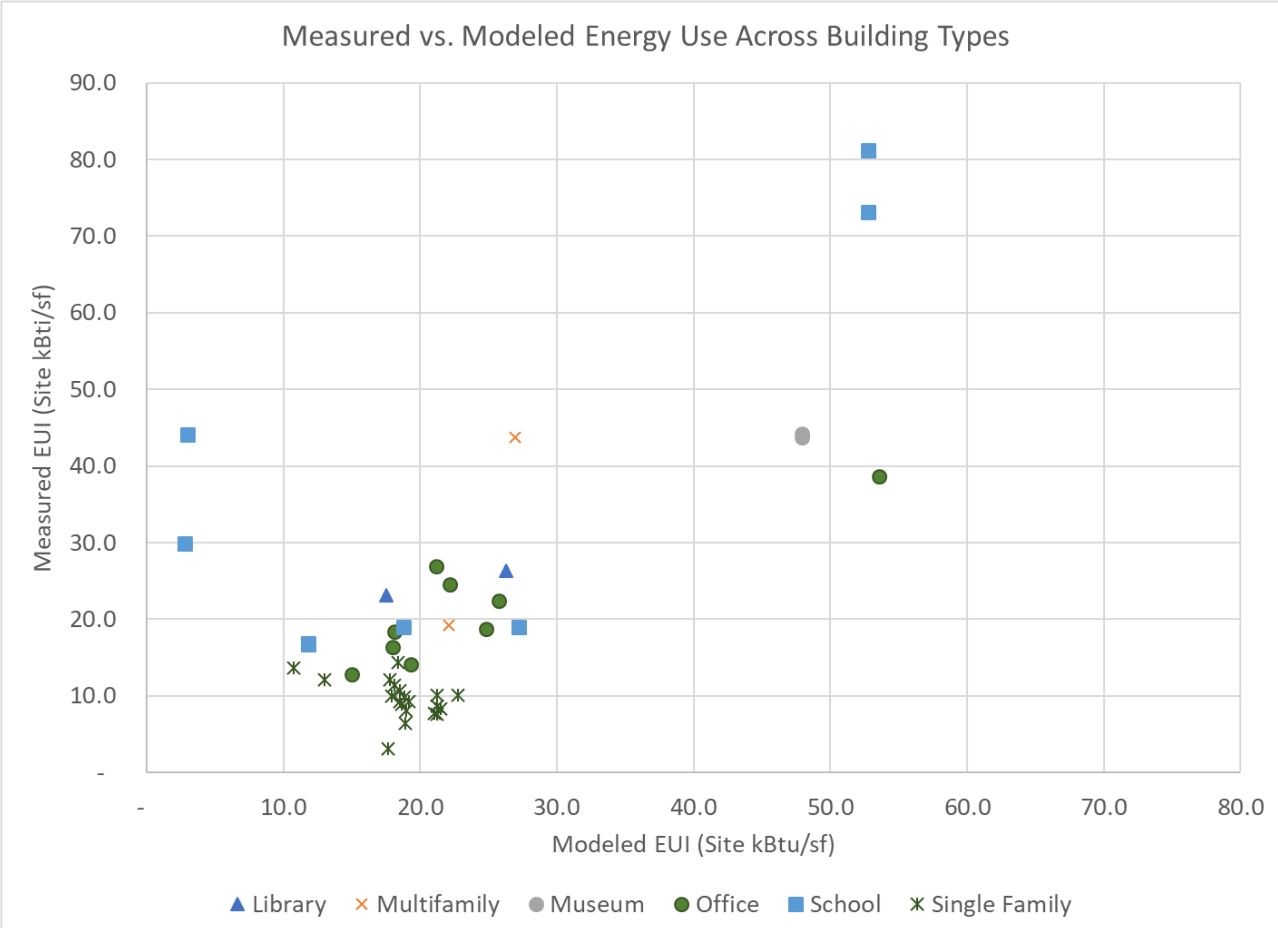

Figure 26. Comparing Measured versus Modeled Energy Use by Building Type

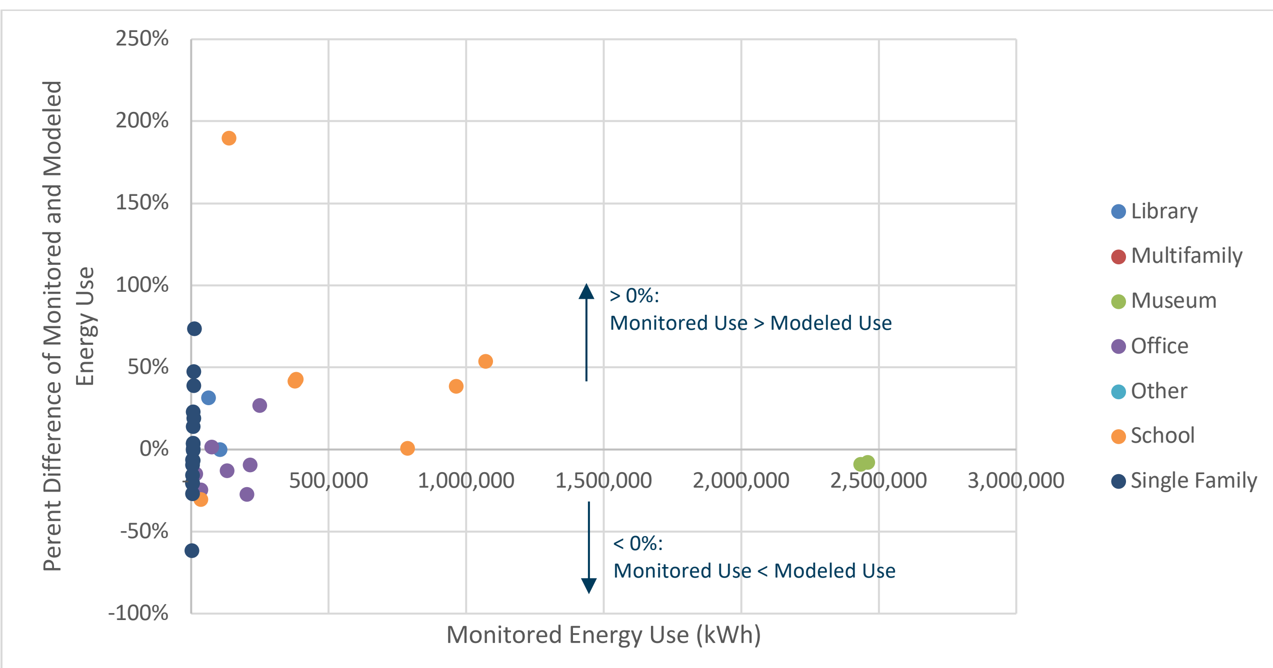

Figure 27. Difference between Monitored and Modeled Energy Use versus Monitored Energy Use

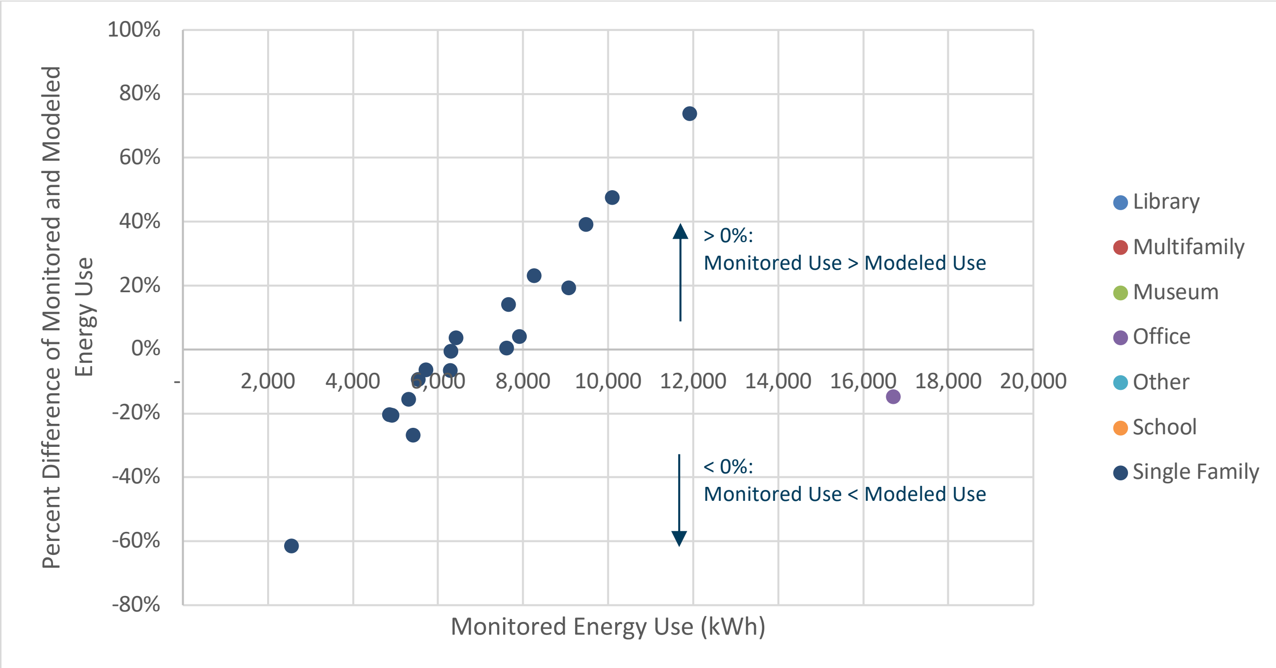

Figure 28. Difference between Monitored and Modeled Energy Use versus Monitored Energy Use, Focus on Single-Family Homes

Figure 29 shows the average percent difference between monitored energy use and modeled energy use, separated by building type as well as by modeled annual energy usage. Schools and Offices have the largest spread of annual energy use, as well as the largest spread of the difference between modeled energy use and modeled energy generation.

		Average % Difference Between Monitored Energy Use and Modeled Energy Use						
Annual Energy Use (kWh)	# Buildings	Library	Multi-family	Museum	Office	Other	School	Single-family
1,000 – 9,999	20	-	-	-	-	0%	-	-3%
10,000 – 99,999	14	32%	0%	0%	-8%	-	-15%	40%
100,000 – 999,999	20	0%	-	-	-3%	0%	39%	-
1,000,000 +	4	-	-	-8%	-	0%	54%	-

Figure 29. Average percent difference between monitored energy use and modeled energy use

4.2.8 ZNE Performance – Difference between Energy Generation Predicted vs Actual

Figure 30 presents the percentage difference between the monitored energy generation and modeled energy generation, plotted against the monitored energy generation, with different colors to distinguish by building type. A positive value on the y-axis indicates that the monitored energy generation is greater than the modeled energy generation. Figure 31 is a similar chart, with a close-up of buildings with low annual energy generation, which are primarily single-family. Most of the single-family homes often have modeled energy generation that is higher than monitored energy generation, whereas for larger buildings there is not generally much discrepancy between the two values.

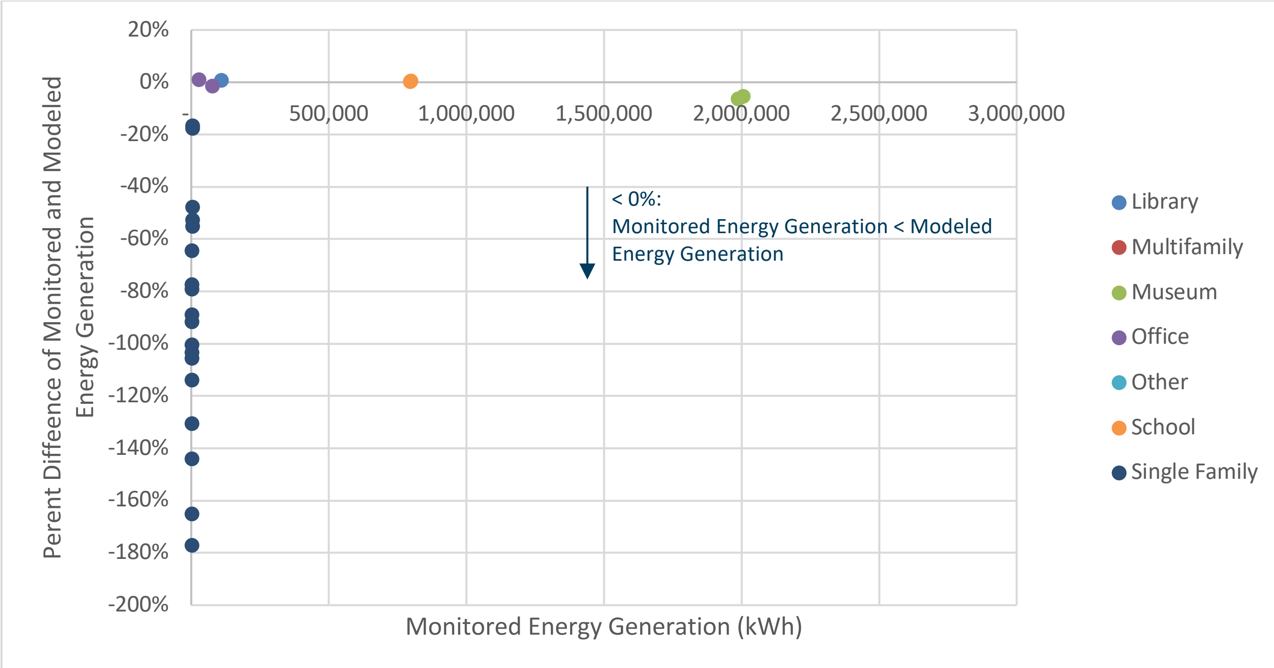

Figure 30. Difference Between Monitored and Modeled Energy Generation versus Monitored Energy Generation

