The Road to ZNE

Mapping Pathways to ZNE Buildings in California

APPENDICES

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9. Appendix A: Goals and Objectives

9.1 Study Goal

The goal of this study is to identify:

- Pathways to achieving ZNE for new construction residential buildings by 2020
- Pathways to achieving ZNE for new construction commercial buildings by 2030

This study has established a ZNE framework to understand what progress has been made toward the ZNE goals from, as well as what remains unknown about whether the ZNE goals can be achieved. Relevant issues and potential pathways for pursuing the ZNE goals have been flagged, such as codes and standards, IOU programs, workforce education and outreach, among others.

While residential and commercial sectors were addressed independently and the differences between the two are outlined where necessary, this report outlines a single set of pathways to pursuing the ZNE goals.

9.2 Study Objectives

This study has three main objectives as explained below. These objectives are interrelated in their intent and scope and together guided the study process. Rather than addressing each objective independent of the other, the team addressed all three objectives together through our research methodology explained in the following sections.

9.2.1 Objective I: Establish Framework for ZNE Research

Objective I involved defining a Framework that guided development of this study and the parallel Technical Potential study to characterize the market for ZNE in California. The Framework is intended to serve as the basis for setting the ZNE research agenda and to identify pathways to operationalize the ZNE goals identified in the Strategic Plan.

The Strategic Plan sets overall targets for achieving ZNE in new construction and existing buildings. However, the Plan is not specific about critical concepts including (but not limited to):

- What a building must achieve to be ZNE
- Building-level energy use intensity (EUI) performance goals
- Actions that owners and designers can apply during the design process and during building operations and maintenance
- User interaction and feedback impacts on ZNE buildings
- Barriers and opportunities from the policy, market and user perspectives

Our task is to translate the Strategic Plan targets into an actionable Framework, and from this to develop research objectives for the next stages of the ZNE strategy that address the concepts listed above.

The focus is on new construction; however, the team will also target relevant information for existing buildings that are trying to reach ZNE.

9.2.2 Objective II: Perform Market Assessment that Identifies Market Intervention Strategies

The second objective of the study is to conduct an assessment of market intervention strategies to identify opportunities and address barriers to the ZNE goals for new construction and major whole building renovations. Work on this objective was based on the literature review and research conducted for Objective I.

This objective is further divided into four focus areas that need to be addressed. It should be noted that not all focus areas did not receive equal attention in terms of project resources. This is further explained in the Research Methodology section of this document.

The first focus area characterizes the current and projected market structure associated with ZNE new construction and major whole building renovations. This identifies the major market actors, their perspectives and motivations towards the ZNE goals and identify opportunities and barriers for achieving the ZNE goals from the market perspective.

The second focus area maps existing regulations, policies, and practices related to building or project design and construction, building operations, and user interaction and feedback. This identifies and develops suggestions for addressing barriers created by conflicts in these regulations or policies.

The third focus area identifies constraints and opportunities that are common across like groups of climate zones. This enabled the development of region-specific strategies for achieving the ZNE goals and also enables regulators and market actors to look at a finite range of weather conditions rather than look at each of the sixteen (16) climate zones officially considered by the Title 24 energy code.

The fourth focus area (and one with limited project resources expended) identifies physical and operational challenges at the grid level that will need to be addressed for the widespread ZNE development needed to meet the Strategic Plan's ZNE goals.

9.2.3 Objective III: Develop a Road to ZNE for Residential and Commercial New Construction

This objective is the net result of the work conducted on the previous two objectives and is the basis for the recommendations and results from this project. The focus of this objective is to utilize the framework (Objective I) and all recommendations from the market assessment (Objective II) to identify pathways for key market actors and institutions to address the barriers and research challenges identified in Objective II.

This is the final deliverable from this study and will serve as a Road to ZNE for market actors in CA. It identifies goals and objectives for meeting the ZNE goals in the Strategic Plan. Specifically, it supports the ability of market actors in California to understand issues related to designing, building, and operating residential and commercial ZNE buildings.

9.3 Study Process

A large body of research has already been completed in each of the specific focus areas covered by this study. This study therefore is a meta-analysis that builds on this existing work. A thorough literature review is the foundation of the project. In addition, data collection includes individual communications as well as structured interviews with market actors.

In our analysis, we strive to understand the connections between the various inputs and studies, as well as the connections and interactions between different market actors.

Further details are provided in the following sections where each of the study objectives is explained along with our approach for the same.

9.4 Limitation of Project Scope

The Road to ZNE project has the following limitations to its scope and recommendations:

- While this study identifies potential pathways to the ZNE goals, it does not prescribe specific regulatory language. The intent of this study to provide a framework that will highlight issues and point out policy choices to be made, rather than suggesting prescriptive regulatory recommendations.
- This study focused more on the new construction ZNE goals relative to the retrofits/renovation ZNE goals due to time and budget constraints.
    - The study findings and recommendations are thus more focused on new construction though many of these apply to retrofits as well. However, barriers and opportunities unique to retrofits are not addressed in this report.
- This study performed an assessment of the early adopters of ZNE to identify market intervention strategies, but this is not a market characterization study. This early assessment provides recommendations on future research needs, such as a thorough market characterization.
- This study did not conduct research on the interactions of electric vehicles charging at homes and work places on the achievement of ZNE goals. This study also did not research the impacts of electric vehicle charging on the need for grid and renewable generation nor did it look at the impact of vehicle charging on the grid.
- This study did not conduct an exhaustive research on the renewable options available to meet ZNE. We provide high level information on the most widely used renewable – solar photovoltaic – in this report but it is not intended to be a detailed market study of solar. There are several other worthy renewables technologies that can be used in place of, or along with, solar but this study did not investigate them in detail.
- This study does not include analysis of energy storage solutions for renewables.

In a similar vein to the caveat above, the study does not answer each and every question that arose during the course of our research. Our approach was to identify research questions that need further study in our recommendations. This project thus serves as a gateway to prioritize ZNE research needs and questions to be answered.

10. Appendix B: Assessing Market Attitudes Towards ZNE Goals

10.1 Market Actors

Because a building is the product of many market actors, the achievement of ZNE goals statewide will require active engagement and support of many market actors. In addition to the policy setting agencies and the IOUs, the market actors include the design community, builders and trade professionals, financing agencies, building owners, building operators, commissioning agents, ratings agencies, research community and building occupants. Note that the market actor matrix is not a list of individuals or companies but rather a list of categories of market actors. Thus, building designers are listed but not the individual designers.

10.1.1 Policy Setting Agencies

Role: Policy setting agencies include federal, state, sustainable communities, and local policy and zoning bodies. These entities set ZNE policy or mandates for the community, state, or nation. They also play an important role in providing financial incentives, rebates, and other financial assistance to help market actors achieve ZNE. Policy setting agencies also carry the responsibility for ensuring implementation of ZNE, or ZNE-equivalent buildings are not "ZNE at any cost", and do not negatively impact nonparticipating customers.

Incentives: Policy setting agencies have an incentive to promote ZNE because of the large energy savings – which helps meet their energy efficiency mandates long term.

Barriers: Achieving ZNE on existing or new buildings can be a significant financial barrier to most market actors. The role of a policy setting agency is to provide financial incentives to help offset some of the cost to achieving ZNE. Due to the high cost of ZNE, funding incentives high enough to encourage implementing ZNE is a large barrier for such agencies.

10.1.2 Utilities

Role: Utilities include IOUs and Municipal districts. The utilities play an integral role in ZNE efforts because of mandates enforced upon them to conserve energy. To do so, the utilities offer programs and incentives to their customers to implement ZNE. Utilities can also inform the process of avoiding negative impacts to nonparticipants from pursing ZNE.

Incentives: Their incentive to promote ZNE is to meet their mandated energy reduction goals set upon them by the CPUC and CEC.

Barriers: The barriers utilities face in promoting ZNE are similar to that of the policy setting agencies, providing enough incentives. Due to the high cost of ZNE, funding incentives high enough to encourage implementing ZNE is a large barrier for utilities. In addition, to the extent ZNE includes renewable DG, Utilities must ensure interconnection policies meet safety and reliability standards and that increased integration costs are recognized and appropriately recovered.

10.1.3 Design Community

Role: The design community is made up of planning & entitlement agencies, architects & designers, engineers, and energy & green building consultants. These market actors play a large role in ZNE goals being achieved, whether it be a single building or a community effort. They offer the design and engineering knowledge behind efficient building systems, mechanical systems, and renewable infrastructure.

Incentives: Their likely incentives are to provide clients design and engineering solutions to achieve their goal of ZNE and as a result, gaining in depth knowledge of ZNE practices and differentiation in competitive markets.

Barriers: A major barrier for the design community is the lack of market demand for ZNE buildings.

10.1.4 Builders and Trades

Role: Builders and trade professionals are the hands on skilled labor implementing new designs and system solutions to achieve ZNE.

Incentives: Their likely incentives are to provide clients with a one-stop shop for implementation of ZNE design and construction solutions. In addition, to serving a up and coming market.

Barriers: Many ZNE projects require renewables (i.e. solar) to achieve their goals, finding subcontractors (i.e. electricians) who also have renewable systems experiences is limited. In addition, many contractors or trades may have to hire out to specialists for skilled labor in renewables or other advanced systems designs.

10.1.5 Building Materials & Technology Manufacturers, & Supply Chains

Role: These are the industry actors that develop and supplies advanced building materials and technologies to support ZNE infrastructure within buildings.

Incentives: Creating an emerging technology or material with a potential to serve the needs of an up-and-coming market.

Barriers: A lack of market demand for advanced materials and technologies can be a barrier for manufactures and supply chains to develop and carry such products.

10.1.6 Financing

Role: Financing institutions and organizations such as PACE, on-bill financing, energy efficient mortgages, PPA's, banks and lenders, appraisers, and real estate brokers all make up the financing segment of ZNE. Their role is to supply financial assistance to market actors implementing ZNE projects.

Incentives: Promoting a vibrant new construction and retrofit industry that improves overall economic stability and provides steady and low-risk income for lenders and investors

Barriers: Lack of metrics to assess valuations for ZNE buildings compared to traditional construction

10.1.7 Building Owners & Operators

Role: Building owners are the decision makers to pursue ZNE projects on their buildings. While building operators play an integral role in post-occupancy, commissioning, and maintenance after the ZNE measures have been implemented.

Incentives: Less operational costs long term.

Barriers: Limited financial and labor resources for ongoing maintenance and commissioning of the building's advanced systems.

10.1.8 Organizations & Programs

Role:
Organizations and programs such as USGBC, ASHRAE, IESNA, the President's Climate Commitment, Living Building Challenge, and Green Point Rated are designed to assist the public or their members in achieving their ZNE goals. Many times these entities will create an incentive by certifying a building has met a certain standard.

Incentives: The incentive these entities have in creating ZNE certifications or programs is to help the public or its members achieve a higher standard of energy efficiency. These organizations mission and goals is to promote energy efficiency and reduce energy consumption of buildings.