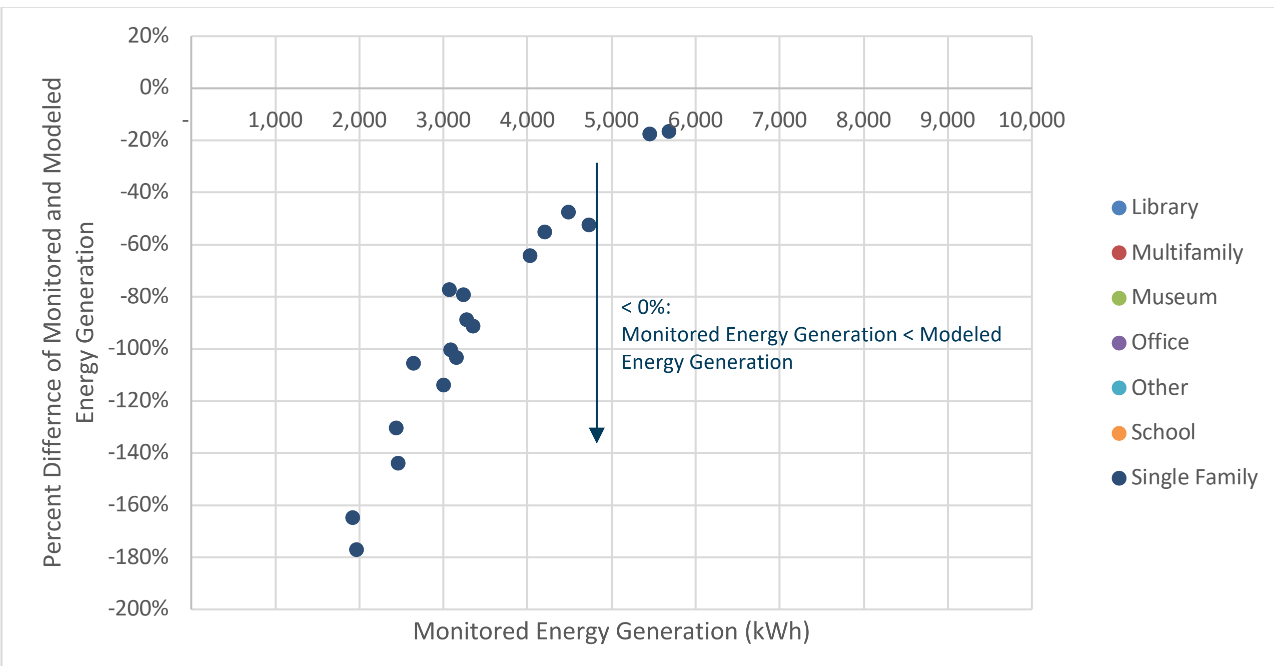

Figure 31. Difference between Monitored and Modeled Energy Generation versus Monitored Energy Generation, Single-Family Homes

Figure 32 shows the average percent difference between modeled energy generation and modeled energy generation, separated by Building Type as well as by modeled annual energy usage. Single-family homes have the largest spread of the difference between monitored energy generation and modeled energy generation.

Average % Difference Between Monitored Energy Generation and Modeled Energy Generation								
Annual Energy Generation (kWh)	# Buildings	Library	Multi-family	Museum	Office	Other	School	Single-family
1,000 – 9,999	22	-	-	-	-	-	-	-74%
10,000 – 99,999	12	0%	0%	0%	0%	0%	0%	0%
100,000 – 999,999	20	1%	-	-	0%	0%	0%	-
1,000,000 +	3	-	-	-6%	-	0%	-	-

Figure 32. Average percent difference between modeled energy generation and modeled energy generation

4.2.9 ZNE Community versus ZNE Building

TRC reviewed several projects with multiple buildings, some where the individual buildings had ZNE claims and in other cases where the overall project was claiming ZNE status. One example project is a community of ZNE homes with energy models and monitored data on 20 homes intended to be ZNE, similar in terms of building and occupancy characteristics. The modeled and monitored energy use and energy generation are presented below in Figure 33 and Figure 34. From the figures several observations can be made. The first is that the monitored energy generation falls well below the modeled generation for nearly every home. For about half of the homes, the monitored energy use exceeds the modeled energy use, whereas in the other half, the opposite is true. While having each home independently be ZNE may have been a goal, a perhaps larger goal may be to have the community be ZNE. Comparing the cumulative monitored energy use to the cumulative monitored energy generation shows that across the community, the energy generated only meets about half of the energy use.

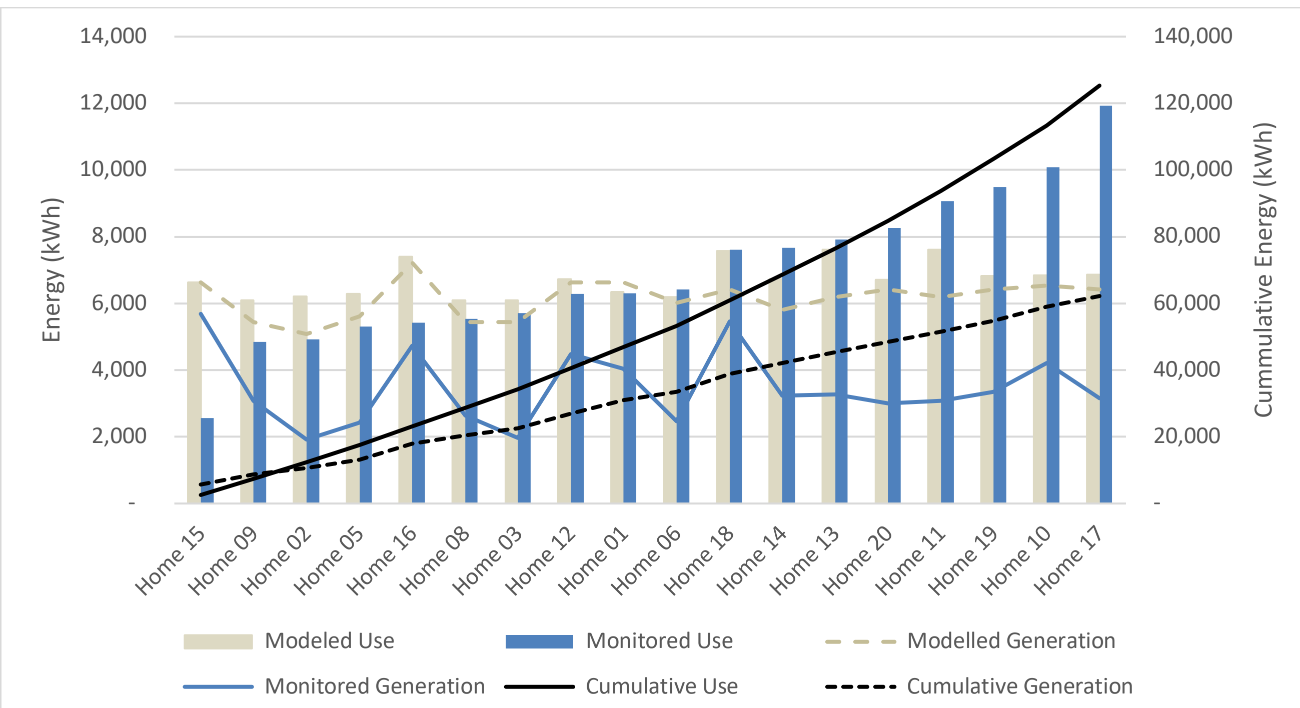

Figure 33. Modeled and Monitored Energy Use and Generation from a Community of ZNE Homes

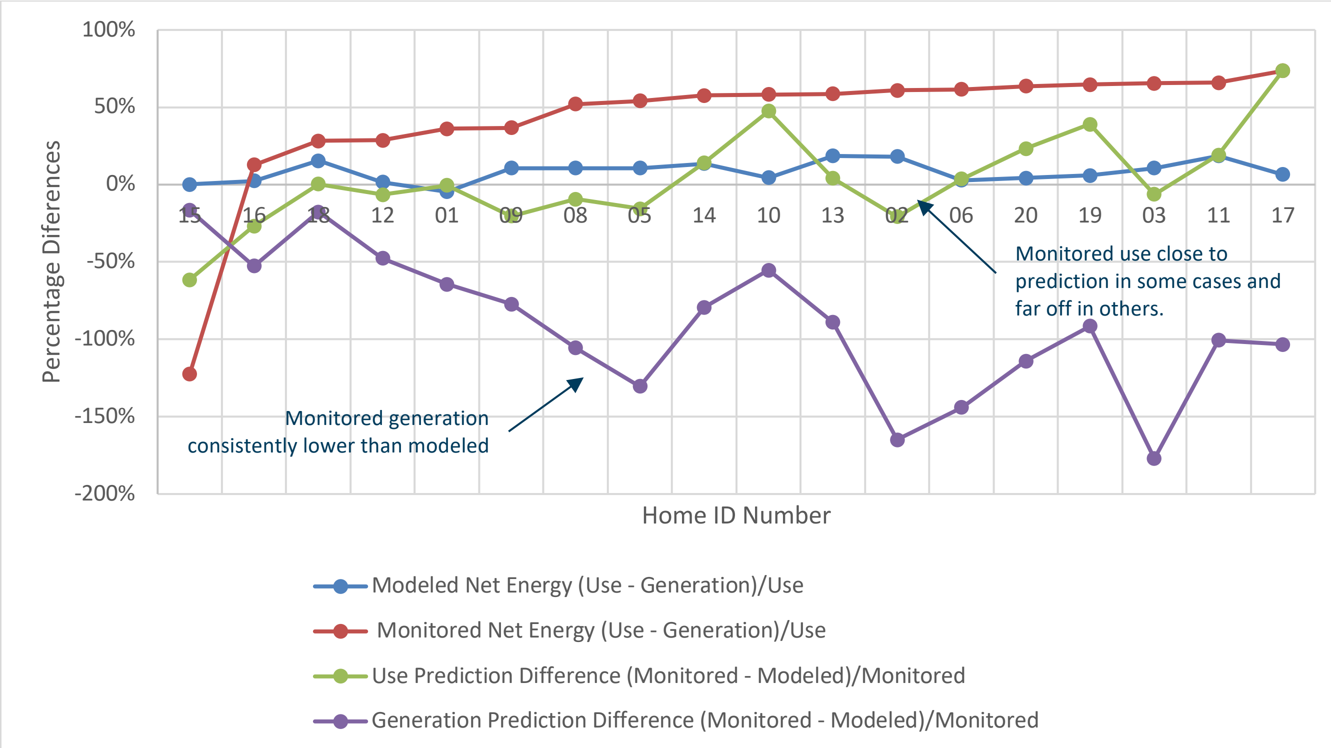

Figure 34. Net Energy Use from a Community of ZNE Homes

4.2.10 Impact of TDV Updates by Code Cycle

One of the concerns with the TDV metric as a basis for ZNE (either by itself or as part of the Energy Design Rating) is that the underlying values for TDV change by each code cycle. TRC reviewed several residential buildings for the impact of changing TDV values on ZNE claims. PG&E and Resource Refocus provided TRC with proposed energy models for six residential builder demonstration projects targeting ZNE status using the 2013 TDV metric (one house was also targeting a Source ZNE metric). At the time of this writing, all six projects have been built and are being monitored, but results are not yet available.

TRC compared the status of each proposed house using four different metrics for establishing ZNE status. The first metric, Site kBtu, simply compares the total annual kBtu value of all energy consumed on site (electricity and natural gas, where applicable) to the total annual kBtu value of the PV generation. The other three metrics use the TDV multipliers for the three most recently available versions of the California Building Energy Efficiency Standards (2013, 2016, and 2019), comparing the annual TDV values of all energy consumed on site to the annual TDV value of the PV generation.

To determine the annual TDV values, TRC multiplied the hourly outputs for energy use and generation from the energy models by the corresponding TDV multipliers from each code version, and for the appropriate California Climate Zone for each site. Figure 35, below, illustrates the results of this analysis, and the differences between a site metric that uses a uniform value for all energy, and a TDV metric that assigns higher or lower value to energy use and generation depending on the time of year and day.

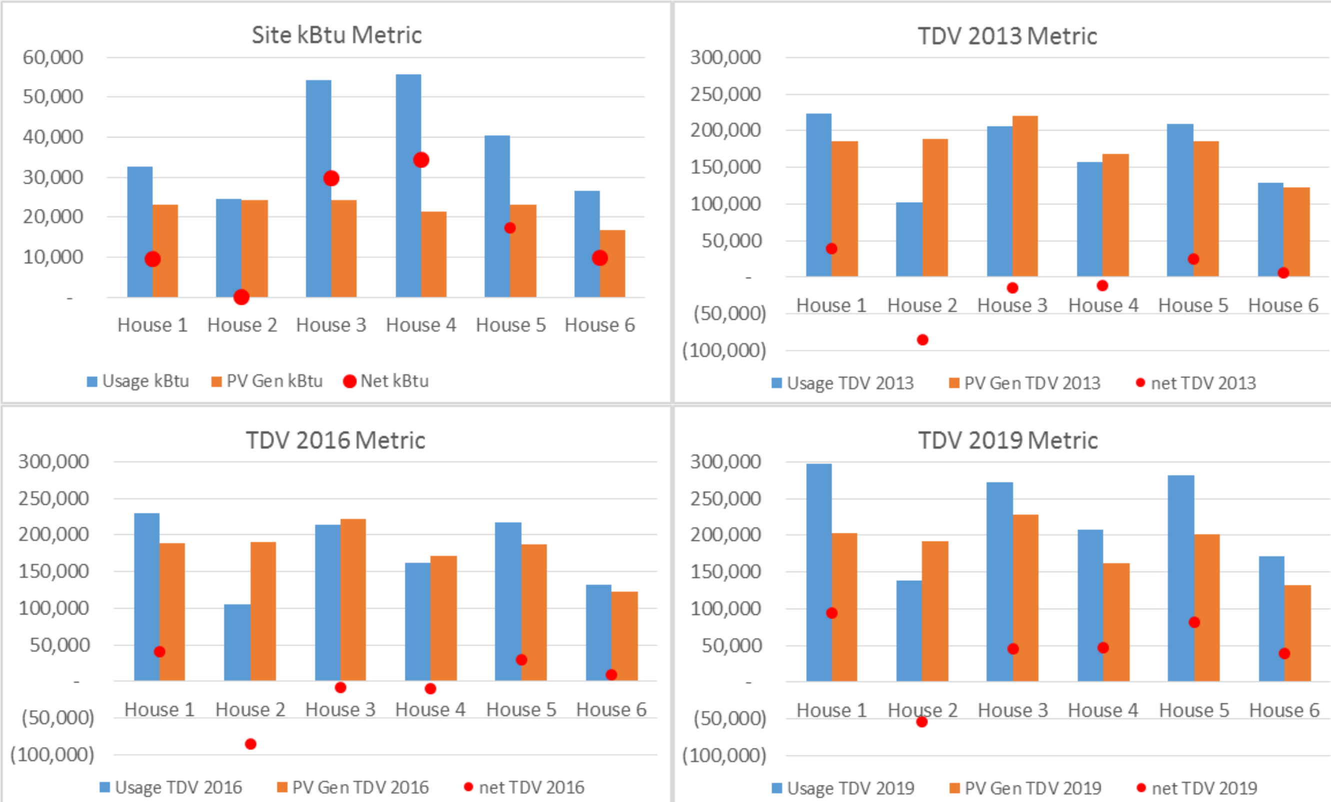

Figure 35: Residential Project TDV Metric Analysis Results Graphs

Using the site metric, only House 2 gets close to achieving ZNE status, but using TDV 2013 metric Houses 2, 3, and 4 all achieve ZNE, House 6 is just shy of ZNE, and Houses 1 and 5 get much closer to ZNE than with the site metric. As TDV values change from 2013, 2016, and 2019 Title 24, the value of generation reduces, and the value of energy use increases as peak demand times shift later in the day. As a result, only House 2 achieves ZNE status under the TDV 2019 metric. These results are also conveyed numerically in the table in Figure 36, below.

Using the TDV 2013 metric, three of the six achieve ZNE, but using the TDV 2019 metric, only one project does. This is likely to be an ongoing challenge going forward as the state's energy mix shifts toward more renewables, and as TDV values update with each subsequent iteration of the Standards.

	Net kBtu	ZNE Site?	Net TDV 2013	ZNE TDV 2013?	Net TDV 2016	ZNE TDV 2016?	Net TDV 2019	ZNE TDV 2019?
House 1	9,509	No	38,435	No	40,946	No	93,601	No
House 2	158	No	(85,725)	Yes	(85,300)	Yes	(54,074)	Yes
House 3	29,775	No	(13,815)	Yes	(8,646)	Yes	44,997	No
House 4	34,252	No	(11,354)	Yes	(10,408)	Yes	46,284	No
House 5	17,135	No	24,736	No	29,673	No	80,851	No
House 6	9,750	No	6,524	No	9,161	No	39,278	No

Figure 36: Residential Project TDV Metric Analysis Results Table

A similar analysis was done on the new community of ZNE homes recently built in California, analyzed above in 4.2.9. The 20 homes analyzed had 17 different associated energy models. Figure 37 shows the predicted energy use for each home model, as provided from a separate study of these homes, and a ZNE metric analysis. These projects used the Home Energy Rating System (HERS) Index score to predict ZNE status. As shown in the table, though some of the homes have positive HERS scores (indicating they are not ZNE), the average for all 20 homes was a HERS score of -3, suggesting that the community should be ZNE. However, predicted net energy use for each model show that only one of the home models would meet a site electric ZNE metric, and none would meet a combined ZNE site metric when gas use is included.

Project	HERS Score Predicted	ZNE based on HERS Score?	Net kWh	ZNE Site Elec?	Net Therms	Net kBtu	ZNE Site?
Model 01	-2	Yes	698	No	57	8,280	No
Model 02	-9	Yes	208	No	57	7,676	No
Model 03	-6	Yes	254	No	57	7,797	No
Model 04	0	Yes	1,074	No	57	10,669	No
Model 05	5	No	1,419	No	57	11,619	No
Model 06	-5	Yes	649	No	57	9,123	No
Model 07	0	Yes	928	No	57	10,047	No
Model 08	-5	Yes	489	No	57	8,601	No
Model 09	-1	Yes	1,003	No	57	10,223	No
Model 10	-7	Yes	471	No	57	8,728	No
Model 11	-4	Yes	377	No	57	8,199	No
Model 12	-3	Yes	600	No	57	8,494	No
Model 13	-4	Yes	556	No	57	8,922	No
Model 14	-7	Yes	456	No	57	10,499	No
Model 15	-12	Yes	-297	Yes	57	5,879	No
Model 16	2	No	1,292	No	66	11,116	No
Model 17	2	No	297	No	66	10,994	No
Community Average	-3	Yes	710	No	59	9,227	No

Figure 37. ZNE community predicted energy use and ZNE Metric Analysis Results Table

Figure 38 shows the TDV analysis TRC performed for the different home models in this community. Though there were some discrepancies between the energy model results TRC found and the values shown in Figure 37, above, the results were all within 5%, and the discrepancies did not impact whether each model would have met the given ZNE metric.

Project	Net kBtu	ZNE Site?	Net TDV 2013	ZNE TDV 2013?	Net TDV 2016	ZNE TDV 2016?	Net TDV 2019	ZNE TDV 2019?
Model 01	8,280	No	86	No	3,500	No	48,411	No
Model 02	7,676	No	-6,544	Yes	-3,429	Yes	39,171	No
Model 03	7,797	No	2,400	No	7,046	No	58,246	No
Model 04	10,669	No	14,885	No	18,987	No	70,260	No
Model 05	11,619	No	21,203	No	24,673	No	72,044	No
Model 06	9,123	No	2,632	No	6,069	No	52,726	No
Model 07	10,047	No	11,568	No	14,919	No	61,364	No
Model 08	8,601	No	1,380	No	4,797	No	50,791	No
Model 09	10,223	No	9,015	No	12,178	No	57,593	No

Model 10	8,728	No	-478	Yes	3,429	No	55,174	No
Model 11	8,199	No	4,987	No	9,498	No	61,755	No
Model 12	8,494	No	3,981	No	8,137	No	59,889	No
Model 13	8,922	No	4,144	No	7,998	No	58,293	No
Model 14	10,499	No	11,965	No	15,688	No	65,356	No
Model 15	5,879	No	-9,991	Yes	-5,992	Yes	40,062	No
Model 16	11,116	No	10,551	No	14,314	No	68,847	No
Model 17	10,994	No	16,084	No	20,221	No	75,161	No
Community Average	9,227	No	5,757	No	9,531	No	58,538	No

Figure 38. ZNE community TDV Metric Analysis Results Table

The number of homes that would be ZNE under the various metrics is quite small, with no homes to be considered ZNE under the Net kBtu metric, 3 homes to be ZNE under TDV 2013, 2 homes to be ZNE under TDV 2016, and no homes to be ZNE under TDV 2019. Though the number of homes that achieve ZNE under varying TDV metrics is small, there are several homes which are close to being ZNE under each metric.

4.2.11 ZNE Persistence

Four buildings which are in Performance Phase have two or more years of monitored energy use and energy generation. The modeled and monitored energy use and energy generation are presented below in Figure 39, Figure 41 and Figure 43 for multiple years for three buildings. The site net energy use is presented in Figure 40, Figure 42, and Figure 44 .

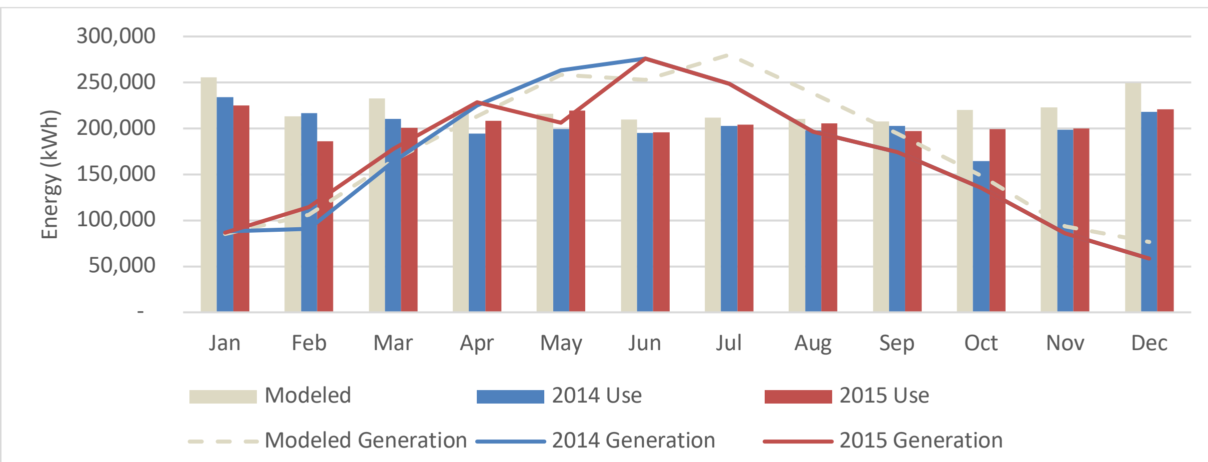

Figure 39. Building A Energy Use and Generation

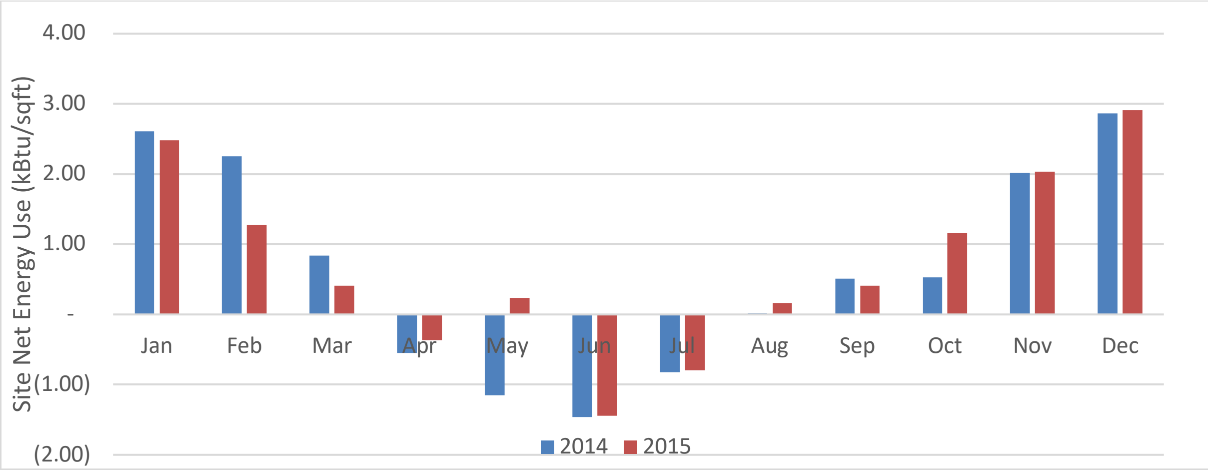

Figure 40. Building A Site Net Energy Use

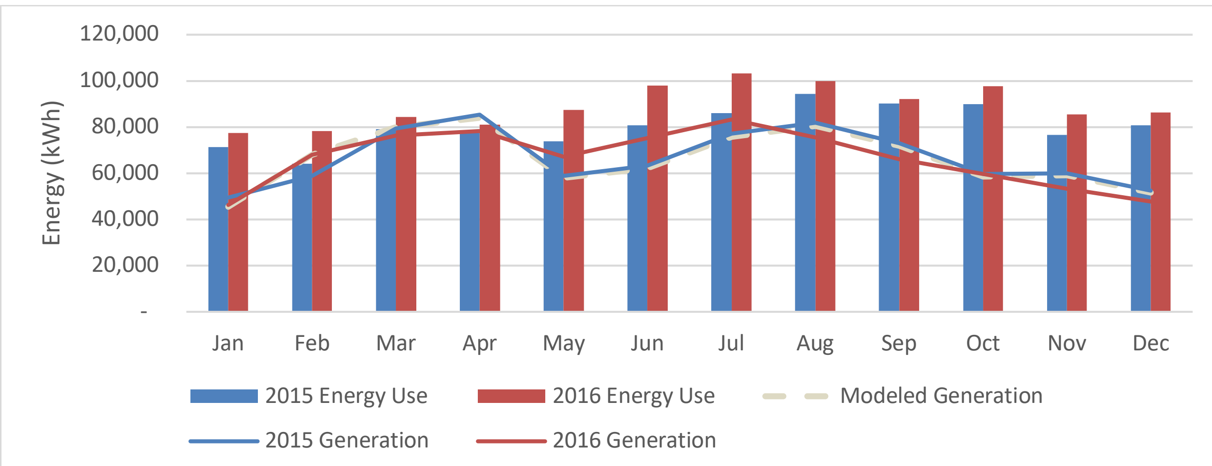

Figure 41. Building B Energy Use and Generation

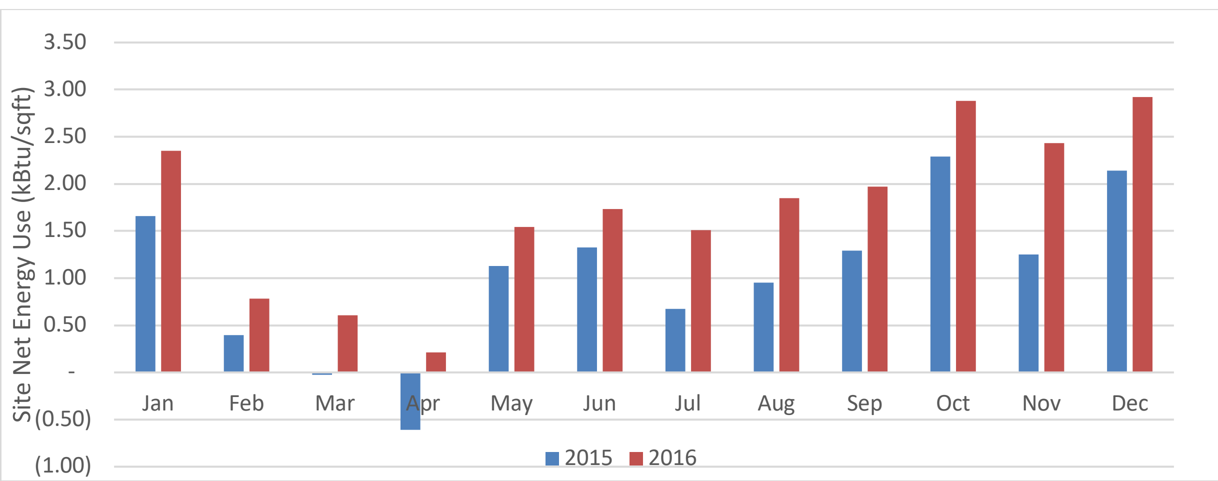

Figure 42. Building B Site Net Energy Use

The monitored energy use of Building A is relatively consistent between Year 1 and Year 2. However, Building B shows a significant increase in monitored energy usage from Year 1 to Year 2. While the results presented have not been normalized for weather or other factors, it is likely that the performance did in fact degrade in Building B from Year 1 to Year 2. Building C shows energy performance that changes from year 1 to 2 but not in a consistent way all year.