Barriers: The primary barrier for such organizations is the lack of ZNE knowledge in the marketplace and commitment of building owners to pursue ZNE.

10.1.9 Research Community

Role: The research community is made up of government labs, federal and state agencies, universities, institutions, and consulting agencies. Each has its own goals and understanding of ZNE standards. These groups conduct research, develop strategies, and inform the industry to energy efficiency strategies.

Incentives: The primary goal of many in the research community is to develop understanding and develop new strategies to inform the energy efficiency industry. Contributing to new developments in the industry serves as an incentive for this market segment.

Barriers: Lack of consistent ZNE definition.

10.1.10 ZNE Education

Role: The market actors in this category are many of the same universities and institutions found in the research community. Their role is to inform and educate the public and industry to energy efficiency strategies to achieve ZNE.

Incentives: Many organizations in this segment have a goal to inform and educate outside of their organization to create broader understanding and acceptance of ZNE.

Barriers: Lack of consistent ZNE definition.

10.2 Summary of Market Actor Interviews

From the market actor matrix, we reached out to a number of market actors to conduct formal interviews. Concentrating on early adopters and key players, we conducted over 40 formal interviews, in addition to a number of informal discussions. Interviewees included:

- Policy setting agencies
- Utilities
- Engineers, consultants, and designers
- Builders and trades
- Financing institutions
- Building owners and operators
- Organizations and programs
- Researchers
- ZNE educators

In this section we present the summary of views expressed by market actors in the interviews without any commentary or recommendations from the study authors. While a number of our recommendations made in the main body of the report are partially based on these interviews, there is a broader set of opinions expressed in this section than those shared by the study authors based on the summation of all available information in addition to the interviews.

10.2.1 ZNE Definition

When asked about their working ZNE definition, the market actors interviewed provided a range of responses. The most common response (and most the most preferred) was ZNE Site energy. Some of the benefits listed for net site energy were that it is the "strictest" definition and that it is generally easier to explain to the owner. However, they also pointed out gas offsets can be challenging.

A number of other definitions were also listed, such as ZNE Source, ZNE all electric, ZNE electric-only, or reaching a triple goal of zero energy, emissions, and landfill. Emerging definitions that were commonly mentioned were ZNE ready or ZNE Equivalent and community scale ZNE.

For ZNE ready or ZNE Equivalent buildings, market actors felt that this was a logical choice because it focuses on deep energy efficiency measures, supporting the loading order. They pointed out that not all buildings can (or should) reach ZNE onsite, but they all should be low energy. However, care should be taken when determining the location of generation or giving credits because of grid ramifications and room for manipulation.

A number of the market actors also recommended considering a community scale ZNE definition. As with ZNE ready/equivalent, generation should not be forced onsite if it doesn't make sense. Considering a community scale solution would allow for more flexibility in renewable options, such as wind, biogas, and micro-hydro. Additionally, community scale solutions would allow some buildings to be net producers. However, care should be taken to consider the locational effects on the grid.

Another common piece of feedback on the ZNE definition was that there should be quantitative performance metrics, such as kBTU/sf/yr targets. Market actors felt that performance should be measured for at least a year, rather than just modeled for a building to be truly called a ZNE building.

When asked about TDV-based ZNE definitions, such as the one recommended in the 2011 IEPR, market actor opinions were fairly split. On one hand, some remarked that TDV is the most expansive in terms of the benefits captured and a good way to address peak electricity use. However, a number of drawbacks were also listed. Some market actors felt that a TDV based definition would be difficult to explain to building owners. If adopted, it would need to be clear that zero TDV does not mean zero bill--or zero energy or emissions. Some felt that compared to definitions like site ZNE, a TDV based definition feels 'watered down'. Additionally, some felt that this path is myopic and too specific to CA. Others also pointed out that TDV is a derived metric that may need to be updated regularly with code cycles.

Many market actors also said that the exact definition of ZNE is not a major concern for them. They said they would ultimately adopt whatever definition the regulatory agencies use. They want a definition that doesn't motivate the "wrong" behavior, such as valuing ZNE at all costs versus balancing the needs of sustainable communities. But, for now, their real goal is to cost effectively find the lowest energy usage. And again, to do this, many felt that measured performance targets would be essential.

10.2.2 Value of ZNE

When asked about the value of ZNE, many market actors commented on different motivations from the standpoint of consumers versus practitioners. At this point, we are still in the early adopter phase. Valuing ZNE can be challenging because the market is so new.

For consumers, ZNE is seen as an investment opportunity with the potential for higher returns on sale, resale, or lease. ZNE buildings can also have lower operating costs. This is especially desirable to schools and universities. With constraints on their operating budgets, shifting costs from operation to upfront capital can be very appealing. Additionally, schools have the potential be a living laboratory where students can learn to use energy differently. Other consumers may be seeking recognition for corporate responsibility. Increased energy security, comfort, health, and productivity were other possible motivating forces for ZNE buildings. And finally, some consumers, especially in the early adopter market are seeking ZNE out of an altruistic response to the climate crisis.

For builders, designers, and engineers, aiming for ZNE today is a way to get ahead of the curve or distinguish themselves in the market. Additionally, ZNE encourages integrated design, which is a desirable framework for many of the market actors.

10.2.3 Challenges and Barriers to ZNE

A number of challenges and barriers to ZNE exist today. Onsite generation continues to be a challenge due to site limitations, difficult building types, net metering caps, and the question of gas offsets. Many said they would have installed larger systems if they knew they would be able to sell it. In general, appropriate recognition of the challenges of on-site generation would include: consideration of community renewable programs that do not shift costs to nonparticipating customers; exploration or rates designed to recover the cost to serve ZNE buildings; and large scale research to understand the grid impacts of ZNE.

Cost effectiveness and financing options also continue to be a barrier to ZNE. Risk causes technology and services to be overpriced, which especially hurts new technology. Separate incentive funds for energy efficiency and renewables can make the financing process more complicated. Additionally, new rate structures will need to be introduced--and explained, since ZNE will not mean zero bill. In general, there is a need for a more streamlined process to achieve ZNE and long term cost benefit analysis. Any cost benefit analysis of a program or measure that is not societally cost-effective should include an examination of the costs shifted to nonparticipating customers.

Many market actors pointed to split incentives and a lack of aligned interests as a major barrier. For example, there is currently little motivation for designers, builders, owners, and operators to work together on common goals.

Market actors pointed to the diversity in California climate zones that will necessitate solutions specific to those climate zones. This makes the ZNE goals a challenge on some levels since one cannot apply solutions across the board for building located in different areas of the state.

A big barrier to ZNE identified by multiple stakeholders and early adopters is the lack of a trained workforce that can install the envelope and systems needed for ZNE. Untrained workers and poor installation quality were commonly mentioned as a significant barrier to making sure that we can actually construct ZNE building as intended.

Having multiple ZNE metrics was often cited as being confusing, and potentially conflicting. The market needs a clear signal from regulators on what they expect the market to do over the next few years.

As a bottom line, many market actors felt that the main ZNE challenges are not technological. Many see the larger challenge as figuring out how to move past early adopters to the mass market. There is a need to invest in continued public education and marketing campaigns.

10.2.4 ZNE Opportunities

First and foremost, ZNE is exciting! It is a rallying call. This is a goal that many people want to learn more about and are enthusiastic about finding solutions for. While California may or may not reach the statewide ZNE goals, having them in place helps to push for faster progress.

More example buildings will help to move past the early adopters. We should focus on the highest impact areas or ones that are likely for success first. We should also highlight and recognize the early adopters. And we should be monitoring and continuously commissioning these building so that we can learn from experience. With more example buildings, we can also explore more ways to engage the owners, occupants, and operators.

Furthermore, we should explore synergies between energy efficiency, demand response, distributed generation, and storage technologies. We should also consider community scale solutions.

There is the also the opportunity to build infrastructure through utility programs and workforce training.

10.2.5 ZNE Design

Three elements were highlighted as import features to successful ZNE design processes:

- **Integrated design:** Almost all of the market actors interviewed said that an integrated design process is essential to the success of a ZNE project. For example, several said that design charettes have been very valuable to their design process. They provide a way to get different players on the same page early in the process. Additionally, experience can be mined across the teams, rather than having isolated teams only working on their specialty. This is especially valuable to ZNE projects, which often involve multidisciplinary challenges.
- **Early performance goals:** Related to the integrated design process, many market actors also said that setting early performance goals is very important. With early performance targets, teams are encouraged to incorporate energy modeling early in the process to explore options such as geometry and orientation. Finding optimal energy solutions can then be paired with design for renewables, and iterated as needed.
- **Aligned interests:** In the current design process, there is a lack of aligned interests to encourage designers, engineers, builders, owners, occupants, and building operators to work together to achieve common goals. Current market actors want to find a way to give financial value to good design and installation. In the current market, projects often go to whoever is the cheapest, with little value attributed to actual performance. On one hand, design teams want to deliver a high quality product, but they need to be able to compete financially. On the other hand, owners may be interested in efficient buildings with lower operating costs, but they need to be able to mitigate the risk of any extra capital investment. One possible solution suggested would be to have higher fees for performance based design and installation, but to share the operating costs of the building for the first year between the various parties.

10.2.6 Monitoring

There is a general consensus that buildings should be monitored at least at the circuit level for monitoring ongoing energy use. Market actors want to see commissioning and monitoring become the industry standard. From the perspective of designers and consultants, they felt that currently the decision to monitor is often driven by the owner and the cost. Some have received support through programs, but they felt that it would be very helpful for programs to continue to provide funding and support for monitoring buildings. They also pointed out that currently, monitoring is being used to validate the performance of a particular technology, but they would prefer to see this move toward whole building continuous commissioning. Several market actors said they are monitoring their ZNE projects, but that the data is still in very early phases.

10.2.7 User Education

When asked about the role of user education, the market actors generally diverge into two schools of thought:

- **User education is very important and a big missing piece along the way to ZNE.** For example, these market actors want to see more demonstration projects, dashboards (especially useful in schools), and building user manuals with regular maintenance schedules--like with a car. One market actor felt that we should think about "recommissioning" the client to be sure that they know how to use their building and that it is responding as expected. Additionally, research has shown that occupants have a wider range of comfort when they feel that they have control over their environments, so there is the potential for substantial setback savings with educated occupants.

There are a number of unresolved issues with user education. For example, who owns the data and where is it stored? Does occupant feedback have lasting results? In general, quantifying the effect of user education and occupant feedback is difficult and warrant further research.

- **Buildings should be designed to require very little user input/control.** In contrast, other market actors believe that people will do whatever they want and the more we can automate the better. Under this approach, smart buildings and building management system are key. For example, rather than focusing on schedules and thermostat settings, design teams could concentrate on appropriately sizing and correctly installing the HVAC system. In the case of residential systems, one market actor has seen installing HVAC that are about one quarter the size of typical installations can be run all the time and still achieve energy savings. However, there are also a number of issues to be resolved with building controls. For example, controls rarely perform as expected and they should be carefully commissioned.