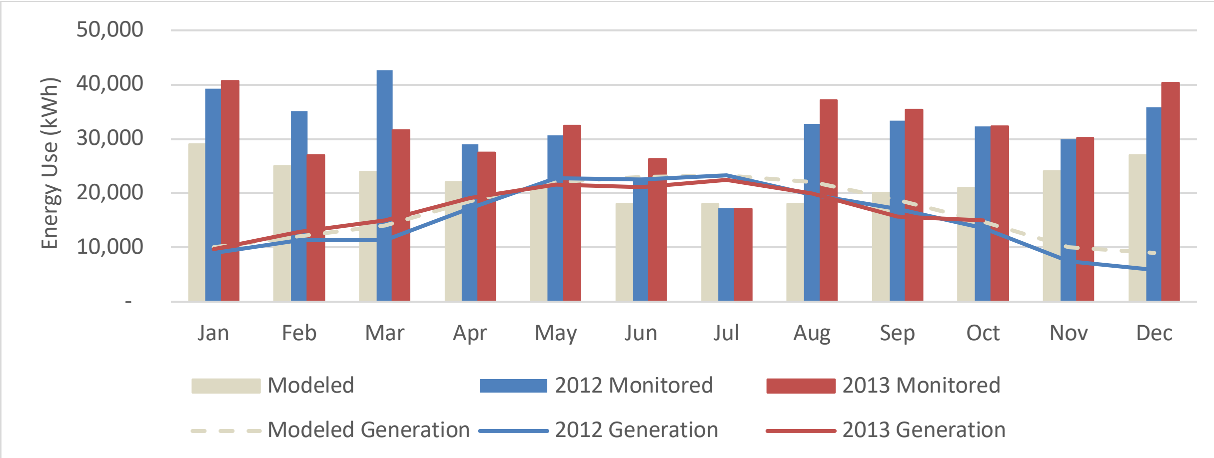

Figure 43. Building C Energy Use and Generation

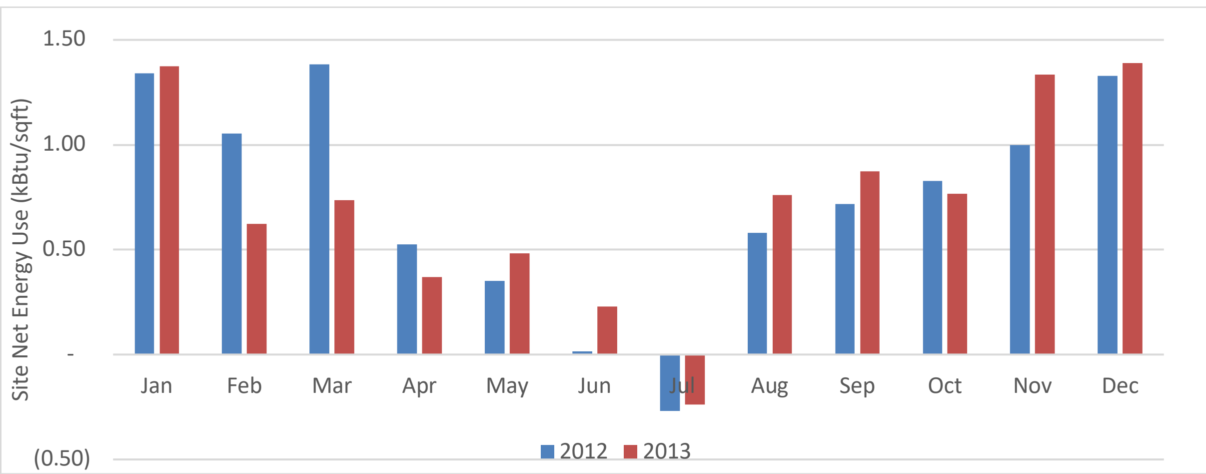

Figure 44. Building C Site Net Energy Use

For a fourth building, no modeling results were available, but partial monitored data from 2008 to 2016 was available. Figure 45 shows the site energy use and generation where available from 2008 to 2016. Though the data has not been normalized to account for weather or other factors, it appears that the energy performance in terms of both use and generation of the building has degraded over time. Figure 46 shows the resulting net site energy use for the same building.

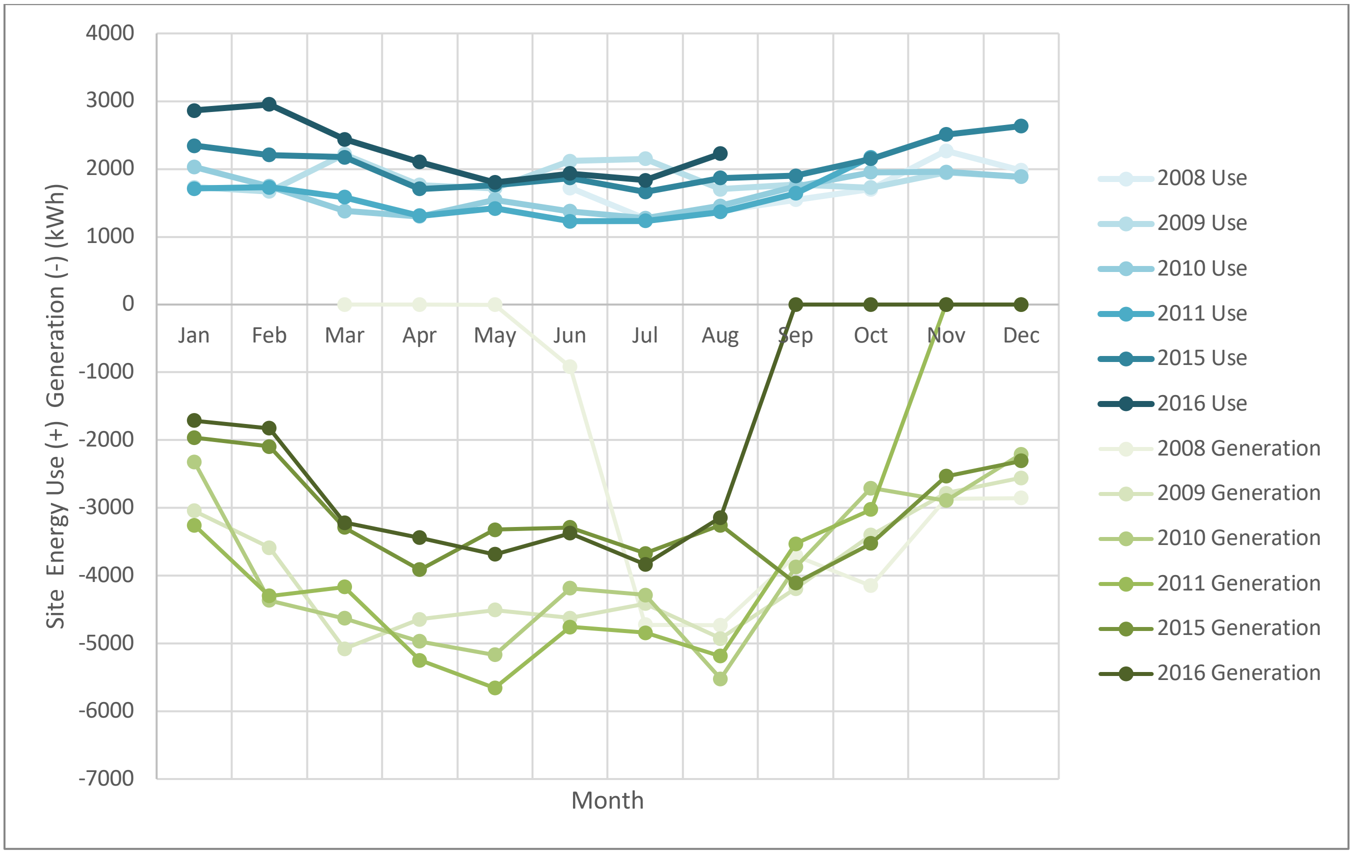

Figure 45. Building D Site Energy Use

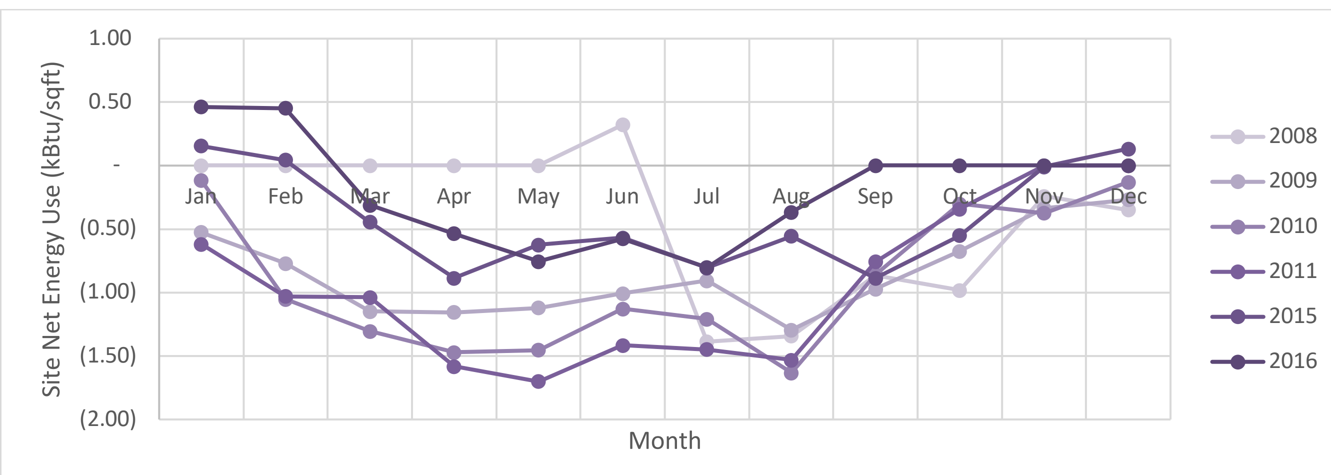

Figure 46. Building D Site Net Energy Use

4.3 Interviews with ZNE Stakeholders

TRC conducted nine interviews with stakeholders that perform various roles in ZNE building projects from building designers, energy modelers, utility staff, and state policymakers.

4.3.1 Purpose of Interviews

The purpose of the ZNE stakeholder interview were twofold. The team wanted to first solicit feedback on the Proposed ZNE Data Documentation Requirements developed in the Phase I study from ZNE practitioners, project and policy decision makers. Secondly the team aimed to investigate in more detail key issues affecting ZNE verification, for example metrics for commercial ZNE buildings, challenges with modeling ZNE buildings, challenges with field data collection and lack of dedicated entities for tracking ZNE performance. Comments and feedback from the interviewers provide the narrative and details which connects the quantitative and qualitative portion of the study objectives.

A subset of the stakeholders interviewed also served as the sources for ZNE building data – models and post-occupancy monitoring. We explained and confirmed these data requests during the interviews so that the intention of the request was clear, and some stakeholders were able to provide additional project data to support the research.

To allow interviewees to be as forthcoming with their answers and building information as possible, TRC guaranteed them anonymity. As a result, the outcomes of the interviews are presented here in this compiled and summarized format.

4.3.2 Summary of Interviewees

The following table characterized the ZNE stakeholders who participated in the interviews.

	Number of Interviews	ZNE Building Experience
Designer, Architect, Engineer	3	20+ each, predominantly commercial buildings with some schools, new construction and retrofits
ZNE Builder or Developer	2	50+ each, residential buildings
ZNE Building Modeler	1	200+, residential buildings
Utility, Facilitator, Researcher, Policy Maker	4	Residential, commercial, new construction, and retrofits

Figure 47: Summary of Interviewees

With help from PG&E in identifying and making contact, the team interviewed two production ZNE home builders, three designer/architectural & engineering firms, two specialty consulting firms with modeling expertise, one staff member from an IOU with a ZNE incentive program offering and related emerging technology research activities, and a state energy efficiency policy maker.

4.3.3 Key Interview Findings

Though the interviewee group represents a range of industry perspectives, interview responses addressed many of the same themes.

One of the primary opportunities for improvement identified by many stakeholders was around energy modeling. A major sticking point for several stakeholders was inflexibility in simulation and compliance tools for modeling innovative solutions and strategies, or in adjusting standard assumptions. For example, several stakeholders noted that the standard use profiles in compliance tools do not accurately reflect how occupants use energy. Another limitation for energy modeling was that energy modeling tools best suited to the design phase of a project are not acceptable for energy code compliance modeling. Thus, there is no unified modeling platform for design and compliance, requiring the use of multiple modeling tools for each project. In addition to causing frustration and difficulty for energy modelers, the limitations of compliance tools lead to workarounds that do not accurately represent the actual design to meet compliance, according to one state policymaker.

Partly because of these modeling challenges, many stakeholders are seeing significant differences between modeled and monitored performance in ZNE buildings. Many stakeholders specifically mentioned difficulties with accurately predicting plug-loads, which have become a larger share of building energy use as other systems become more efficient. Two engineering firms interviewed specifically mentioned plug loads as sources of inaccuracy in energy models, noting that building owners frequently overestimate their plug load uses. One of the engineers suggested the need for plug load studies prior to designing for ZNE to more accurately understand plug load uses. These discrepancies can then have major implications on how effectively a building can meet its ZNE performance targets. Several stakeholders noted that overestimated energy use has led to inefficiently oversized PV systems. On the other hand, designers also expressed concerns over design-build contracts that mandate performance targets that architects, and engineers have little or no control over once a building is operational. Without the ability to more accurately model building energy use, contract-mandated performance targets can also lead to oversized PV systems to protect against liability for performance penalties.

These challenges extend beyond discrepancies between predicted and actual performance, to encompass questions about how ZNE is defined, and how it is determined. Multiple stakeholders brought up questions about how electric vehicle charging or battery storage systems should be considered in ZNE definitions and strategies.

Design and sizing for PV systems to meet generation needs was another topic that was mentioned repeatedly as a stumbling block by many stakeholders. Builders and engineers consistently described prioritizing energy efficiency measures first, to minimize the need for generation. One engineering firm also described a process of starting the design from a net-zero or net-producer baseline based on the overall potential for production, rather than determining production based on the energy needs of the building design after the fact. However, one utility representative also mentioned that the falling price of PV systems may shift priorities away from energy efficiency measures over time. And while PV system sizing is based on expected energy demands, the limitations and challenges in modeling energy use described above make accurate predictions difficult. To further complicate matters, several stakeholders mentioned that final PV system sizing and installation is frequently handled by third parties, through lease agreements or power purchase agreements, which poses additional challenges for maintaining documentation and collection accurate information about what was installed and how the systems are performing. System sizing can be further complicated for community scale or campus generation, where systems are planned to support multiple buildings. Planning for residential development also adds complication, with one home builder describing a system they have developed that limits which sites certain home designs can be located on to prevent shading on neighboring PV systems.

Stakeholders described a variety of approaches in how they typically define ZNE for their building projects. Many stakeholders expressed an overall preference for a site ZNE definition because it was easier for customers to understand than a source metric. However, one home builder noted a preference for source ZNE because of its ability to account for mixed fuel homes. Another builder reported focusing on a site electric-only ZNE metric, which more appropriately sets customer expectations for overall energy use and future utility bills. All interviewees emphasized the importance of communicating the fact that ZNE does not mean “zero energy bill” or “zero energy cost” to their customers. The state policy maker emphasized the need to consider ZNE from an energy code perspective as an asset rating or design rating, and that actual performance would vary. A handful of stakeholders mentioned considering ZNE from a TDV perspective, but that this was generally not the preferred method for communicating to clients. One consultant indicated a preference for moving toward a GHG-based metric, and the state policymaker indicated that the energy code may shift toward a GHG basis in future iterations. At the same time one homebuilder noted that customers do not typically relate to GHG and need a metric that can be understood on a more basic level. At the same time, some stakeholders noted a sales advantage related to ZNE and high-performance buildings. One homebuilder noted high demand for their ZNE homes, and the ability to charge a premium for high performance homes. One engineer also noted that developers realize they can charge a premium for high performance buildings, often keeping the profits rather than passing any energy savings on to their tenants.

Another frequent topic of discussion among all stakeholders is the difficulty of ongoing performance verification. As the utility representative noted, ZNE really needs to be about ongoing performance, which comes down to occupant behaviors and how buildings are used. But many stakeholders reported challenges in monitoring or collecting data to understand ongoing performance. One homebuilder includes monitoring in select ZNE homes because it provides a feedback loop, both for the builder to improve on their design strategies in the future, and for the homeowners to understand their energy use and home performance. However, this is the exception in the broader industry. Many stakeholders noted that ongoing energy monitoring is usually out of the hands of the building design team. Even for many of the green building rating systems, providing performance data is usually the responsibility of the building owner. This can present challenges in situations as mentioned above for design-build contracts that include performance guarantees. One engineer also noted that most buildings don't have the resources, and clients are not being trained to effectively operate ZNE buildings. They recommended the need for a new type of role that manages the ZNE needs of a building across both the design and operation sides of the process, a sort of "ZNE Integrator" role. As the utility representative noted, there is a need for nearly real-time energy performance feedback to ensure a building is operating in line with ZNE performance targets. But as many stakeholders reported, the responsibility for monitoring that performance is largely undefined, and can easily fall through the cracks. And as the state policymaker noted, there is currently no mechanism to track or verify ZNE home performance from a code compliance perspective.

Several stakeholders also reported general market barriers, such as the fact that mortgage companies do not recognize or assess the added value of high performance or ZNE homes, despite the report sales price premium builders can command.

While all the stakeholders interviewed for this study have achieved success in their various efforts toward ZNE construction, the challenges and barriers they report are instructive in developing and determining strategies for ZNE verification going forward.

5. Findings

In this section we provide the findings of the data collection and analysis described in Section 4 and provide answers to the research questions identified in Section 3.1. The TRC Team addressed some of the research questions completely within the scope of this project while some questions require additional work beyond the scope of this study due to the changing nature of California policies and the still nascent stage of ZNE buildings in the state. Figure 48 provides an overall completion status of each research question using the following rating criteria:

- Research Question Completely Addressed: ● Rating used for all research questions that were adequately addressed by the TRC Team's primary and secondary research findings.
- Research Question Partially Addressed: ◑ Rating used for all partially addressed research questions by the TRC Team's primary and secondary research findings. Developing complete answers to these questions was not possible due to limitations in the primary and secondary data available and/or the still uncertain aspects of CA ZNE policies.

The 'Report Sections' column provides a key to sections of the report where relevant information is provided.

RESEARCH QUESTION SCOPE	REPORT SECTIONS	OVERALL STATUS
QUALITATIVE ANALYSIS		
1: Challenges with Commercial Building Verification	5.4, 4.2.2, 4.2.3	●
2a: Modeling challenges	4.3, 5.4	●
2b: Pros/cons of data quantity versus time and expense	6.1, 6.2	●
3: Target Audience for Verification Methods	6.1	●
QUANTITATIVE ANALYSIS		
1a: Replicable standard inputs for Site, Source and TDV	6.4	●
1b: Examples of methodology applications	4.2	●
1c: Impact of TDV changes by code cycle	4.2.10, 4.2.11	●
1d: Impact of fuel types on verification methods	6.2, 6.3	●
2a: How does compliance modeling compare to design modeling	4.3.2	●
2b: Differences between TDV and Source ZNE definitions	4.2.10, 4.2.11	◑
3: Greenhouse Gas (GHG) metrics versus energy	5.4.6	◑
4: Persistence of Performance	4.2.9, 5.7	◑
5: Verification methods for existing buildings and retrofits	5.6, 6.3, 6.4	●

Figure 48: Overall Status Summary of Individual Research Questions

5.1 ZNE Design and ZNE Performance Require Different Verification Methods

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.

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 verification and focuses on whether the building is constructed as designed. While design and 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.

5.2 Different Metrics Require Different Criteria and Data Sources

There are various ZNE metrics that are being used by entities in the state of California and across the country. The choice of metric also affects the choice of the verification method and the data relied upon for ZNE verification. Figure 49 outlines the differences in the criteria and data sources necessary to verify ZNE. As seen in the figure, and as outlined above, the design verification is based largely on energy simulation analysis, but the metric influences the choice of energy analysis tools as well as the outputs to be verified. For example, the TDV metric requires using a compliance tool (CBECC-Res/CBECC-Com) whereas the site energy metrics, other simulation tools may also be used.

For the source energy metric, there are choices for what multipliers are used to calculate source energy from site energy numbers. For this report, we recommend using the national multipliers used by DOE for their common definition of ZNE, which have been already adopted by the DGS.

ZNE Metric	Stage	Criteria Used to Prove Building is ZNE	Key Data Source	Energy Unit Used
TDV	Design	EDR = 0, TDV = 0	Compliance Energy Simulation Model	TDV
Site Energy	Design	Predicted Net Energy Use = 0	Design Energy Simulation Model	kBtu (site)
	Performance	Actual Net Energy Use = 0	Utility Billing Analysis	kBtu (site)
Source Energy	Design	Predicted Net Energy Use = 0	Design Energy Simulation Model	kBtu (source)
	Performance	Actual Net Energy Use = 0	Utility Billing Analysis, Source Energy Multipliers	kBtu (source)

Figure 49: Verification Criteria Based on ZNE Metric of Interest

5.3 Different Audiences May Have Different Verification Needs

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 Design or ZNE

Performance metrics. Figure 50 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 Design (TDV)	EDR = 0	Energy Simulation
Utility Incentive Programs	ZNE Design (Site)	Net predicted site energy	Energy Simulation
	ZNE Performance (Site)	Net actual site energy	Utility Billing Analysis
Voluntary and Recognition Programs	ZNE Design (Site)	Net predicted site energy	Energy Simulation
	ZNE Design (Source)	Net predicted source energy	Energy Simulation
	ZNE Performance (Site)	Net actual site energy	Utility Billing Analysis
	ZNE Performance (Source)	Net actual source energy	Utility Billing Analysis with Source factors

Figure 50: Proposed Verification Approaches by Use Case

5.3.1 Codes and Standards Savings Verification

To verify that a building is a ZNE Code building, the key criteria of interest is whether the Energy Design Rating (EDR) of the building is Zero (0) or lower. EDR itself is based on the Time Dependent Valuation (TDV) concept and not on site/source energy.

5.3.2 Utility Incentive Programs

For utility incentive programs, there is currently no one ZNE metric that is prevalent since 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. For those programs targeting ZNE performance, the savings verification is largely based on verification of utility bills and renewable energy generation.

5.3.3 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. DGS for example has standardized on the ZNE Source metric aligned with the DOE Common Definition of ZNE. Some residential builders also prefer this source energy-based definition while other residential builders prefer the site energy-based definition. Starting in 2020, all residential builders will need to build new homes to the ZNE Code metric enshrined in the 2019 Title 24 code.

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.

5.4 Carbon Metrics and the Evolving ZNE Landscape

ZNE definitions, strategies, and metrics are still evolving, with recent efforts at regulatory level focusing on a potential new approach - still in early stages – using carbon emissions or an equivalent as the metric for ZNE. This approach differs from current metrics that focus solely on net energy use, or on a time-dependent valuation of the cost of energy generation.

Several stakeholders TRC spoke with in the preparation of this report predicted carbon-based metrics would be the next major change in how California approaches building energy use. In contrast to current metrics, a carbon-based metric could better respond to California's emissions goals, and reflect the state's shift toward increased renewable generation sources. However, many questions remain about what form a carbon metric would take, and there is not yet a consensus on a preferred strategy. Potential approaches include one or a combination of the following:

- Focusing on avoided carbon, or emissions "saved" through efficiency and use of renewables
- Valuing carbon based on the emissions of the source energy generation
- Developing a system of time-dependent carbon or time-dependent source values, like the current TDV energy metric, which takes into consideration both the energy demand and the fuel mix for the available energy at a given time
- Establishing a dollar value of carbon, potentially in alignment with the state's cap and trade program

One example is a proposal developed by the organization Architecture 2030 known as Zero Code. Zero Code is model code language that combines energy efficiency and renewable energy provisions to achieve Zero Net Carbon buildings. To parallel the structure of California's Title 24, Zero Code uses a metric called Time Dependent Source (TDS) to value a building's renewable generation offset based on overall energy demand and source input mix from the electrical grid at the time. For example, TDS values are lowest at midday when solar generation is abundant, and highest in the early evening and early morning hours when energy demand is high but renewables are in short supply. Because it is based on source energy input in kBTU, and the source input for renewables is zero, TDS functions as an energy metric that matches the pattern of hourly carbon emissions, as illustrated in Figure 51 below.

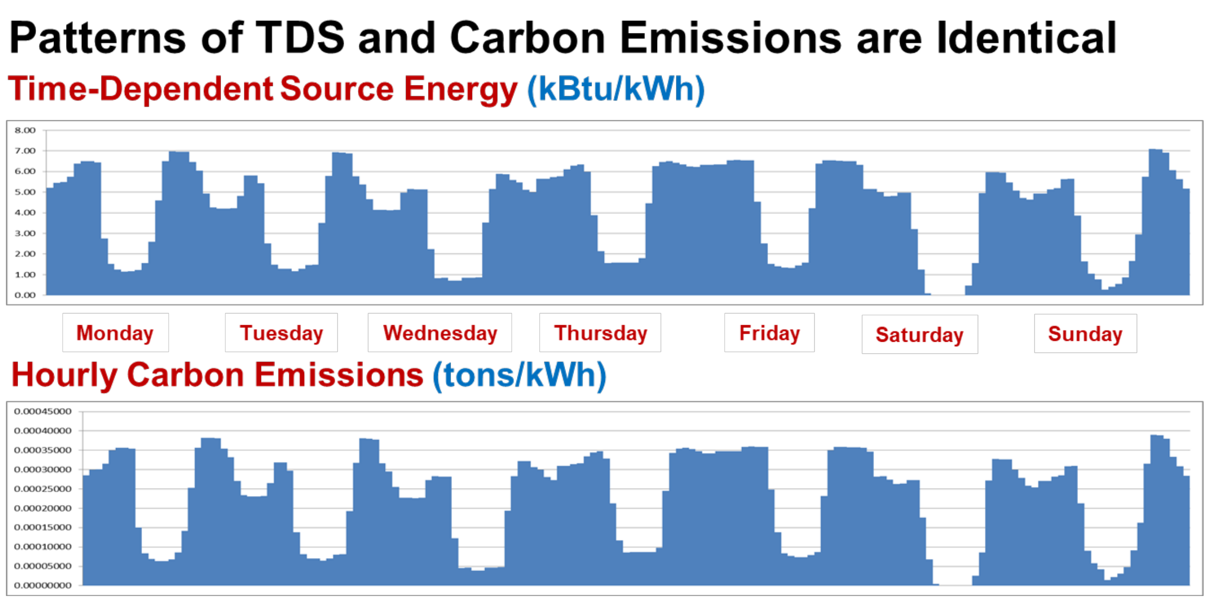

Figure 51: Comparison of Time-Dependent Source Energy and Hourly Carbon Emissions (graphic via Zero Code)

In addition, while both TDS and TDV are 8,760 hour time-series datasets to value electricity use at each hour of the year they have very different outcomes. Because TDS is based on source mix on the electricity grid, values vary throughout the day and over the course of the year. In contrast, TDV, based on the avoided cost of generation that values peak demands much higher, is relatively flat for most of the year, with a large spike during peak hours. Figure 52 below shows a visual representation of this contrast between TDS and TDV, using California climate zone 12 as an example.