10.2.8 What Should the State be Doing?

- Marketing: Some efforts are underway to address the need for ZNE marketing, but one of the most common barriers to ZNE that was listed is the lack of consumer demand for ZNE. At this point, many consumers are not familiar with the concept, and if they are, many are not yet ready to invest any additional capital into a ZNE project. It would be very helpful to develop the case for ZNE buildings. Furthermore, some market actors said that while utilities often have good programs, often people don't know about them.
- Education: Almost all of the market actors interviewed said that there is a need for increased education. This applies to consumer, workforce, and marketing/outreach educations efforts.
- Streamlined process: Many market actors said that there are good programs and incentives already in place, but that there is a need to streamline the process. They feel that the extensive paperwork is a barrier that is difficult to surmount given tight design schedules.
- Design Assistance: In line with the desire for increased education efforts, many market actors also said that providing technical design assistance would be essential in moving past the early adopters.
- Mandates: Most market actors felt that we will not reach our ZNE targets with voluntary efforts. They believe that if the state continues to the increase requirements, then people with figure out how to reach them. This recommendation needs to be balanced against cost, however, as the state should not pursue "ZNE at any cost".
- Financing options: There is a need for long term solutions for third parties. Additionally, it should be easier to incorporate ZNE costs into existing mortgages and not just be limited to new construction.

- Aligned interests: The state is in a position to be a facilitator between different market actors and helped to created aligned interests through programs, incentives, and policies.
- Net metering: Most market actors felt that net metering is a critical component to the success of ZNE. However, since net metering imposes costs on nonparticipants, the state should explore pursuit of "ZNE Equivalent" goals.
- Community scale solutions: Many market actors felt that our ZNE goals should be framed at the community level, rather than building by building. For some building types, there is simply not enough roof space to reach ZNE with onsite PV. Community scale ZNE allows resources to be pooled and to consider more options, such as cogeneration and district hot water. The state should explore community renewable programs that do not shift costs to nonparticipating customers.
- Research funding: There is a need for further research efforts in a number of areas, including energy management systems, plug loads, behavior, grid impacts and pricing, long term cost benefit analysis.

10.2.9 General Prognosis

Most market actors agree that ZNE is technically feasible for many buildings, but that we will not reach our goals with our current trajectory. On the residential side, most market actors felt that the biggest challenge is the time constraint combined with lack of market traction for ZNE and costs of doing ZNE construction. On the nonresidential side, there are more challenging building types to contend with.

The main issues are cost effectiveness, plug loads, and the need for consumer, workforce, and marketing/outreach education. Most market actors felt that voluntary efforts won't get us there in time and if we are to implement appropriate codes in time, we need to make the changes now. A number felt that this is the time to go all in with a "revolution, not evolution."

10.3 Priority Commercial Markets for ZNE Adoption

The process of innovation begins with a very small set of innovators, perhaps 1 percent to 2 percent of the market, who are inspired to create ZNE properties. In general, owners and designers of projects that achieve Gold and Platinum levels in LEED New Construction (NC) represent this leadership, along with a handful of ZNE and ZNE Capable buildings already developed in California over the last few years. In an example of how the market might move towards ZNE, approximately 10 years ago the earliest adopters of LEED-NC tended to be private schools, colleges and universities, environmental groups and corporate offices—all entities with a business interest in being seen as innovative and future oriented, and also markets where more time spent on design was allowable within the business framework. More recently, LEED-NC has become almost a market requirement for new commercial office real estate in urban centers, but not until tenant interest, relatively low costs of compliance, and marketing benefits made green construction less risky than standard construction.

A similar pattern of innovators leading to early adopters leading to broad market adoption is anticipated for the ZNE market. Strategies that consciously support a market transformation strategy should be able to accelerate the market adoption curve by emphasizing markets that focus on the future, desire to be seen as leaders, or obtain other market benefits from adopting advanced strategies. Other factors that can help advance market adoption are market organization and control points, technical feasibility for the building type, and reasonable cost/benefit scenarios.

Key target groups that, with the right cultivation and support, can help advance ZNE adoption more rapidly are:

- **Education**—Both K-12 and higher education have already demonstrated an interest in deep energy efficiency and ZNE projects. Among the key reasons why k-12 schools are an early adopter market are:

  The K-12 market is well organized and easy to reach, both at the owner level and at the design community where a small number of firms specialize in schools.

  Educational buildings are operated for long periods of time by their owners, and the benefits of lower operating costs are an important consideration in the budgeting process.

  Educational buildings offer opportunities to engage students and the community in learning activities related to energy, building science and environmental relationships. Schools are preparing students for the future, and the buildings can be a teaching tool as well as a symbol of thinking about the future.

  From a technical perspective, energy densities in schools are relatively low, and most buildings are low rise with reasonable solar access, making zero-net energy projects more feasible than in many other markets.

  And, perhaps most importantly, the success of the Collaborative for High Performance Schools (CHPS) over the last decade has already paved the pathway to higher performance schools. CHPS has been supported by utility energy efficiency efforts for the ability of schools to deliver savings. While CHPS was founded in California, it has now been adopted in 10 states, demonstrating the strength of the model.

  At the university level, several ZNE and very high efficiency buildings have already been developed, for example, on the UC Merced and UC Davis campuses. A focus on leadership and the future can be important to the identity and marketing of higher education. Like K-12, buildings are in use for many years, and low operating costs are important. Both individual and campus scale projects are possible.

- **State and Local Government Buildings** – The Governor has already recognized the role of government leading the market by example to ZNE and has issued an Executive Order to accelerate the transition of state buildings to ZNE by 2025 for both new and existing facilities. Similar opportunities for leadership exist at the local government as well. Again, the long service life and ownership constancy of government buildings make ZNE goals more important than markets with tenant changes over time. A recent national meeting of multiple states and cities targeted education and state/local government buildings as the most appropriate markets for ZNE.

- **Retail**— While the retail market is quite diverse, elements of retail, particularly chain dry goods that build to suit, are another large commercial market with relatively low energy intensities and some leadership in deep efficiency and zero-net energy. Walmart, Target and other major retailers have been active in the DOE Retailers Alliance and participants in new construction programs. Because chain retailers with larger building footprints build to a prototypical design, a given design/technology/control solution set can be applied to many projects with limited variation, reducing design costs and supporting bulk purchase arrangements.

- **Offices**—Offices are the largest commercial building type in California at approximately 1 billion square feet. Office properties are the most active market in ENERGY STAR benchmarking. However, ownership is quite diverse with public, corporate and commercial real estate interests. Public and corporate owners are more likely to participate in the early stages; commercial real estate interests will follow only when costs, risks and the business case for ZNE are more fully understood. Within the office market, the best initial candidates for ZNE will be low-rise buildings, although deep savings are possible for all office types.

The general approach to all of the leading markets can be similar, combining a market specific outreach and communication approach with the well-established statewide Savings By Design program providing technical support and incentives. To reach deeper savings and ZNE goals, the role and elements of the Savings by Design must be enhanced and more clearly focused, as demonstrated by early successes with a Path to Zero program element within Savings By Design (and a similar pilot effort at the Energy Trust of Oregon).

While building codes may be the ultimate strategy that will bring ZNE to the whole market, it is important to begin working with leading markets and early adopters to better understand costs, bring emerging technologies to scale (and reduce prices), and help the design/construction/building operations industry work to assure performance and reduce risks. Pushing regulatory strategies too far and too fast could lead to significant resistance from owners and developers.

The business case for each market and submarket of commercial buildings is different, based on access to financing, market position, intended use or ownership of the building over time, and a variety of other issues. Building the business case (costs, performance risks, building value, market perception of leadership or productivity, etc.) in each market will be critical, so expanding real world examples in each market will be important to track and share within the market. Building this solid body of evidence in the early adopter buildings within each market will be critical to convince the majority of owners that ZNE buildings can move to a reasonable option for consideration, and then finally to a market expectation and/or a code reality.

11. APPENDIX C: ROLE OF BUILDING OPERATORS AND OPERATIONS

This section presents a summary of the literature review findings. These findings inform the recommendations made in the main body of the report but there is not a one-to-one correlation between a finding in this section and a recommendation made in the main body of the report.

11.1 Impacts of Building Operations, Maintenance, and Occupants on Building Energy Use

11.1.1 Defining Building "Users"

Building "users" are typically considered as a single group of occupants who work in the building. Most occupant engagement programs focus on this group of occupants. It is important to recognize that there are really four distinct building "user groups", each with a unique sphere of influence on building operations and energy use., These four "user groups" include:

- Building Occupants (e.g., those traditionally thought of as the building "users")
- Building Operators (e.g., facility engineers, facility maintenance staff, etc.)
- Building Decision Makers (e.g., managers, portfolio managers, etc.)
- Building Design Support (e.g., architects, engineers, contractors, etc. hired to support ongoing building operations and adaptations)

It is important to recognize the role that each of these building user groups/stakeholders can play in helping attain and maintain ZNE performance, and to engage their participation and support in meeting ZNE performance goals. Each stakeholder group and the ways they touch/impact building energy use are described below.

1) Building Occupants

Building occupants are the ultimate end-users of building energy. They include workers, customers and other occupants for whom significant amounts of energy are expended to maintain comfortable space conditions, provide fresh air for, provide illumination for, and who directly use computers and other equipment and plug loads. In most commercial buildings, the occupants usually have very little direct control over the majority of the building energy end-uses. They have limited ability to adjust temperature setpoints and HVAC schedules, they have no access to the underlying HVAC systems and controls, and they often have limited control over general lighting (the majority of which is typically automatically controlled). They do have direct control over task lighting, general lighting that is manually controlled (typically a small percent of the total lighting in most medium and large office buildings), and the majority of the plug and equipment loads. Occupants often have control of window shades, which impact daylighting and solar heat gains.

There are an increasing number of high performing buildings which use natural or mixed mode ventilation. Some of these buildings require occupant control of operable windows and similar devices to manage natural ventilation. This increases the control that building occupants have over the successful implementation and energy savings of these systems. Some anecdotal reports indicate that some of these systems are confusing to building occupants (e.g., one naturally ventilated dormitory used a system of multi-colored lights to indicate when occupants should open widows for ventilation, which occupants found confusing and didn't use to the extent envisioned). For these types of buildings, extra attention will need to be paid to ensuring the expected level of occupant participation.