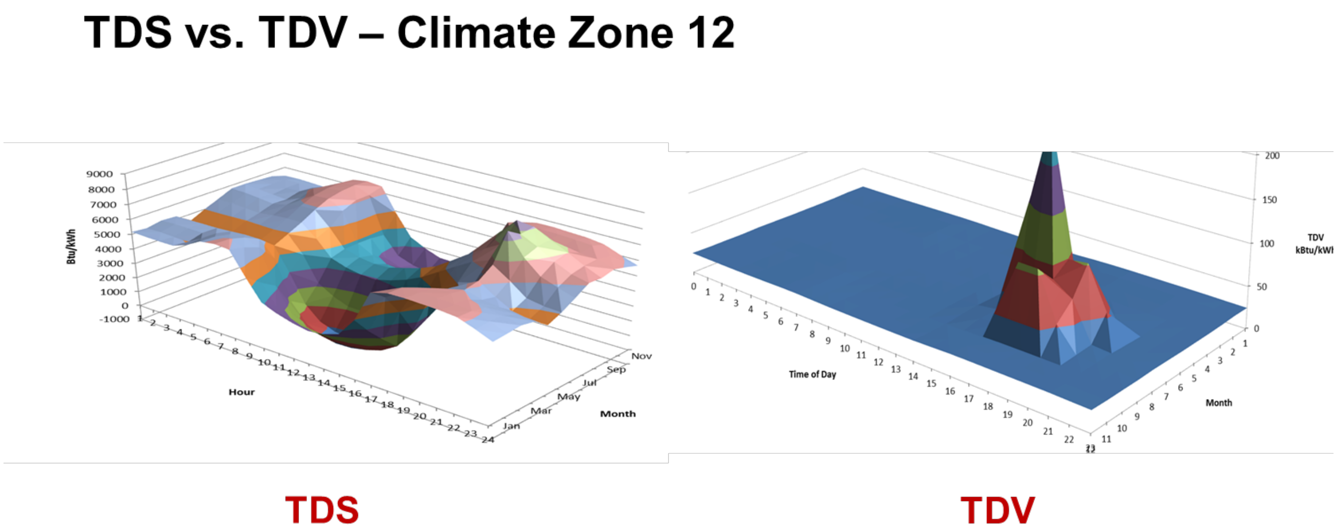

Figure 52: Comparison of Time-Dependent Source and the current California TDV for climate zone 12 (graphic via Zero Code)

The developers of Zero Code believe the TDS metric will encourage building designers to maximize both energy efficiency and load shifting toward periods with lower TDS values, which will in turn promote grid harmonization.

The California Energy Commission is also considering alternative metrics to the TDV metric to better account for carbon emissions and impacts in the next iteration of Title 24 updates in 2022. Complicating the discussion of carbon metrics for code development is the legal requirement that efficiency measures be cost effective as established in the Warren-Alquist act. So a measure that may save carbon but is not otherwise cost effective may not become basis of a code requirement. Some stakeholders have expressed concerns that cost effectiveness requirement, along with other legal barriers at the federal and state level, could make a carbon metric difficult to implement in Title 24. Others have suggested that a carbon metric could be devised in a way that conforms to the existing legal framework. To that end, the Energy Commission is working with Southern California Edison and E3 to consider new metrics for use in the building standards. Any viable and sustainable new metric would have to support all the following requirements:

- Meet the state's decarbonization goals
- Preserve grid harmonization signals
- Protect envelope efficiency measures
- Not increase operating and energy costs for buildings
- Minimize confusion and potential for 'gaming'

The group has considered 18 different potential metrics, including variations on TDV, emissions, and source energy, as well as combined metrics, and dual-metric strategies. Results of this analysis are not publicly available but based on interviews with individuals involved with the initiative, so far, no single strategy has met all the requirements outlined above, but some have come close, including a metric that combines a carbon metric with a traditional energy cost metric. Alternately, there could be a dual metric approach where a measure is vetted both for carbon reductions and cost effectiveness independently.

Because carbon metrics are still in the early stages of development TRC did not evaluate the project data in this report against any potential Zero Net Carbon metrics. It is likely that a carbon metric would require additional or different inputs from those described in this report. In addition, many of the inputs necessary for an accurate determination of Zero Net Carbon status, such as detailed information on utility generation fuel mix, is not yet readily available at a sufficient level of detail.

As metrics and standards for verifying ZNE status continue to develop and evolve over time, the details of the verification requirements will need to evolve alongside, but the overall approach and strategy recommended in the sections below will still be valid.

5.5 TDV Impacts for IEPR ZNE Code

As mentioned in the ZNE terminology section, the ZNE Code definition and what is required in the 2019 Title 24 are aligned but not the same. A building meeting the 2019 Title 24 code would not automatically result in an IEPR ZNE Code building if the building meets the prescriptive requirements or targets performance compliance to equal the EDR of the prescriptive package of measures. Underlying the EDR metric is the TDV valuation of the energy efficiency savings and renewable generation. In this study we looked at ZNE projects that were designed to meet the IEPR ZNE Code definition and analyzed them through the lens of the different TDV valuations used in the 2013, 2016 and the proposed 2019 Title 24 part 6 and 11 standards. As seen in Figure 35 through Figure 14, buildings that were designed to meet IEPR ZNE Code using the 2013 TDV valuation may not necessary meet the IEPR ZNE Code definition using the 2019 TDV valuation. This presents a challenge to the IPER ZNE Code definition since changes to TDV in the future may invalidate ZNE claims currently being made. One potential solution is to specifically identify which Title 24 standard/TDV version was used to make the IEPR ZNE Code claim.

5.6 ZNE for Retrofit and Renovation

In Phase 1 of this project, the verification requirements were set up primarily to support new construction projects but with an intention to be applicable to retrofits and renovations. However, there was limited data available to review and confirm the verification methods would apply. In Phase 2, we reviewed retrofits/renovations projects and conducted interviews with stakeholders involved with ZNE retrofits. Based on these, we find that the verification methods identified in Phase 1 apply equally to retrofits/renovations as far as confirming that the net energy use is zero under some chosen metric (site, source etc.). However, the added challenge posed by retrofits/renovations is to also compare the proposed/actual design against the baseline of the existing conditions to see whether the ZNE building is saving energy compared to the existing baseline. This is important for efforts such as Prop 39 for schools and other programs supporting ZNE retrofits where the program administrator would need to make claims for energy savings not based on the ZNE design/performance but based on the savings compared to the existing conditions. Thus, verification for retrofits and renovations is a two-step process: a. confirm savings compared to baseline, and b. confirm ZNE design/performance.

5.7 Persistence of Performance

Establishing persistence of performance is an ongoing challenge for ZNE buildings since ZNE buildings tend to fall into one of three categories – a. Buildings that have made design claims but have not been verified to perform as ZNE; b. Buildings that have been designed as and have been verified to perform as a ZNE building once (typically a year or two after the building is first fully occupied), or c. Buildings that failed initial verification of ZNE due to lack of proper commissioning, under-performing systems or lack of user training, made changes and then were verified as ZNE performance.

Typically, designers and engineers don't have contractual methods of continuing performance verification beyond the initial verification. Most ZNE buildings are designed, built and operated under traditional methods where the role of the designer and engineers ends at completion of the initial commissioning process. After that, the building owners have less incentive to continue verification of ZNE unless there is an internal champion or the ZNE performance is part of a larger corporate sustainability culture and has educational or business value. Typically, buildings with dedicated energy managers or energy performance built into the building management have a better opportunity to continue ZNE verification.

To address these challenges and to emphasize that a building is only ZNE for the period it is verified for, this study finds that ZNE performance verification needs to be an ongoing activity that is repeated at set intervals – much like cars in California are required to periodically undergo smog check to ensure they meet emissions standards.

5.8 Documentation Challenges

The review of existing ZNE tracking databases, and interviews with stakeholders identified several challenges with consistent documentation that would meet the documentation criteria identified in Phase 1 of this project.

5.8.1 Lack of Standardized Formats and Source Data

ZNE recognition programs such as the International Living Futures Institute and New Buildings Institute have specific procedures and criteria for ZNE verification. However, not all entities have consistent data requirements nor do all claimants of ZNE have the right information readily available.

A common issue is that while the verifier receives data on the ZNE building for performance verification, typically this is in the form of a report, memo or similar communication from the project team but without any of the underlying data being shared. For example, energy use data is shared through Excel files or email text without the actual energy bills provided to independently verify that the Excel file or memo/email is accurate.

In some instances, the data being provided for ZNE performance includes a combination of actual monitored data (utility bills, building energy dashboards) and data that is extrapolated or otherwise edited due to data loss or other unspecified issues. In the most extreme instance close to half a year's worth of billing data was extrapolated from billing data from other months on a commercial project. The verifier has no recourse but to either accept the data as is and decide, or outright reject the project.

To make matters complicated, the different audiences for the verification have varying capabilities of providing the required data for verification. For example, building owners often don't have the energy models whereas the designers/MEP firms don't have access to actual energy use data. Thus, for verification of ZNE design and performance, the data needs to be provided by multiple project stakeholders adding to the time and effort needed to provide adequate and appropriate data.

5.8.2 Multi-buildings, Campuses

For ZNE projects that involve multiple buildings there are additional challenges for documentation and verification since some campus buildings are not individually metered or existing metering (for retrofits) is not aligned with the end uses and loads that are covered as part of the ZNE scope. For example, a campus-wide initiative to install solar may not keep good records of how the solar output is to be distributed across buildings, or whether the solar installed on any one building on campus is dedicated to that one building. Further, many multi-building or campus projects conduct construction activities in a phased manner with often months or even years between the first and last building project. Clear demarcation of when construction activities (especially retrofits/renovations) occur is necessary to confirm that a given building/project is indeed ZNE. Adding to the problem is that many buildings do not separately meter the solar from the building energy use, so if the PV system is installed on one building but the output is to be shared with other buildings through virtual net metering or similar methods, that detail is not apparent in the billing data analysis.

5.8.3 Solar System Sizing

Perhaps the area of most concern for ZNE verification is getting accurate numbers for the actual solar or renewable energy system installed on the building. Often the solar system analysis is done by a third party separate from the design and specification of the building itself and the exact capacity of the installed system is known only to the entities that are party to the solar contract (especially in a Power Purchase Agreement situation). As we noted in Phase 1 and seen in projects reviewed for Phase 2, the PV system sizes assumed in the ZNE claims often have different annual predictions versus the actuals – with the actuals being generally higher than the predicted. In interviews, many stakeholders confirmed informally that the customer may have indeed installed a different sized solar system than what they assumed in the ZNE design. For performance verification, the building operations staff often does not have the details of the system size. The best information available is the number of panels but that does not provide enough details to confirm actual size.

5.8.4 Energy Modeling

ZNE design verification requires confirmation that the appropriate energy software is used, and that the energy analysis done accurately reflects what was constructed. In many instances, the details of any changes between the energy model and the actual constructed building are not known. Also, sometimes the designer/MEP firm/energy consultant conducts multiple simulation analyses for different purposes. A compliance energy model is done to meet the code compliance requirements whereas an engineering simulation model is done to specify the building systems. Thus, a building that is targeting ZNE Design might have one for IEPR ZNE Code and a different one for ZNE Design Site which may or may not agree in terms of all the assumptions.

5.8.5 Crosswalk to Translate Across ZNE Definitions

Perhaps the most common challenge is when the ZNE claim is made without specificity for what the ZNE metric to be used is – site/source/TDV. This is common in early design predictions or when ZNE claims are made for buildings that may meet multiple metrics. In such instances the ZNE verifier needs to apply multiple metrics to the ZNE claim to see which ones are the best fit. The next challenge is to confirm that the assumption made by the verifier is indeed accurate.

5.8.6 Source and Greenhouse Gas/Carbon Calculations

The values to be used for site energy and TDV are known and/or prescribed, but the values for source energy and greenhouse gas/carbon are not. At the national level there are values preferred by the DOE in their common definition for ZNE for converting site energy into source energy metrics. In California, DGS uses similar values though the actual site to source conversion values for CA are different than those used nationally. Using national values has the advantage of providing a consistent basis for comparing across buildings but has the disadvantage that the source values may not reflect the reality in a state like CA that has a much greener energy mix for electricity generation.

For those targeting Zero Carbon, there is no standard method of converting site/source energy to carbon metrics. Again, the numbers vary by the relative cleanliness of the energy generation and the value assigned to each pound of carbon saved. The California Energy Commission, California Air Resources Board and the California Public Utilities Commission are all working on developing standardized metrics to account for carbon emissions and emissions reductions due to building energy use/savings. These would need to address not only statewide conditions, but also utility-specific conditions based on the time of year/day as well as the mix of fuels used for electricity generation.

6. Proposed Verification Methods

TRC proposes the following verification methods based on the findings identified in the previous section and the analysis done for this project. The methods outline the process separately from the documentation requirements.