2) Building Operators and O&M Staff

Building operators play a critical role in how much energy buildings use and are key to making ZNE designed buildings actually achieve ZNE. Building operators control the largest percent of building energy end uses of any user-group, and are the front-line "users" of the building controls and key building systems. They are directly responsible for the efficient operation of HVAC systems, space temperature setpoints, schedules, implementation of energy conservation strategies, control systems, occupant comfort, equipment maintenance, and must respond to all building-related emergencies and problems. They are typically very busy, and many buildings suffer from underfunded and/or under-staffed O&M departments. Building operators have not traditionally been considered "building users" and included in various occupant engagement programs. However, given the percent of building energy they control and the impacts they can have on building performance, it would be wise for ZNE policy makers and building owners to pay equal if not more attention on how to engage the building operators in energy conservation as they do to the building occupants. It is critical that focus be paid to this group of users to ensure they are equipped and motivated to make the building perform. Opportunities to more fully engage and facilitate building operators in achieving maximum energy performance include:

- Provide the needed information served up in quick to interpret and actionable format for facilities staff to manage energy use. This will typically require additional data analytics and energy information presented in a way that empowers them to understand and actively manage building energy use. This will likely require some type of analytics and building performance dashboards that are beyond the capabilities of what typical BMS systems can provide.
- Ensure appropriate O&M systems are in place.
- Incent facilities personnel and building managers to effectively use available data to actually increase efficient operations of their buildings.
- Understand why operators do what they do (e.g., responses to employee complaints, BMS usability) and use this knowledge in interpreting and improving operations.

3) Building Decision Makers

The third group of building users are those who make key building management, investment and related decisions that have wide-ranging impact on building operation. Building decision makers will vary depending on building type and ownership, but can include building managers, owners, base commanders, corporate leaders, building portfolio managers, etc. While this group does not have day to day operational control over building performance, they nonetheless have significant influence over operations, control budgets, make major investment decisions, and set the general "tone" for building operators and occupants. This group plays a key role in long term ZNE performance. Decisions to underfund O&M, defer maintenance, etc. can profoundly impact operations. Conversely, they can set strong performance goals, keep building operators incented and accountable for energy performance, and wisely guide building investments and budgets to ensure optimal operation. They also play an important role in communicating building performance to other user groups and other stakeholders, and engaging all building users to engage in helping achieve ZNE.

There are a number of opportunities for ZNE building designers and policy makers to more fully engage and incent building decision makers to help ensure long term ZNE performance. For example, building decision makers are not typically included in occupant engagement programs, nor are their needs discretely considered during the design of building performance dashboards and related systems. Building M&V and dashboard systems could include summary screens with key performance indicators useful for building decision makers; e.g., building performance benchmarks that they can follow up with building operators if they are not where they should be, or communicate successful performance to stakeholders; energy and dollar savings summaries that track performance of efficiency investments and justify continued investment to maintain high performance levels, etc.

4) Planning & Design Support

Planning and design support teams (these can be internal or contracted personnel) are charged with making significant building design decisions during construction, renovations, remodeling. These decisions will likely influence building energy use for the life of the building. It is important that these personnel be made aware of energy policy and goals, and encouraged and empowered to work towards innovative solutions that depart from “business as usual” in order to meet energy goals. Key issues relevant to these stakeholders include:

- Integrated design practices
- Empowerment to depart from traditional design practices and find innovative solutions
- Appropriate specifications
- Consideration of long-term O&M issues, i.e., being cautious about specifying technically complex solutions that may be difficult to maintain, or that significantly increases probability of challenges operating or maintaining the building as designed.
- Funding
- Billing, larger scale M&V, submetering/metering programs.

11.1.2 Design vs. Actual Performance

The majority of ZNE building programmatic focus has been on the design phase of new buildings. While the design and technological features required to achieve a ZNE building are important and merit significant attention, it is important to recognize that by the time a building reaches the design phase, many of the key building design features have already been made (or limited) during the planning, permitting and entitlement processes. This is particularly relevant for multi-building projects which often have much more involved planning and entitlement requirements which must be considered. Furthermore, buildings endure for decades and sometimes centuries, and must adapt to ever changing context (people, uses, policy, environment, etc.). It is critical that the entire lifecycle of a ZNE building be addressed. Failure to do so presents a significant barrier to realizing ZNE buildings that actually perform over the long-term. Achieving true ZNE buildings requires that the divide between the design and operational performance be bridged. This section examines ZNE issues, challenges and barriers across the building life-cycle.

This section addresses the following key issues related to estimated design energy use versus actual energy performance:

- Design challenges with an absolute performance metric
- To what extent does occupant behavior influence building energy use?
- How well do design-phase energy estimates match actual energy use?
- What are the key factors driving these differences?
- How can these issues be addressed in the ZNE context?

Design Challenges

One of the challenges facing ZNE building designers and policy makers is the fact that ZNE is an absolute performance metric (i.e., actual energy consumption and renewable energy generation should net out on an annual basis and can be easily metered), as opposed to a relative metric (e.g., comparing estimated design building energy use to a hypothetical base-case building meeting code requirements as is currently done to meet Title 24's performance method). It will be immediately obvious when a ZNE-designed building is not achieving ZNE. This presents obvious challenges to the design team. Many of the key variables driving energy use (e.g., occupant schedules, temperature setpoints, occupant installed equipment and plug loads, etc.) can only be estimated, and often have significant uncertainty.

To What Extent Does Occupant Behavior Influence Building Energy Use?

This is an important question for ZNE buildings. There is good data for homes, and the answer is easy—A LOT! An NREL study of two side-by-side neighborhoods, one conventional and one designed with energy efficiency and renewable energy features shows that annual household electricity use varies by a factor of five or more for similar sized and equipped houses. In other words, occupant behavior (including homeowner installed equipment such as pools, spas, and double refrigerators) is *the most significant factor* driving home energy use. This finding is consistent with other residential building performance studies and collective author design experience. This clearly presents a problem for ZNE home designers, who have no control over what equipment the homeowner installs and how they use their homes.

The study referenced above was conducted by the National Renewable Energy Laboratory (NREL), and compares a 103 home conventional development in San Diego to the adjacent 306 home energy efficient Scripps Ranch development which incorporated a variety of "zero energy home" features and renewable energy systems[1,2]. This is the first subdivision built by a production homebuilder, Shea Homes, to explore ZNE. All homes incorporated a variety of

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[1] Farhar, B., and Coburn, T. A "New Market Paradigm for Zero-Energy Homes: The Comparative San Diego Case Study." NREL Technical Report NREL/TP-550-38304-01. 12/2006. http://www.nrel.gov/docs/fy07osti/38304-01.pdf, http://www.nrel.gov/docs/fy07osti/38304-02.pdf

[2] Farhar, B., Coburn, T., and Collins, N. "Market Response to New Zero Energy Homes in San Diego, California." http://cgec.ucdavis.edu/ACEEE/2002/pdfs/panel08/04_347.pdf

energy efficiency measures, some homes had PV systems and solar water heating systems (integral-collector-storage systems) as a standard feature, and the rest were given the option for adding these. 293 homes had solar water heating systems, and 120 had PV systems. The homes were built and sold from 2001 through the end of 2003. While none of the homes achieved ZNE, a small number came close to zero electricity use. The study provides a rich set of data including homebuyer motivation, market value impacts, measured energy use, etc. One of the key findings from this study is the role that occupant behavior plays in household energy use. Table 6 summarizes the energy consumption statistics by house type. Note the variation in electricity use for the homes without PV varies by a factor of five. Variation is greater (factor of 50) for the homes with PV, with one house nearly achieving net-zero electricity use, while at the other end of the spectrum another home using over 1.5 times more electricity than the average home without PV. The primary driver of these differences is occupant behavior and differences in lifestyles, including homeowner installations of energy-intensive equipment and amenities such as pools, hot tubs, and multiple refrigerators. One of the homes with very high energy use was occupied by a single occupant, so while household size can influence energy use, this example shows that occupant behavior can have a larger impact. Another noteworthy result is that the houses built earlier in the project exhibit greater utility consumption variability than houses built later in the project. This suggests that the builder became more effective in implementing the high-performance home designs with practice, and this improvement is reflected in the energy consumption data for individual homes. This aligns with experience from Energy Star Homes, Title 24, etc. and highlights the need for builder training, quality assurance, and related acceptance testing programs to minimize construction-related problems in ZNE buildings.

Table 6: Scripps Highlands energy consumption statistics[1]

Home Category	Statistic	Total 12-Month Electricity Consumption (kWh)	Average Monthly Electricity Consumption (kWh)	Total 12-Month Gas Consumption (therms)	Average Monthly Gas Consumption (therms)
Comparison community (n=28*)	Minimum	3,716.0	309.4	202.0	16.9
	Mean	9,502.8	792.6	497.3	41.6
	Median	9,050.0	754.9	526.5	44.0
	Maximum	17,707.0	1,475.9	893.0	74.7
	Standard deviation	4,138.6	345.3	190.7	15.9
	Coefficient of variation	43.6%	43.6%	38.3%	38.3%
SheaHomes, without PV (n=44*)	Minimum	3,333.0	277.7	128.0	10.7
	Mean	8,314.7	694.0	413.7	34.6
	Median	8,098.0	676.1	424.0	35.4
	Maximum	1,6741.0	1,399.8	739.0	61.9
	Standard deviation	3,223.5	269.4	136.4	11.4
	Coefficient of variation	38.8%	38.8%	33.0%	33.0%
With PV (n=37*)	Minimum	267.0	22.3	100.0	8.3
	Mean	6,368.9	531.7	366.0	30.7
	Median	6,535.0	545.5	333.0	27.9
	Maximum	12,868.0	1,073.4	678.0	56.6
	Standard deviation	3,206.6	267.5	140.0	11.7
	Coefficient of variation	50.3%	50.3%	38.2%	38.2%

[1] Table from Farhar, B., and Coburn, T. A "New Market Paradigm for Zero-Energy Homes: The Comparative San Diego Case Study." NREL Technical Report NREL/TP-550-38304-01. 12/2006. http://www.nrel.gov/docs/fy07osti/38304-02.pdf

On the commercial side, the answer is that occupants have less influence on building energy use than homes, but the data is not as clear. There are several factors in commercial buildings that mitigate occupant impacts on building energy use. First, commercial buildings are generally much more automated, and individual occupants have much less ability to control HVAC settings. Occupants can neither turn the entire HVAC system off and open all the windows for natural ventilation/passive cooling, nor can they lock the thermostat setpoint to "icebox" with all the windows open. Similarly, lights and other equipment are typically on automated schedules and not directly controlled by occupants. This level of automation results in a much higher energy "base-load" that is not directly controllable by the occupants, for better or worse. Another moderating influence is that there are generally many occupants in commercial buildings, which tends to "average out" the use of occupant controllable loads such as computers, plug loads, task lighting, etc. In other words, you will have some occupants who are very conscientious about turning equipment off and others who never bother, with the average occupant controllable load somewhere in the middle.

Plug loads make up a significant piece of energy use that is closely tied to occupant behavior. Plug loads are one of the largest and fastest growing end uses of the commercial sector. Between 2005 and 2030 they are expected to nearly double.[1] Estimates of their share of the total electrical load range between 25-50%. Lucid Design Group, a developer of monitoring and feedback systems, has metered buildings and reported empiric plug loads of up to 50%. [2] The analysis of LEED NC projects in the state of California (refer to the Appendix) have plug load fractions that range from 35% to 49% for California LEED rated projects (depending on building use type), and 32% - 45% for "ZNE Capable[3]" California LEED buildings. 2003 CBECs data shows a plug-load fraction of 34%, and the 2006 CEUS study shows 32%. Refer to Figure 45 for details.

Another interesting note is that as the regulated building loads (e.g., HVAC, lighting, DHW) become more efficient, the plug load increases. The analysis of the California LEED building data illustrates the impacts of this. Figure 45 also plots the plug load fraction of the "design" and "base-case" building. Plug and process loads are generally kept constant between these two cases. Increasing HVAC, lighting and DHW efficiency causes the plug load fraction to increase from 5% to 18%, depending on building use type. This is a significant change, and illustrates the increasing importance that controlling plug loads will have in ZNE buildings.

[1] Mercier 2010, op. cit.

[2] Michael Murray. Personal communication from the Founder and CEO, Lucid Design Group, Inc., October 2011.

[3] ZNE Capable buildings have an EUI < 35 kBTU/SF

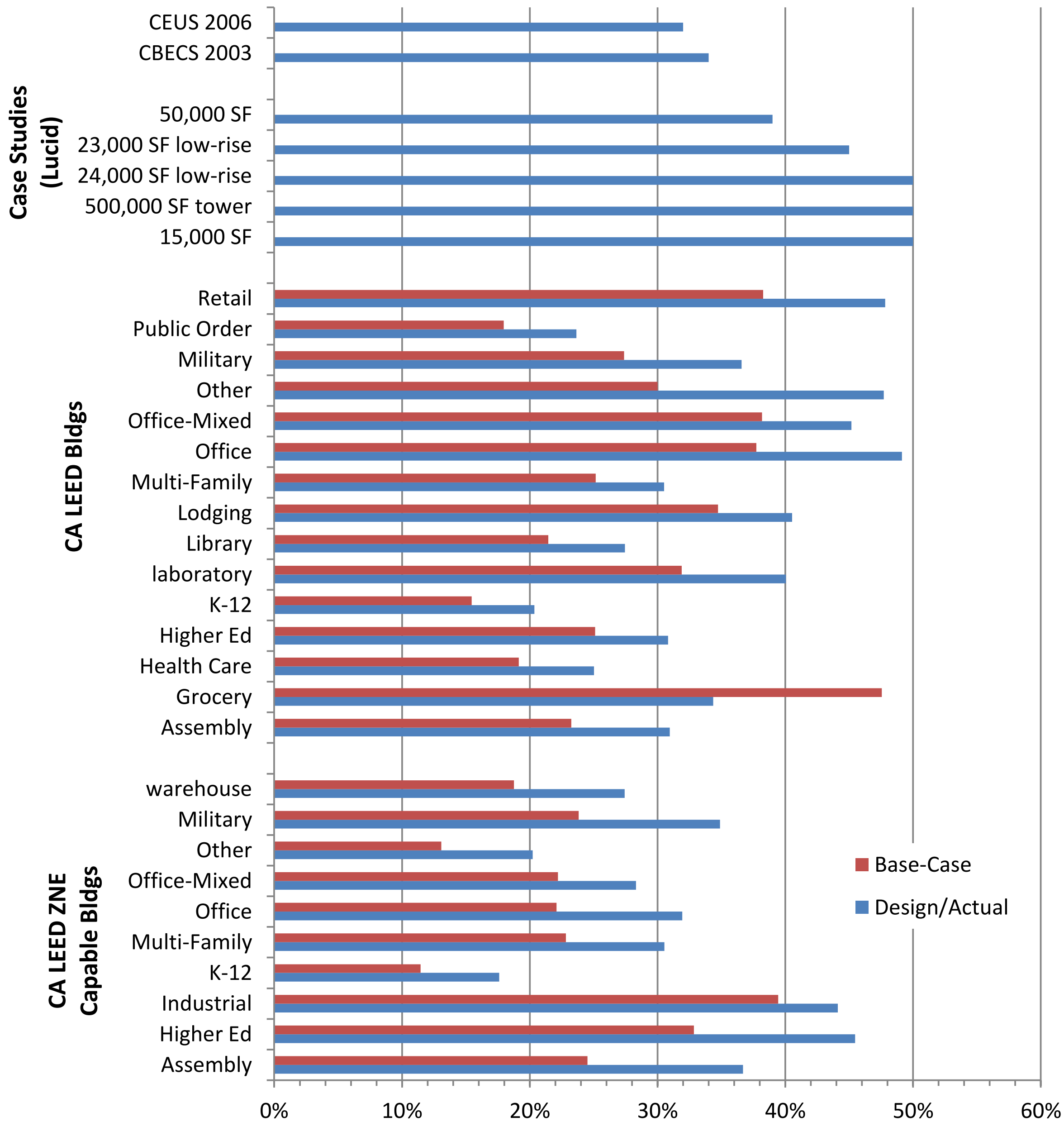

Figure 49: Comparison of plug and process loads as percent of total electricity use (plug fraction)

Comparison of Design Energy Estimates to Energy Bills

Building designers and energy modelers rarely follow-up to determine how well their design-phase energy estimates align with actual performance data. There is currently little demand from building owners and clients for this information. There several studies comparing design phase energy estimates to actual energy use. The more recent and relevant studies are summarized below, starting with commercial and ending with residential.

The National Renewable Energy Laboratory (NREL) conducted a detailed analysis of six high performing buildings[1] over four years to understand the issues related to the design, construction, and operation of low-energy commercial buildings and to develop best practices and research needs. The buildings studied include: The Adam Joseph Lewis Center for Environmental Studies (Oberlin College, Ohio), The Zion National Park Visitor Center (Utah), the Cambria Department of Environmental Protection Office (Pennsylvania), the Philip Merrill Environmental Center (Annapolis, Maryland), NREL's Thermal Test Facility (Golden, Colorado) and the Big Horn Home improvement Center (Silverthorne, Colorado). The study found that all six buildings used more energy and produced less energy than predicted in design. The reasons for this include[2]:

- There was often a lack of control software or appropriate control logic to allow the technologies to work well together.
- Design teams were too optimistic about the behavior of the occupants and their acceptance of systems.
- Energy savings from daylighting were substantial, but were generally less than expected.
- Plug loads were often greater than design predictions. Plug and loads ranged from 24% to 41% of the total energy use.
- Effective insulation values are often inflated when comparing the actual building to the as designed building.
- PV systems experienced a range of operational performance degradations. Common degradation sources included snow, inverter faults, shading, and parasitic standby losses.

The New Buildings Institute (NBI) analyzed the energy performance for 121 LEED New Construction (NC) buildings[3]. They compared predicted verses modeled EUI. The following figures are excerpted from the NBI Study. Figure 50 plots the design verses measured EUI, and Figure 51 plots the ratio of measured to design EUI. The results showed that while there is significant scatter for individual buildings, that on average the modeled results compare closely to actual results. Since this study has come out, the LEED energy modeling review process has increased in stringency with new quality assurance and review standards in place. It is believed (but not documented) that energy modeling quality has improved and that some of the project-level variation in modeled verses actual energy use has decreased.

[1] Torcellini et. al. "Lessons Learned from Case Studies of Six High-Performance Buildings." NREL Technical Report NREL/TP-550-37542. June 2006. http://www.nrel.gov/docs/fy06osti/37542.pdf

[2] Torcellini et. al. "Lessons Learned from Case Studies of Six High-Performance Buildings." NREL Technical Report NREL/TP-550-37542. June 2006. http://www.nrel.gov/docs/fy06osti/37542.pdf

[3] New Buildings Institute. "Energy Performance of LEED® for New Construction Buildings." 2008. http://www.newbuildings.org/sites/default/files/Energy_Performance_of_LEED-NC_Buildings-Final_3-4-08b.pdf

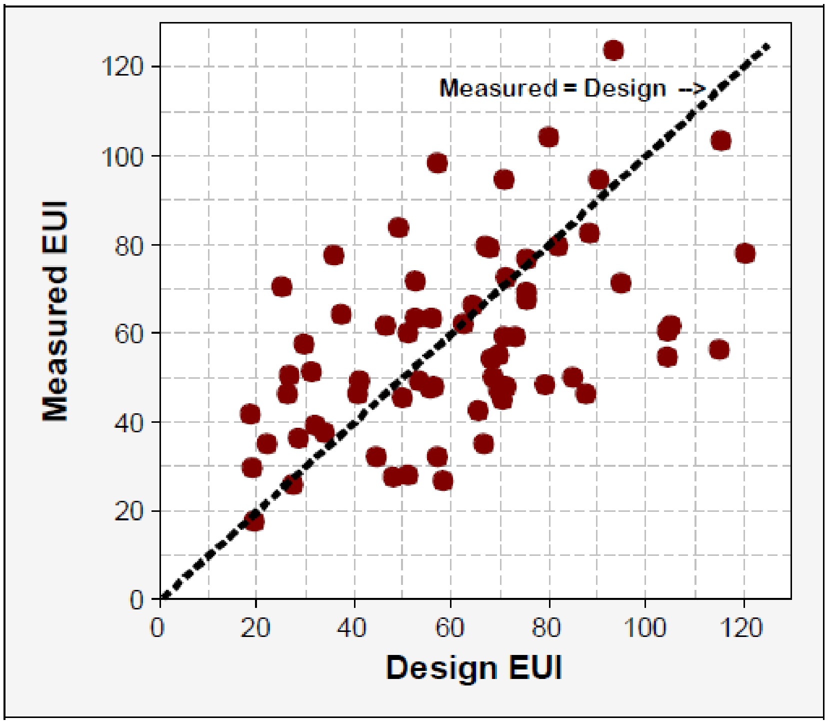

Figure 50: Measured versus design EUI (kBTU/SF) comparison from the NBI study

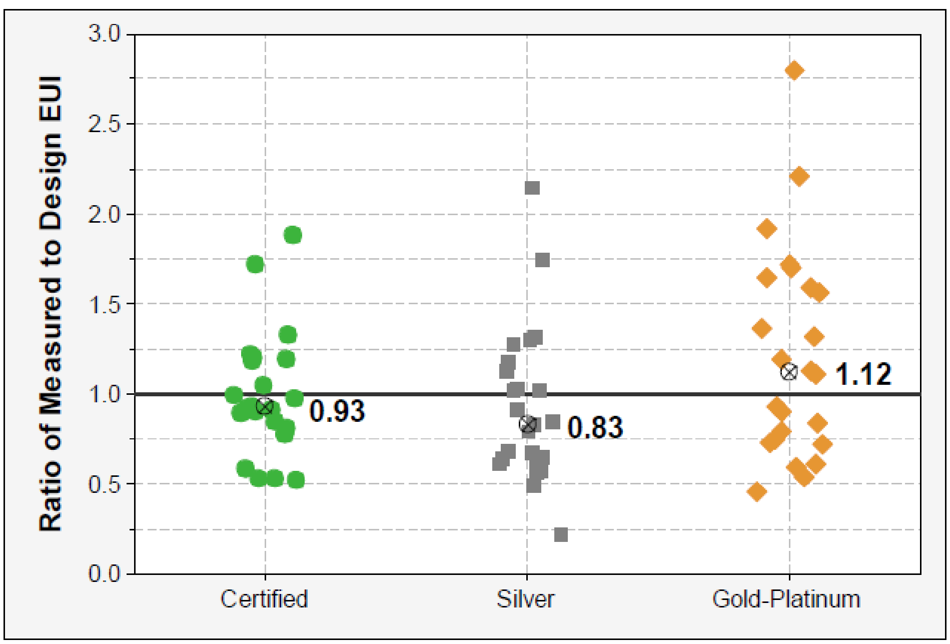

Figure 51: Ratio of measured to design EUI from the NBI study

Key Factors for Design vs. Actual Performance Mismatch

The key factors influencing the difference between design (estimated) energy vs. actual energy use include:

- Occupants not behaving as expected

  One of the largest sources of uncertainty between predicted versus actual energy use relates to the occupants and their behavior. This includes differences between modeled versus actual occupancy levels, occupant schedules, occupant activity, occupant installed equipment and plug loads, the extent to which occupants turn off this equipment after hours, temperature setpoints and related HVAC schedules, the level to which occupants participate in non-automated energy conservation measures (e.g., turning off task lights, closing blinds to reduce solar gains), etc. Design phase energy modeling relies on either best estimates of what the designers think about the occupants, or if detailed knowledge is lacking, standardized schedules based on building type.