6.1 Intended Use Cases and Users

Based on the review of projects and interviews with stakeholders we anticipate the following potential audiences for ZNE verification:

1. **Homeowners** that are purchasing ZNE buildings would expect that a building being sold as ZNE does what is advertised. They may or may not be interested in the procedures being followed or be actively engaged in verification activities but are interested in the outcomes. Most homeowners intuitively understand 'zero bills' but have limited understanding of ZNE metrics described in this report.
2. **Residential builders** – a couple of small builders are implicitly or explicitly promising ZNE performance and one has gone as far as guaranteeing zero energy bills. Most larger residential builders see this as a significant risk and rather prefer to couch ZNE in terms of a 'miles per gallon' type rhetoric that touts the advantages of the superior construction and features of the ZNE home, the ability to be able to perform as ZNE, <u>but</u> with significant caveats that 'your mileage may vary based on your use'.
3. **Commercial property developers** that are building new or retrofitting existing commercial facilities with the goal of leasing the properties to single or multiple tenants. In this case, the ZNE claims are based on the potential to be ZNE. There is an option with certain lease structures to provide ZNE guarantees but that is not the preferred option of the stakeholders engaged through this project.
4. **Designers and MEP firms** that are responsible for designing the building to be capable of ZNE (design or performance). Some of these entities have internal motivations for promoting ZNE designs – either as a competitive advantage or because it is their company's goal – while others are responding to request by building owners to provide ZNE designs. Currently, a very small percentage of designers and MEP firms have contractual obligations or opportunities to verify actual building performance, but they are strongly interested in knowing how their designs are performing so that they can improve their future designs.
5. **Local building code officials**, especially in jurisdictions with local reach codes that require ZNE levels of design as part of their code compliance. The goal here is an asset rating (EDR) that shows the capability of the building to be ZNE. The verification methods developed in Phase 1 had intended that the verification activity for IEPR ZNE code would be done by local building officials. That was assuming that the 2019 Title 24 code would mandate ZNE levels of performance. However, the 2019 Title 24 code does not require EDR to be zero and as such the local building officials are only likely to verify IEPR ZNE Code in cases where applicants are voluntarily proposing a ZNE design or where local ordinances require so.
6. **Program Implementers** that operate or will be offering programs that promote ZNE designs and performance would need to show that they are being good stewards of ratepayer funds. Savings claims for these programs (whether new construction or retrofits) will be based on either a code baseline or existing conditions compared with the actual energy use post-retrofit/construction. Currently, programs like the California Advanced Homes Program (CAHP) are providing incentives based on ZNE Design but also claiming certain kWh and therm savings based on predictions. Verifying that a ZNE Design home is such will provide a degree of assurance of predicted savings. For those programs – especially retrofit efforts – where the ZNE performance is the better metric, the actual energy use and savings from baseline are even more critical to get accurate.
7. **The California Public Utilities Commission (CPUC)** has several needs for ZNE verification. For any programs that promise ZNE design or performance, it is the CPUC's responsibility through their evaluation consultants to verify program effectiveness and this report <u>does not</u> address that need. However, this report does identify project specific procedures that may be followed <u>if</u> the evaluators

choose to verify individual building ZNE claims at design or performance stages. Second, the CPUC has been developing a ZNE recognition program where standardized verification procedures such as those proposed in this report would be invaluable to ensure a level playing field. Lastly, as the agency ultimately responsible for the Strategic Plan goals, the verification methods would allow for a standardized way to track progress towards ZNE goals and avoid the current 'brand confusion' where there are varied and competing ZNE metrics and inconsistent methods to verify those claims.

6.2 Proposed Verification Levels

We propose three levels of ZNE Verification and one level that is short of ZNE for those projects that don't quite meet the ZNE designation. These ZNE levels are designed for multiple use cases and differ in terms of the verification methods and the stringency of the data and verification process.

6.2.1 Ultra-Efficient

Phase 1 of this study recommended methods to identify whether buildings were ZNE at the design or performance stage and then with multiple metrics (site, source, TDV). However, based on review of the expanded list of projects, TRC recommends an additional level called Ultra-Efficient which are buildings that do not quite meet the ZNE specification for design or performance. This designation is essentially an 'off-ramp' for those projects that do not meet the three ZNE designations that are described below. Instead of calling the project as 'Not ZNE', the Ultra-Efficient designation allows these projects to be recognized for their superior energy performance while confirming that they do not meet the ZNE designation. In this report, we do not identify a separate process for verifying this designation. Rather, we propose that the verification methods for the next three classifications described below be applied and the projects that don't meet any of these designations be deemed Ultra-Efficient.

The criteria for calling a project Ultra-Efficient is not set in stone but the intent is to have projects that have a high level of energy efficiency and some renewables. Like ZNE buildings, a building can have Ultra-Efficient Design and/or Ultra-Efficient Performance.

6.2.2 ZNE Design

The ZNE Design designation is assigned to those buildings where there is demonstrated design intent to have a building/project to be ZNE. This designation by its nature is for those buildings that are in design or construction but not yet occupied or operated. In almost all cases, the ZNE Design designation is like a mile-per-gallon (MPG) rating for vehicles where the ZNE status is determined based on prescribed assumptions and inputs to the building energy simulation model. As with MPG for vehicles, it is anticipated that there will be differences in actual energy use and generation in building operation as seen in Section 4.2 of this report.

It is possible that ZNE Design rated projects may not actually perform at ZNE levels.

6.2.3 ZNE Performance Monitored

The ZNE Performance Monitored designation is assigned to those ZNE projects where the building has been operational for at least 12 months and there is a credible claim for ZNE performance, but not enough data to validate that claim. This is a common occurrence based on the 94 buildings studied by TRC for this project. Often, the claims for ZNE are not substantiated with the underlying data in enough quantity (less than 12 months of billing data for instance) or enough quality (energy use data spreadsheet without any backup of underlying data). Most voluntary claims of ZNE would fall under this category of ZNE designation. There is expectation that a building that performs at ZNE level also meets the ZNE Design, but this is not guaranteed. Therefore, a building seeking both ZNE Design and ZNE Performance designations would need to independently verify each stage for ZNE.

6.2.4 ZNE Performance Verified

ZNE Performance Verified is the highest level of ZNE designation awarded to those projects where the ZNE Performance claim is credible, backed by the right quality and quantity of data that is verified by an independent verifier. This level has the most degree of difficulty to achieve but the most guarantee of accuracy and verification of ZNE Performance. This level is appropriate where the ZNE performance is part of a contractual agreement or when ratepayer funds are being used to support the ZNE performance project. There is expectation that a building that performs at ZNE level also meets the ZNE Design, but this is not guaranteed. Therefore, a building seeking both ZNE Design and ZNE Performance designations would need to independently verify each stage for ZNE.

6.3 Verification Process

In Phase 1, the verification process was predicated on the ZNE metric used and the stage of the verification (Design, Performance). However, based on review of additional projects and stakeholder engagement through this phase, TRC proposes the following decision-tree and process for ZNE verification.

Figure 53: Proposed 7-Step ZNE Verification Process

6.3.1 Step 1: Identify Type of ZNE Project

There are two aspects to identifying the type of the project – the scale of the project and whether the project is new construction versus retrofit/renovation.

Individual Buildings versus Campus/Community Scale

As identified in the findings, whether ZNE is to be sought at the building, campus, portfolio, or community level does impact the data needs and the level of sophistication needed in the verification process. For example, for a campus level ZNE project, it is important to note the scope of the verification activities – are all buildings being considered or just a few. Further, the broader the scale (community scale), the more stakeholders are likely involved and responsible for providing data for the verification process. For example, a single home being verified involves one building owner or designer, but a community of dozens or even hundreds of homes may involve multiple homeowners if the performance is to be verified.

New Construction versus Retrofits

Another important factor is whether the ZNE project is a new construction project (subject to a code baseline) or a retrofit (subject to existing conditions baseline). For both these types of projects the verification metrics may remain the same but as identified in the previous section, the savings estimation for retrofits/renovations may have a different basis than new construction.

6.3.2 Step 2: Define Project Stage – Design versus Performance Verification

The second step is to confirm the intended stage of the ZNE project – Design or Performance. Verification for ZNE design is primarily based on review of energy models. For retrofits, an added step is to compare the existing energy use to the proposed/predicted energy use.

For ZNE Performance, the verification is largely based on monitored/utility data with added scope for retrofits/renovations to confirm actual savings from baseline to those predicted at the design stage.

Another reason to choose the stage is that in many cases, the stage of the ZNE project determines who the verifier is likely to be. For example, at the design stage, the reviewers are likely either local building officials who will verify IEPR ZNE Code claims or a program administrator that is requiring ZNE designs. At the performance stage, the verifier may be the program implementer, a certification entity like ILFI or a building owner or their agent.

6.3.3 Step 3: Establish Data Sufficiency

Once the type and stage of the project are established, the proposed Required Documentation comes into play. The documentation itself is outlined in the next sub-section of this document, but in this section the process of using this documentation is described.

Meet documentation requirements – required, preferred and optional inputs based on ZNE metric used and the ZNE Verification Level desired

Individual Buildings: Identify loads and uses included or excluded. For performance verification, identify and cite source of data. Verify renewable generation output and distribution to loads (i.e. confirm if non-building/process/other uses are also covered).

Multiple Buildings (Campus, Community, Portfolio): Identify relevant data for all buildings individually (if distinct) or aggregate (if prototypical). Identify renewable energy distribution across buildings and loads. Identify building meters and loads for performance verification.

At this stage, the primary goal is to first ensure that the requested data is provided by the project stakeholders, and that the quality of the data provided is sufficient to conduct verification activities. For example, for utility bills, the actual bills or an annual summary of all relevant electric and gas meters is necessary. For multiple buildings, it is also necessary to confirm that data from all relevant meters is included.

Compare to Data Standards

The next sub-step is to compare the data provided against the data standards for certain ZNE metrics. For example, for IEPR ZNE Code, it is important that the tool used for the claim is a CEC approved tool and that appropriate inputs and outputs are used.

6.3.4 Step 4: Verify Data Accuracy

Once the data sufficiency is established, the next step is to confirm that the provided data is indeed accurate by comparing the data with actual conditions or the underlying data sources (e.g. utility bills, energy model results). Here there are two options for how the accuracy verification may be done.

Option 1: Self Certification for ZNE Design and ZNE Performance Monitored

In this option, the data provider self-certifies that they have provided accurate information and provides backup documentation to confirm that they have conducted due diligence that meets the documentation requirements outlined in this document. The advantage of this approach is that this is pretty much the current norm for ZNE claims and works well in a voluntary verification of ZNE. However, the downside is that there is ample opportunity to cherry pick data and to 'game' the system. Further, for programs and codes, that is not a viable option since there are responsible entities for making sure that data is accurate.

Option 2: Independent Third-Party Verification for ZNE Design and ZNE Performance Verified

The second, and a more robust option is that the verification is done by an independent third-party entity such as a ZNE certification entity like ILFI. The advantage is that there is independent verification, consistency of data verification and reduced 'gaming'. On the flip side, this would necessitate either designating an existing entity as the go-to entity for all ZNE verification or allow multiple entities that all compete for the same 'client' base. For residential buildings in CA, it is possible that the HERS regime can be leveraged to confirm ZNE design claims, but similar entities don't exist for performance verification. Then there is the question of who establishes and maintains this entity and who pays whom for the certification.

6.3.5 Step 5: Confirm ZNE Status

Once the data is verified, one of three outcomes can be envisioned:

1. Building meets ZNE verification level criteria – The verifier provides certification including caveats (e.g. design based on certain standards, or performance for a specific period). For performance verification, it is recommended that recertification be required every 3-5 years.
2. Building does not meet ZNE verification criteria – ask for revisions and if those don't change verification status, mark project as ultra-efficient. In such a case, it would behoove the applicant to conduct diagnosis on the reasons for rejection of ZNE status and address the underlying problems (e.g. operational issues or systems not performing as intended).
3. Verifier unsure if project is ZNE – verifier asks for more documentation and backup details. If new information is if meets the verification criteria, a ZNE designation is assigned. If new information is not provided of the information provided does not support ZNE designation, the verifier assigns the designation of Ultra-Efficient.

6.3.6 Step 6: ZNE Registry

This step is not critical to the verification itself but having a centralized registry where all the ZNE projects are documented along with some publicly available information will support broader adoption of ZNE. Further, it would allow an entity like the CPUC or the CEC to monitor progress towards the ZNE goals in the State of CA. Currently, no central registry exists for ZNE buildings in CA, so the essential question is whether one should be created or whether the state should leverage existing lists by NBI/ILFI/CPUC Recognition programs.

6.3.7 Step 7: Verify Persistence (Performance stage only)

As mentioned above, verification for ZNE performance should not be a one-time activity but rather a recurring activity every 3-5 year to ensure that the ZNE performance persists.

6.4 Required Documentation

The tables below outline the required documentation for each of the proposed project stages (ZNE Design, ZNE Performance Monitoring, or ZNE Performance Verified). Each table indicates submittal requirements for each topic and subtopic, as well as any specific reference or unit requirements depending on which ZNE metric is used. In addition, for each submittal requirement the table indicates whether the information is required, preferred, or optional. The logic for defining each item as required, preferred, or optional is as follows:

- Required: Elements listed as "required" represent the minimum information necessary to verify ZNE status for each project stage, and to validate the results of the verification.
- Preferred: Elements listed as "preferred" are typically items that would provide a more complete picture of building performance and are often elements that are "required" in subsequent project stages (i.e., an item that is "preferred" in the ZNE Design stage may be "required" in one or both ZNE Performance stages). "Preferred" elements may also be items that may not apply to all projects, such as electric cars, but should be included where applicable.
- Optional: Elements listed as "optional" represent project information that when available would help validate findings on the ZNE status of a project or help identify the source of any issues or discrepancies in the verification process.

As illustrated in the tables below, the verification process requires more complete information with each subsequent stage. All the information requested should be readily available for a typical new construction project, though the individual submittals may come from different sources or project stakeholders. Project teams are likely to approach the verification process on a case-by-case basis, depending on the stage of verification targeted. Projects that are solely focused on a ZNE Design verification may see only minimal benefit from pursuing preferred and optional submittal information. On the other hand, projects that intend to achieve one or both Performance verifications may find the preferred or optional submittals vital to identifying and resolving any discrepancies that arise that could otherwise prevent verification.

6.4.1 ZNE Design

Topic	SubTopic	Submittal Requirements	ZNE Metric Used: Site	ZNE Metric Used: Source	ZNE Metric Used: Code/TDV	Required?	Data Source
Background	Project Team Description	Owner/Developer/Builder, Architect, Engineer, Contractor, Energy Consultant, Other Consultants				Required	Building Energy Simulation Report
	Project Goals	ZNE metric targeted; specific goals and targets relevant to ZNE	Net kWh, kBtu or ERI ≤0	Net Source kBtu ≤0	Net TDV or EDR ≤0		
General Building Information	Project Name					Required	
	Location	City, County, Climate Zone					
	Building Type	Residential Single Family, Residential Multifamily Lowrise, 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	Proposed design inputs to the simulation analysis.			Optional	
	HVAC System	System capacity, efficiency, # of systems					
	DHW System	System capacity, efficiency, # of systems					
	Lighting	Lighting efficacy (lumens/watt)					
Building Occupancy	Number of Occupants	Document Design Assumptions or Defaults Used. Identify if deviating from defaults, and reasons for deviation.	ANSI/ RESNET/ ICC 301		Title 24 Defaults	Required	
	Occupancy Schedule						
	Equipment Schedule						
	Lighting Schedule						
Analysis Methodology	Software Used for Predictions	Name and version of software	ANSI/ RESNET/ ICC 301 Approved		Title 24 Approved	Required	
	Period of Analysis	Annual based on hourly analysis					
Annual Energy Consumption Onsite	Identify Energy Loads Included	List Building Energy loads Included and Excluded	Proposed design loads			Required	
	Predited Electricity Use (kWh)	Total kWh for a 12-month period	Y		Y		
	Predicted Fuel Use (Therm)	Total Therm for a 12-month period	Y		Y		
	Predited Total Energy Use Intensity	Kbtu/sf/yr for a 12-month period		Y			
	Predicted Total TDV/ Energy Efficiency EDR	TDV kBtu/sf/yr for a 12-month period OR proposed EDR			Y		
	Predicted Energy Use by End Use Category	kBtu/sf/yr by end uses - Space Cooling, Space Heating, Ventilation, DHW, Lighting, Appliances and MELs.	Y	Y	Y	Preferred	
Annual Renewable Energy Generated Onsite	Predicted Annual Renewable Electricity Produced Onsite dedicated to offset Building Energy Use	Total kWh for a 12-month period	Y		Y	Required	
		Total kBtu/sf for a 12-month period		Y			
		Total TDV/sf or PV EDR for a 12-month period			Y		
Net Energy Use Onsite	Net Building Energy Use	Based on ZNE Metric Targeted	Net kWh or ERI ≤0	Net kBtu ≤0	Net TDV or EDR ≤0	Required	
Renewable Energy Systems	Photovoltaic (PV) System Generation Capacity (kW)	Total rated capacity in kW DC and kW AC				Required	PV Design Document
	Photovoltaic (PV) System Capacity Dedicated to Offset Building Energy Use (kW)	Total rated capacity in kW DC and kW AC dedicated to offset building energy use. Renewable capacity dedicated for Electric Vehicle (EV) or Storage needs to be subtracted from the total generation capacity to calculate this number.				Required	
	Photovoltaic (PV) Orientation and Tilt	Orientation in degrees from North (0=North, 90 = East); Tilt (angle from horizontal); If multiple panels used, provide				Optional	
	Photovoltaic (PV) System Location	Specify location of renewable system (e.g. Roof). System must be installed within the building site.				Optional	
	Photovoltaic (PV) Manufacturer and Make	Make, model number, manufacturer name				Optional	
	Other Renewable Energy Systems	Rated capacity, total annual output, location onsite, manufacturer and make.				Optional	
Electric Vehicles	If Electric Vehicle Charging is Anticipated	# of Electric Vehicles Predicted to be Charging at Home				Preferred	Report
Energy Storage	Active Energy Storage System	Estimated Storage Capacity				Optional	Report

Figure 54: Proposed Documentation Requirements for ZNE Design Verification

6.4.2 ZNE Performance Monitoring

Topic	SubTopic	Submittal Requirements	ZNE Metric Used: Site	ZNE Metric Used: Source	Required?	Data Source
Background	Project Team	Owner/Developer/Builder, Architect, Engineer, Contractor, Energy Consultant, Other Consultants			Required	Owner's Statement
	Project Goals	ZNE metric targeted; specific goals and targets relevant to ZNE	Net kWh, kBtu or ERI ≤0	Net Source kBtu ≤0		
General Building Information	Project Name				Required	
	Location	City, County, Climate Zone				
	Building Type	Residential Single Family, Residential Multifamily Lowrise, 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	As-Built Conditions		Optional	Commissioning Report
	HVAC System	System capacity, efficiency, # of systems				
	DHW System	System capacity, efficiency, # of systems				
	Lighting	Lighting efficacy (lumens/watt)				
Building Occupancy	Number of Occupants	Actual average number of occupants	As-Built Conditions		Preferred	
	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.				
Building Commissioning	System Commissioning	Commissioning Report outlining key activities performed	Commissioning Report		Preferred	
	Building Operations	Building Operations Manual or other documentation outlining building operational strategies				
Billing and Metering Data	Electricity Bills	Monthly electricity bills for at least 12 months post-occupancy	Y	Y	Preferred	Utility Bills, Submeters
	Natural Gas/Fuel Bills	Monthly natural gas/fuel bills for at least 12 months post-occupancy	Y	Y	Preferred	
	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.	Y	Y	Optional	
Annual Energy Consumption Onsite	Actual Electricity Use (kWh)	Total kWh for a 12-month period post-occupancy	Y	Y	Required	
	Actual Fuel Use (Therm)	Total Therm for a 12-month period post-occupancy	Y	Y	Required	
	Actual Total Energy Use (kBtu)	Total energy use in Source kBtu for a 12-month period post-occupancy		Y	Required	
	Actual Total Energy Use Intensity	Kbtu/sf/yr for a 12-month period post-occupancy	Y	Y	Required	
	Actual Energy Use by End Use Category (Optional)	kWh and Therm by end uses - Space Cooling, Space Heating, Ventilation, DHW, Lighting, Appliances and MELs.	Y	Y	Optional	
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	Y	Y	Required	
	Actual Onsite Renewable Electricity Generation Dedicated to Offset Building Energy Use (kBtu)	Total source kBtu for a 12-month period		Y	Required	
Net Energy Use Onsite	Net Annual Actual Energy Use (kWh)	Actual Electricity Use (kWh) - Actual Annual Renewable Electricity Produced Onsite Dedicated to Offset Building Energy Use (kWh) = Zero or Negative (Note: Convert Actual Fuel Use (Therm) to equivalent Site kWh)	Y		Required	Owner's Statement
	Net Annual Actual Energy Use (kBtu)	Actual Source Energy Use (kBtu) - Actual Annual Renewable Electricity Produced Onsite Dedicated to Offset Building Energy Use (kBtu) = Zero or Negative (Note: Convert all fuels to source energy)	Y	Y	Required	
Renewable Energy Systems	Photovoltaic (PV) System Generation Capacity (kW)	Total installed rated capacity in kW DC and kW AC			Required	PV Installation Review
	Photovoltaic (PV) System Capacity Dedicated to Offset Building Energy Use (kW)	Total installed rated capacity in kW DC and kW AC dedicated to offset Building energy use. Renewable capacity dedicated for Electric Vehicle (EV) or Storage needs to be subtracted from the total generation capacity to calculate this number.			Required	
	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			Optional	
	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			Optional	
	Photovoltaic (PV) Manufacturer and Make	Make, model number, manufacturer name			Optional	
	Other Renewable Energy Systems	Rated capacity, total annual output, location onsite, manufacturer and make.			Optional	
Electric Vehicles	If Electric Vehicle Charging is Anticipated	# of Electric Vehicles Charging at Building			Preferred	Owner's Statement
Energy Storage	Active Energy Storage System	Actual Storage Capacity			Optional	

Figure 55: Proposed Documentation Requirements for ZNE Performance Monitoring

6.4.3 ZNE Performance Verified

Topic	SubTopic	Submittal Requirements	ZNE Metric Used: Site	ZNE Metric Used: Source	Required?	Data Source
Background	Project Team	Owner/Developer/Builder, Architect, Engineer, Contractor, Energy Consultant, Other Consultants			Required	Owner's Statement
	Project Goals	ZNE metric targeted; specific goals and targets relevant to ZNE	Net kWh, kBtu or ERI ≤0	Net Source kBtu ≤0		
General Building Information	Project Name				Required	
	Location	City, County, Climate Zone				
	Building Type	Residential Single Family, Residential Multifamily Lowrise, 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	As-Built Conditions		Optional	Commissioning Report
	HVAC System	System capacity, efficiency, # of systems				
	DHW System	System capacity, efficiency, # of systems				
	Lighting	Lighting efficacy (lumens/watt)				
Building Occupancy	Number of Occupants	Actual average number of occupants	As-Built Conditions		Required	
	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.				
Building Commissioning	System Commissioning	Commissioning Report outlining key activities performed	Commissioning Report		Required (Commercial Buildings)	
	Building Operations	Building Operations Manual or other documentation outlining building operational strategies				
Billing and Metering Data	Electricity Bills	Monthly electricity bills for at least 12 months post-occupancy	Y	Y	Required	Utility Bills, Submeters
	Natural Gas/Fuel Bills	Monthly natural gas/fuel bills for at least 12 months post-occupancy	Y	Y	Required	
	Renewable Electricity Metering	Monthly renewable electricity production for at least 12 months post-occupancy. If separate PV Meter is not installed onsite, note source of estimate.	Y	Y	Preferred	
Annual Energy Consumption Onsite	Actual Electricity Use (kWh)	Total kWh for a 12-month period post-occupancy	Y	Y	Required	
	Actual Fuel Use (Therm)	Total Therm for a 12-month period post-occupancy	Y	Y	Required	
	Actual Total Energy Use (kBtu)	Total energy use in Source kBtu for a 12-month period post-occupancy		Y	Required	
	Actual Total Energy Use Intensity	Kbtu/sf/yr for a 12-month period post-occupancy	Y	Y	Required	
	Actual Energy Use by End Use Category	kWh and Therm by end uses - Space Cooling, Space Heating, Ventilation, DHW, Lighting, Appliances and MELs.	Y	Y	Preferred	
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	Y	Y	Required	
	Actual Onsite Renewable Electricity Generation Dedicated to Offset Building Energy Use (kBtu)	Total source kBtu for a 12-month period		Y	Required	
Net Energy Use Onsite	Net Annual Actual Energy Use (kWh)	Actual Electricity Use (kWh) - Actual Annual Renewable Electricity Produced Onsite Dedicated to Offset Building Energy Use (kWh) = Zero or Negative (Note: Convert Actual Fuel Use (Therm) to equivalent Site kWh)	Y		Required	Owner's Statement
	Net Annual Actual Energy Use (kBtu)	Actual Source Energy Use (kBtu) - Actual Annual Renewable Electricity Produced Onsite Dedicated to Offset Building Energy Use (kBtu) = Zero or Negative (Note: Convert all fuels to source energy)	Y	Y	Required	
Renewable Energy Systems	Photovoltaic (PV) System Generation Capacity (kW)	Total installed rated capacity in kW DC and kW AC			Required	PV Installation Review
	Photovoltaic (PV) System Capacity Dedicated to Offset Building Energy Use (kW)	Total installed rated capacity in kW DC and kW AC dedicated to offset Building energy use. Renewable capacity dedicated for Electric Vehicle (EV) or Storage needs to be subtracted from the total generation capacity to calculate this number.			Required	
	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			Optional	
	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			Optional	
	Photovoltaic (PV) Manufacturer and Make	Make, model number, manufacturer name			Optional	
	Other Renewable Energy Systems	Rated capacity, total annual output, location onsite, manufacturer and make.			Optional	
Electric Vehicles	If Electric Vehicle Charging is Anticipated	# of Electric Vehicles Charging at Building			Preferred	Owner's Statement
Energy Storage	Active Energy Storage System	Actual Storage Capacity			Optional	

Figure 56: Proposed Documentation Requirements for ZNE Performance Verified

7. Recommendations

7.1 Proposed mapping of Use Cases and ZNE Verification Levels

As identified in Section 6, there are various potential end users for these verification methods and different levels of rigor that they are likely to need with ZNE verification. On one end of the spectrum are all the voluntary claims of ZNE design and performance that need to be credible but may not need independent verification, whereas on the other end of the spectrum, the verification activities need to be conducted by independent third parties subject to stringent requirements.

Figure 57 shows the proposed mapping of the intended users and the ZNE Verification Levels. As discussed above, the Verified designation is most useful to those users who need independent verification of ZNE claims to justify spending ratepayer funds (program implementers, CPUC) or meet contractual obligations (designers and MEP firms that have signed performance guarantees).

Intended Use Cases/Users	ZNE Design	ZNE Performance Monitored	ZNE Performance Verified
Homeowners	X	X	
Residential Builders	X		
Commercial Developers	X	X	
Designers and MEP Firms	X	X	X
Local building code officials	X		
Program Implementers	X		X
CPUC			X

Figure 57: Intended Use Cases for the ZNE Verification Levels

7.2 Need for ZNE Registry

TRC has developed comprehensive methods for verifying claims of ZNE Design and Performance based on extensive review of existing ZNE projects – a total of 90 projects were reviewed for this study. To date, this is the most comprehensive review of California ZNE buildings that included both quantitative (review of underlying energy use and generation data) as well as qualitative (degree of difficulty and accuracy of verification methods). However, this is still not likely an exhaustive list and with the expected increase in ZNE construction in the state, there is a need to conduct ongoing tracking of ZNE claims and verifications.

Ideally, the CPUC would work with its sister agencies (CEC, CARB) to develop such as registry or at least support the development of such a registry. The registry would allow for a transparent way to provide insights into ZNE growth, energy performance of ZNE buildings and challenges and opportunities for ZNE buildings.

7.3 ZNE Performance Verification Not be a One-time Activity

As outlined in Section Verification Process, the status of ZNE Performance Monitoring or ZNE Performance Verified should be in perpetuity but rather a time-bound rating like how vehicles need to prove they are meeting emissions standards every few years. We recommend that buildings undergo ZNE performance verification every 3-5 years to get insights into whether/how ZNE buildings can maintain energy performance.

8. Appendices

8.1 "Call for Data" Handout

Call for ZNE Building Design and Performance Data

On behalf of the statewide IOUs led by PG&E, TRC issues a call to the industry for information on Zero Net Energy (ZNE) buildings:

1. ZNE building project data – energy design and performance
2. ZNE project stakeholder interviews to understand key issues with ZNE design and performance

Share your data and insights – to help inform future California ZNE building verification methodologies.

Entities and programs that verify ZNE buildings will benefit from your information, and California utilities and regulatory agencies can use this information to consider the implications of potential ZNE-related policy choices.

PARTICIPATION CRITERIA

- Projects designed and intended for ZNE performance
- Residential or non-residential projects
- Retrofit or new construction projects
- Projects located in California
- ≥ 1 year data post-performance (if submitting data)

POTENTIAL DATA TYPES

- Modeled energy performance – core compliance models and as-built engineering drawings
- Utility meter data (annual) – net or separate energy use/renewable energy
- End use monitoring (annual or hourly)

** TRC will anonymize data unless specifically requested otherwise.*

Submit your data and/or volunteer for an interview by

October 31

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For more information on TRC ZNE research, visit: http://www.trcsolutions.com/services/energy-efficiency/zero-net-energy-emerging-technologies

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