- Weather not behaving as expected.

  This year's extreme and uncharacteristic weather throughout the U.S. illustrates the year-to-year weather variability from the ~30 year average climate data used for energy modeling. This weather variation significantly impacts building energy use and onsite renewable generation, and will present significant challenges for ZNE buildings. There is an outstanding need to determine how to deal with yearly weather fluctuation in the ZNE context. There are two different approaches that can be taken: (1) design ZNE buildings for the "worst case" weather-conditions, or (2) normalize annual energy consumption to weather and compare this to the projected energy use base on average climate conditions. The first approach is analogous to how the HVAC design community uses worst-case design conditions to size HVAC equipment to ensure that it will meet space conditioning needs during the hottest and coldest conditions the building can be expected to encounter. Applying this approach to ZNE buildings would require significant "over-building" (and attendant costs) to ensure that a building would achieve ZNE even in the most adverse year. This approach would also help mitigate risk for the design team to reduce the likelihood of having a ZNE designed building not achieve ZNE. The second approach is analogous to how Energy Star Portfolio Manager[1], Energy Service Companies (ESCOs) engaged in energy saving performance contracting, and others take actual energy data and adjust, or "weather-normalize" it to estimate how much energy the building would have used *if* the weather was average, and then compare this to energy projections made using the climate data files. Applying this approach to ZNE buildings has a number of policy advantages, but would lead to inevitable hard to explain situations where a "ZNE building" on paper is not a ZNE building in actuality.

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[1] U.S. EPA. "ENERGY STAR Portfolio Manager Methodology for Accounting for Weather." Online. Accessed 9/2012. http://www.energystar.gov/ia/business/evaluate_performance/Methodology_Weather_20110224.pdf

Another weather related issue that causes mismatch between predicted verses actual energy use is the low spatial resolution of climatic files available for energy modeling. California's 16 Climate Zones cover large areas which include significant variations in local microclimate, wind exposure, elevation, shading and other factors. The hourly weather data in these climate zone files is based on a single representative city within each zone. There is need for climate data at an enhanced spatial resolution. In support of the 2013 Title 24 update, the California Climate Zone weather files were updated, and climate files for an additional 54 sites were generated. Although these sites are not currently used for Title 24 compliance, they could be used for ZNE building modeling to improve energy modeling accuracy.

A final weather-related issue that is increasingly important in the ZNE building context is climate change. California's climate is already warming, with statewide temperatures projected to rise between ~5 to 8 ^{o}F depending on location by the end of the century[1]. This, along with an increase in extreme weather events (e.g., heat storms) will increase building HVAC energy use. Nighttime temperatures are rising faster than daytime temperatures, which can reduce the effectiveness of some of the low-energy HVAC strategies that high performing buildings often rely upon (e.g., utilizing high diurnal temperature swings and/or low nighttime temperatures for night-time ventilation flushouts and morning precooling). Warming temperatures will also reduce PV output[2]. The hourly climatic datasets used to estimate building energy use are based on historical weather patterns and do not reflect the change weather patterns ZNE buildings will likely see. As Chris Pyke, Director of Research for the U.S. Green Building Council notes, "We're designing tomorrow's buildings while looking through the rear view mirror of yesterday's weather and that's [a] fundamental problem.[3]"

- Equipment not behaving as expected

  It is well documented that buildings never operate quite as designed out of the box. And that things break over time, schedules aren't updated, filters plug, and a host of other issues arise to degrade building performance.

  This has led to the popularity of commissioning, the incorporation of acceptance testing into the code, etc. There are several studies that quantify the energy impacts of these issues. Lawrence Berkeley National Laboratory (LBNL) has conducted an extensive study of commissioning benefits[4]. The median commissioning cost is $1.16/SF for new buildings (0.4% of total construction cost) with a median whole building energy savings

[1] For more information refer to the Cal-Adapt website (http://cal-adapt.org/temperature/century/), which synthesizes and visualizes much of the statewide climate change projection data, including providing interactive temperature projection maps. See also Cayan et. al., "Climate Change Scenarios and Sea Level Rise Estimates for California - 2008 Climate Change Scenarios Assessment - Final Report." California Energy Commission. 2009. http://www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2009-014-F

[2] PV output drops approximately 0.5% for every ^{o}C temperature increase.

[3] The Daily Energy Report. "UMich & USGBC Study Finds LEED Buildings Are More Resilient." Accessed 10/1/2012. http://www.dailyenergyreport.com/umich-usgbc-study-finds-leed-buildings-are-more-resilient/.

[4] Lawrence Berkeley National Lab. "Building Commission: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions." July 21, 2009. http://cx.lbl.gov/2009-assessment.html

of 13% and a median payback time of 4.2 years. Projects utilizing a "comprehensive" commissioning approach realized twice the median savings and five times the savings of a "constrained" (minimal) approach to commissioning. In other words, the energy impacts of new buildings not working quite as expected is a ~13% energy penalty. Commissioning existing buildings results in a 16% energy savings. Monitoring-based commissioning (MBCx) is an innovative approach to commissioning developed through the UC/CSU/IOU Energy Efficiency Partnership program[1]. LBNL has analyzed the performance of 24 MBCx projects in UC/CSU buildings[2]. These buildings achieved energy savings ranging from of 2% to 25%, with an average of 10%. Median electricity savings were 1.9 kWh/SF (9%), with a range of 1% to 17%.

It is critical that steps be taken to ensure that new ZNE buildings function as designed from the beginning, and that they experience routing retro-commissioning or similar "tune-ups." This effort should include attention to building user experience and interactions, as well as analyzing more technical components.

11.1.3 Efficacy of Occupant Engagement vs. Automation

The Importance of Normative Behavior

Normative behavior is essentially "what everyone else is doing". Letting people know that others are conserving resources improves their conservation. One study of the familiar hotel–room water conservation cards is instructive[3]. Note how differently worded messages sparked higher levels of compliance:

- "Help save the environment—please re-use towels." (37% compliance)
- "Partner with us to help save the environment--*please* re-use towels." (44% compliance)
- "Join your fellow citizens to help save the environment-–please re-use towels." (49% compliance)

Similarly-aimed utility bills told customers how much electricity comparable households were using. Resultant increases in energy conservation were approximately 2.2%.[4]

An important application for ZNE buildings is that building stakeholders may conserve more energy if they know their peers are also doing so. This has implications occupant engagement, recognition, communications, building dashboards, and other feedback channels.

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[1] http://www.uccsuiouee.org/mbc.html

[2] http://cx.lbl.gov/MBCx.html

[3] Goldstein, N., Griskevicius, V., & Cialdini, R. B. (2007). Invoking Social Norms: A Social Psychological Perspective on Improving Hotels' Linen-Reuse Programs. "Cornell Hotel and Restaurant Administration Quarterly" (May 2007), 7.

[4] Hoffman, Jeff. "Using the Water Bill to Foster Conservation," On Tap, Winter 2010, pp. 18-21. Accessed from www.esc.vwu.edu, Feb. 2012.

Two design strategies for low-energy buildings are often contrasted. One relies on human action and adaptability. The other relies on intelligent systems designed to produce highly controlled environments, circumscribing human interaction (Berker 2006). Presumably there should be room for both poles in ZNE construction, and for variations in between (Brown and Cole 2009; Rajkovich et al. 2010). Designed automation does not always equal effective implementation and use. Different situations will require different approaches, and the details matter.

How much should occupants be relied upon on to manage energy services in ZNE-design buildings, versus through automation? The answer depends entirely on the specifics of the situation – what building, what is being automated, which users – and on which goals are prioritized. To advance understanding here requires careful attention to how automation is designed and executed and how it is evaluated, paying attention to both energy use and to occupant interactions and reactions, as much as possible on both narrow (e.g., how much did lighting use change?) as well as broader (e.g., might automation work against occupant engagement?) scales.

Because automation vs .manual operation is such an important clash, it is useful to step back to some of the guiding paradigms. Societies have had a millennia-old fascination with automation leading up to current visions of the smart buildings of the near future as a "solution" for building sustainability. The increasing mechanization of buildings over the last century has meant that the responsibility for designing for comfort transferred from architects to mechanical engineers, and responsibility for achieving comfort transferred from occupants to environmental control systems (Cole et al. 2010). These shifts have made it easier to link design to performance, and better align with common technical and policy definitions of energy efficiency. Occupants are hard to control and predict, and even the most effective behavior change programs may only marginally change behavior toward some more desirable mode.

Meanwhile, many argue that occupants prefer some degree of direct control – or at least the illusion of control -- over their immediate environment, whether through manual operation, the possibility of override, or the ability to set the parameters of automation (Cole and Brown 2009). The ability to control personal environment is linked to comfort, pleasure, and overall satisfaction. Given the opportunity, truly engaged occupants may do much better at negotiating energy use and personal comfort than do automated systems (Cole and Brown 2009). Ongoing development of adaptive systems that learn from and adapt to users and other conditions (e.g., Banerjee et al. 2007; the NEST thermostat; multi-agent HVAC control systems in commercial buildings) are promising, but there is no guarantee of energy savings or user satisfaction with these systems, and some possible unintended consequences (Rodgers et al. 2010).

The technical literature on automation for energy efficiency largely assumes that automation reduces energy use over manual behavior, and that smart controls will be a key element of ZNE buildings (Rajkovich et al. 2010). Savings estimates for automation, however, are often based on modeled assumptions of baseline occupant manual behavior rather than long-term monitoring or empirical data on occupant behavior. Nor do comparisons acknowledge the potential savings of optimizing system design for manual operation (Makonin et al. 2012), e.g., more granular lighting design or improving the usability of manual control systems. So, though automated systems may often be effective at saving energy and reducing the need for (and possibility of) human intervention, published savings estimates of automation cannot necessarily be taken at face value.

Well-functioning automation is more consistent in its control strategies than human actors. However automation can also use energy where manual control would not. For example, some households that install programmable thermostats used the programming to run HVAC longer than they had previously (Nevius and Pigg 2000; Meier et al. 2010) and energy programming in commercial buildings may lead to longer HVAC run hours (U.S. DOE 2009). Automated systems may also be set to correspond to particular energy service standards that are higher than occupants would choose. This was the case with automated daylighting system investigated in a San Francisco LEED-certified building (Konis 2012).

These examples highlight the potential for continuing to try to improve design, use, and evaluation of automation. A second concern is that automation can go wrong or be disabled without notice, repair, or compensation. Where building performance depends on precise alignment of interrelated systems, deviations from expected performance of one element can have cascading effects that degrade indoor environment and increase energy use. Automated systems can have higher maintenance requirements and pose greater risks when they fail. Finally, automation and mechanization tend to disassociate occupants from the building and physical environment, which may lead to *lower* engagement with the building. Designers sometimes recommend layered control systems that allow for both manual and automated control centrally and by building operators, e.g., for lighting in a ZNE-design commercial building (Gugliemetti et al. 2011).

What about empirical data? Automation may take various forms: occupancy and motion sensors, light sensors or timers, as well as adaptive systems that learn from occupant behavior and other conditions. A general summary on the energy consequences of automation versus manual behavior would require a detailed meta-analysis, well beyond the scope of our review. There is little empirical data, however, and failures are unlikely to be reported in the literature.

11.1.4 How Do Users Interact With Energy-Using Systems?

The Basic Problem of Describing Interactions

There has been little systematized attention to how building users actually interact with energy-using devices and the building envelope: opening windows, adjusting thermostats, drawing shades, switching on and off, drawing hot water, overriding the BMS, etc. Building energy simulation, codes and standards, design logics, and the mental models of researchers, policy makers, and practitioners all call on descriptions of occupant energy use behavior and assumptions about what occupants need. These descriptions are seldom debated. But there are millions, even billions, of effectively different interaction patterns between building users and building systems. Some field studies and experiments measure interactions in specific circumstances, but these studies are rare and give little basis for generalization (Lopes et al. 2011). Much is pure assumption, anecdotal, or derived from simple survey self-reports (e.g., California's Residential Appliance Saturation Surveys; the Energy Information Administration's Residential Energy Consumption Survey). And there is little end use metered data with which to reconcile these assumptions (KEMA 2009).

This review focuses on technical descriptions of user interactions. Apart from these technical descriptions, behavioral and social scientists in the building energy field, who are more interested in why people do what they do, approach interactions in terms such as attitudes, mental models, habits and practices (Lutzenhiser 1993; Shove 2010; Stern 2011; Spaargaren 2011; Wilson and Dowlatabadi 2007).

What could be considered inherent variability of occupant behavior in ZNE and other buildings clearly exceeds our current ability to describe, predict, or influence this behavior. Even with better data, it is difficult to express user interactions and to understand patterns given their diversity and uncertainties. However new data collection capabilities, and a better acknowledgment of how much occupant interactions matter, can almost surely improve on current understanding and practices. The complexity of building-user interactions, the sparseness of data, and the basic intractability of describing behavior leads to challenges: how do occupants in any specific building interact with any particular subsystem; what is the variability of occupant behavior across people, time, and buildings; how should this diversity be reflected in standards, codes, policy, research, and ultimately design; and what are the policy and design implications of this highly uncertain ability to predict and characterize occupant behavior? To the extent that occupant behavior can be shaped by policies, programs, and design, what difference does this make, and what other influences enter? These questions apply equally to ZNE buildings and more conventional construction.

The remainder of this section provides some basic description of behavioral variability and diversity and its consequences, drawing on examples of heating in residences and on plug loads in both residential and commercial buildings. Some recent reviews give excellent comprehensive summaries of the technical literature on user interactions in residential (Lopes et al. 2011) and commercial (Parys et al. 2011) settings.

How Much Difference Do Occupants Make to The Energy Consumption of A Building?

At some level, all building energy use is a result of what people do (Janda 2011). There are different ways that the impact of occupant behavior can be measured and defined, but one study attributed as much as 75% (Lutzenhiser et al. 2012). What is clear is that how people use energy in their homes varies tremendously, both in terms of the total energy use and in the various end uses comprising it (e.g., Hackett and Lutzenhiser 1991; Lutzenhiser and Bender 2008; Morley and Hazas 2011). Differences in lifestyles, behaviors, and practices account for several-fold variation in even in neighboring, physically-similar homes (Lutzenhiser 1993), a finding echoed in many field studies, some of which were summarized above. Given the high levels of technical efficiency in ZNE residences, energy use and systems performance may be even more sensitive to occupant behavior (Brandemuel and Field 2011).

In commercial buildings, the contribution of occupants to building energy use variability is harder to characterize. Occupants shape energy use through their interactions with devices and the building envelope, and by influencing on building operations decisions. Apart from occupants themselves, assumptions about what needs to happen in a given commercial building –what occupants want, and what business services are required – have a profound effect on energy use via building design, programming, and daily building operations. Depending on the building and how behavioral effects are defined, occupants may have little direct effect on site energy use even in ZNE buildings (Rajkovich et al. 2010), or they may account for 50% or more of building energy use (Melton 2011).

When buildings use more energy than they are designed to use, the difference is often automatically attributed to the behavior of building occupants, implying that that shortfall between actual and predicted performance is caused by occupant behavior (Melton 2011). The assumption that occupants are to blame merits empirical investigation on a case by case basis (Lenoir et al. 2012; Menezes et al. 2012). Where actual behavior clashes with design assumptions, design assumptions and systems usability also need to be examined. For example, assuming that occupants of commercial building will be content with a 68^{o} F interior temperature when they expect 72^{o} F will almost invariably result in actual energy use that is higher than predicted.

People will adapt the building, systems, controls and features to their needs and wants (Heerwagen and Diamond 1992; Lenoir et al. 2012; Melton 2011). This is not to say that they will screw everything up, but they will make things work *for them* if they can. Such adaptation can increase the energy requirements of a building. For example, office occupants who feel too cold often add portable heaters, even when they are officially not allowed, and homeowners may overhaul systems that they do not think works. Green devices and features not necessarily green if they are not used that way (Cole and Brown 2009; Lorenzen 2012), and green design assumptions are not necessarily reasonable if they do not or cannot match what occupants are willing or able to accept.

Thermostat Management

Heating and cooling are both end uses where occupant behavior matters tremendously. In most California climates, in fact, little to no mechanical heating or cooling are required for subsistence, so it practices and preferences are the key to "needs" (Lutzenhiser et al. 2012). As to heating, survey data for California single family residences indicate that one of the most common ways of setting the home's thermostat during the winter is to keep it at 55 degrees or even off both night and day, while another of the most common practices is to set temperature at a uniform 75 degrees.[1] Neither of these patterns is close to California's Title 24 standard assumptions of how thermostats are used. There little monitoring data on actual thermostat settings, but a study on a small subset of California homes suggest that households typically change thermostat settings much more frequently than Title 24 thermostat assumptions assume (Woods 2006). Peffer et al. (2011) review other differences between how households actually use thermostat s and how they have been assumed to use them. Similar levels of variety are evident in self-reported behaviors for cooling, water heating, and other end uses, with tendencies and patterns that vary moderately by location, house characteristics, etc.

Incorrect or incomplete assumptions about occupant behavior can lead to design and policy missteps. For example, in the case of programmable thermostats, incorrect assumptions about how people used manual thermostats, as well as how they would use programmable thermostats, led to over-optimistic assumptions about the aggregate benefits of promoting programmable thermostats (Peffer et al. 2011; Nevius and Pigg 2000). Many households already managed non-programmable thermostats for energy conservation, so that automation is not necessarily an improvement. Fifty percent of households with programmable thermostats may not regularly use the programming features (Peffer et al. 2011). More attention to device design can help usability, but even easy-to-use devices are not necessarily used.

[1] Portland State University analysis of the 2009 California Residential Appliance Saturation Survey.

Residential Plug Loads

Plug loads, and their corollary standby consumption, are often projected to become a much larger percentage of total building energy use in the future (IEA 2009; Parekh et al., 2012), doubling in the next 20 years. Plug loads are estimated to consume on average 9%-18% of residential electricity (Comstock et al. 2012; Moorfield and Calwell 2011; EIA 2012; Ross and Meier 2002), though the percentage contribution can vary greatly from house to house. Numerous detailed reports are available (e.g.,Bensch et al. 2010; Porter et al.2006;) though there is no statistically comprehensive picture, and studies may not report in statistically comparable terms (e.g., energy versus electricity, what end uses are included, sampling period, power status).

The contribution of plug loads to ZNE residential energy use has become a particular point of concern in ZNE planning, given their unpredictability and increasing relative importance to total electricity consumption. As energy efficiency reduces the expected HVAC and water heating energy use, plug loads increase as a proportion of total energy use. In highly efficient homes, plug loads can represent more than 50% of a home's energy draw (Amram and Latham 2012). However, plug loads are not necessarily any less legitimate, or a bigger source of behavioral energy savings potential, than other household energy uses.

The jury is still out as to how well behavior change programs might be able to get households to reduce their plug load energy use, though some programs conducted with volunteer participants show modest savings (Amran and Latham 2012). Well- designed technologies of power management and automation such as advanced power strips or improved power management engineering likely have better prospects for reducing energy use than does manual management (Acker et al. 2011; Metzger et al. 2011; Metzger et al. 2012). This is not surprising, given the quantity of plug loads that any individual or group might have control over, and the fact that there may rarely be any palpable personal advantage in micro-managing plug loads. Software control, or advanced power strips, may have relatively higher potential to reduce plug load energy use. For example, one pilot study on advanced power strips conducted in Australia achieved a savings of 50% of plug load consumption (Ryan and Grant 2012). Though various potentially-effective power management technologies exist today, they have little penetration into the market. Other potential measures include power draw limits for devices in standby modes, requiring active-mode power-scaling, and legislating the power factor can also produce savings (Porter et al. 2012). While user education can help some, these technology-centered efforts (including improved usability) seem potentially more effective than methods that rely on a great deal of conscious effort from building users.

User Experience with Low-Energy Residences

Several recent reviews on user reactions to ZNE- and low-energy-design residences are available for Europe (Hauge et al. 2011; Mlenick 2012; Schnieders and Hermelink 2006) and there are a number of case-specific reports for the US (Parker 2009, Perkins 2011) and Europe (Bell et al. 2010; Larsen). One finding particular for European homes is that energy systems may be overly complex or inflexible relative to actual occupant behavior and expectations. One of the particular problems has to do with expectations about user controls. User may not know how these controls are supposed to work and they may not use them as designed, and they may often want more control than is actually provided (Mlenick et al. 2012; Hauge et al. 2011). Design/construction assumptions made about how a building should be operated to achieve given levels of comfort and energy use may also challenge building user's habits and preferences. For example, European work has shown that users often prefer to air their house by opening windows during the winter, even if doing so not recommended from a technical systems point of view (e.g., Larsen et al. 2011).

Occupant Interactions in Commercial Buildings

There is a widespread perception that many occupants tend to “misbehave” in terms of their energy practices commercial buildings, but limited work characterizing what they actually do and why. The most systematic descriptions of user interaction with commercial building envelopes are provided in technical design and simulation literature (reviewed further below). For example, Parys et al. (2011) provides a comprehensive literature review on data on occupant behavior in office buildings, such as opening windows, lamp switching etc. This technical literature often links occupant behavior to physical conditions such as indoor temperature and humidity. But there is little assessment of the behavioral and social explanations for why commercial building occupants do or not undertake conservation actions. The vast majority of discussion on occupant behavior in commercial buildings is for office and educational buildings, but these constitute less than one third of commercial building floor area (CBECS 2003), and what occupants and building operators do in other building types (and why) may be far different.

Plug Loads in Commercial Buildings

As for the residential case, plug loads are often identified as posing a special problem for ZNE commercial buildings, though with the twist that some commercial buildings are unoccupied more than half the hours of the year, e.g., 66%-75% (Lobato et al. 2011; Logan and Klaasen 2010). Yet office buildings, for example, may often have substantial loads during unoccupied hours, on average 56% of all load in the case of several buildings audited in Southern Africa (Masoso and Grobler 2010) and about half according to a U.S. study (Lobato et al. 2011). In one ZNE-design office building, the contribution of plug loads to building energy use (vs. electricity use) was 45%, whereas in typical California office buildings, it is close to 15% in (Kaneda et al. 2010). Several reports on a low-energy office building at NREL, the Research Support Facility, discuss monitoring results and occupant interactions with plug and process loads (Lobato et al. 2011). The question has become: why are these devices contributing load when many might be managed by manual shut off or by activating power management to low-power mode?

Though there is no comprehensive statistical data source, a number of metering studies have measured energy consumption and power modes of plug-in devices in offices (e.g., Mercier and Moorfield 2011; Roberson 2004; Sanchez et al. 2007). Field studies find that desktop computer power management is often not activated (Mercier and Moorfield 2011). Several studies have tried behavioral interventions such as prompts, education, and feedback to get occupants to more actively manage plug loads and power modes, with little to modest success (Mercier and Moorfield 2011; Metzger et al. 2011). Technological interventions (power management via networked IT, smart sensors, advanced power strips) seem to be the most reasonable primary approach to plug load management.

Building Energy Simulation and Occupant Behavior

Building energy simulation has become a platform for more systematic description of occupant behavior as well as assessment of how much difference this behavior makes. Most of the effort has been for commercial buildings (Hoes et al 2009; Parys et al. 2012; Nicol 2001l) but there is some work for residential buildings as well (Brandemuehl and Field 2011; Kashif et al. 2012). Previously, building energy simulations treated occupants as generally passive objects with stable energy service requirements. But recent advances in energy simulation research have led to more flexible and sophisticated renderings of occupant behavior, shifting from deterministic descriptions to stochastic ones (Parys et al. 2011). ZNE and similar energy-efficient design buildings may often rely on systems that are more dynamic and complex than in conventional buildings. Representing these systems adequately requires more sophisticated modeling software than in the past, as well as more effort to assess what happens if building systems are not used as expected (e.g., if the HVAC system is set to higher settings than advised, or if windows remain open when they are designed to closed). Some conditions are cannot be predicted well *a priori*, especially many determined by occupant and user actions (Kolokotsa et al. 2011).

11.1.5 Current Approaches and Trends to User Engagement in ZNE/High-Performing Buildings

It is often claimed that building users must be engaged with the building they occupy in order for it to achieve ZNE energy performance. Expectations about the degree and nature of engagement required vary (Cole et al. 2010), ranging from careful management of plug loads, buy-in to broader ranges of indoor temperature, and to active management of the building envelope. In many U.S. commercial buildings of the last few decades, though, little has specifically been asked of occupants in terms of actively engaging in comfort and energy management in the buildings they occupy. Occupants regularly cope and adapt to the indoor conditions they face toward achieving satisfactory comfort levels (Heerwagen and Diamond 1992), but they may not know what works best from a building point of view. Even in residential buildings, "literacy" in conservation and thermal management may often be low. There has also been no strong tradition to even design buildings for active management by occupants.

The recent shift in attention toward occupant behavior has been accompanied by plenty of enthusiasm about prospects for influencing occupants to take on more active, more accepting, roles as a condition of their occupancy. Despite the enthusiasm and various published success stories, the emerging realization is that substantively influencing occupants is harder than it first appears. There is no reliable or simple set of techniques to transform occupants toward "better" behavior. Rather, the behavior change field's emphasis on individual choice, behavior, and attitudes may be trumped by many other factors that shape what people do and why. These include design, habits, mixed messages about consumption, competing priorities, and the low rewards of change. In getting buildings to work well, building environment researchers have underscored the importance of seeing the user's point of view as opposed to just a top-down perspective (e.g., Harmon 2012; Janda 2011; Vischer 2008), and reconciling human intelligence versus automation (Cole and Brown 2009).

The remainder of this section summarizes recent literature on engagement programs, education, general behavior change, and feedback in the residential and commercial sectors.

Education

Education is defined here as information supplied to users about how a building and its systems work and how they are designed to be used, as well as efforts to manage occupant expectations about what conditions the building should provide. As is, building occupants may often get little or no training on how they are supposed to use energy-relevant features of low-energy houses (Hauge et al. 2011; Mlecnik et al. 2012; Schneiders and Hermelink 2006) or low-energy commercial buildings (Brown and Cole 2007; Janda 2011). Well-planned educational material, in-person communication, and more persistent education can help in getting occupants to use the building as designed. Since the responsibility for this education rarely naturally falls to any particular party in construction, handoff, and operations, it is often done haphazardly, if at all. Occupants are often seen as uninterested or resistant to this education, especially if it involves reading through technical manuals or logging on to websites. Some may learn how to better use the building as time goes on, particularly in residential buildings, but others may not.

Even occupants who have received adequate information on how to use particular systems will not necessarily use them as designed. Design expectations of what users are supposed to do can be complex and context-specific. For example, a commercial building may be designed with the expectation that occupants will open windows only under certain combinations of outdoor temperature and humidity. In-building signaling systems (e.g., "red light, green light") can be devised to direct occupants to manage windows accordingly, but compliance is often not very high (Ackerly and Brager 2012). As these authors summarize, expectations of occupants should not be too complex and, perhaps most importantly, occupants are more likely to comply with requests when doing so has clear benefits *for them*.

Education is usually considered as a top-down affair, flowing from designers and building managers to tenants and occupants. But work in user satisfaction and post-occupancy evaluation has stressed the importance of learning from building occupants as well (Zagreus et al. 2004). That is, education should not be a one-way transfer of information to occupants. Building systems and designs do not necessarily work as designed, and design assumptions do not necessarily fit what occupants want (Lockton et al 2011; Harmon 2012). Recent work in the fields of ergonomics, Human Computer Interface, and persuasive computing have made advances in understanding the details of interactions between humans and devices or structures (Sanquist et al. 2010). Most of the usability and occupant feedback work is for commercial rather than residential buildings, but this combination – of educating building users *and* modifying device and building design to better fit and persuade these building users – may have great potential for improving "engagement."

Current engagement programs in commercial buildings

Many organizations report having some level of employee engagement program, but there are relatively few programs with significant presence or analysis in the literature. These programs often draw, at least symbolically, on Community Based Social Marketing (Melton 2011). Examples include HOK's Occupant Engagement Program™, work by U.S. Department of Energy Federal Energy Management Program (FEMP 2011), and other efforts in federal workplaces (Shui 2012). ISO Standard 50001 includes an "employee engagement" component. There is also a pilot LEED Credit for Occupant Engagement (Pilot Credit 59) applicable to the LEED Existing Buildings: Operations & Maintenance projects (USGBC 2012). The pilot outlines requirements for consumption feedback and "occupant empowerment" programs. It specifically states calls out that engagement programs should not encourage behaviors expected to "significantly affect the productivity of occupants or their comfort."

Behavior Change

Behavior changes all the time, but getting behavior to change in specific ways is another matter. It is often argued that major changes in behavior are needed, e.g., "radical changes in energy-related behavior are needed to implement even … modest policies for efficiency and use of renewable energy" (Gynther et al. 2012). This perceived need has to compete with another conclusion: "Decades of research on human behavior have produced at least one consistent finding: a lasting change in behavior is difficult to achieve" (Zalesney 2012). Though some studies on behavior change efforts report savings of 10% or more, behavior change interventions typically only yield energy consumption reductions of a few percent (Hazas et al. 2012), which is often not enough to make or break the ZNE-status of a building.

The energy behavior change literature calls on a number different theories about why people do what they do, usually focusing on the "levers" for change that these theories seem to suggest. There is a long and varied vocabulary including attitudes, barriers, behaviors, beliefs, commitments, contexts, habits, intentions, norms, practices, etc., viewed in different ways from the disciplines and practices of behavioral psychology, social psychology, sociology, environmental economics, behavioral economics, social anthropology, Community Based Social Marketing, Human Computer Interface studies, etc. These formulations can certainly be useful, but in practice, evocations are often formulaic and low-dimensional, as if the theories themselves translate to technologies of transformation that can successfully be applied to convert building users to something other than what they are. Many critiques are available (e.g., Lutzenhiser 1992; Shove 2010; Shove and Walker 2007).

Energy behavior change programs often rest on an information deficit model, which assumes that the core problems behind occupants' current behaviors are that occupants do not understand why it is important to reduce energy use, and do not know how to do so (Owens and Driffill 2008). This perspective assumes that occupants will have the same goals as the program, and stresses attention to individual behavior without recognizing the reasons for the behaviors and the degree to which practices are shaped by myriad factors such as device design, mixed messages about consumption, etc.

There is an immense literature on behavior change, including many efforts to try to systematize evidence and show how it might apply to energy use in buildings (Abrahamse et al. 2007; Crosbie and Baker 2010; Gynther et al. 2012). One of the difficulties of assessing how well interventions work is that, in many cases, the statistical bases are weak (e.g., no control group) and there is no necessary transferability of results from program participants to the larger population. Large-scale OPOWER-type efforts aside, participants are usually self-selected and represent only a small proportion of the relevant population.

Feedback

Over the past decade, there has been tremendous attention to the potential of energy use feedback in reducing energy use in residences (and in commercial buildings, but to a lesser extent). The overall conclusion of this research is that feedback can make a difference to what people do, but it is not a stand-alone technique. It does not necessarily influence consumption downward, and even when it does, the changes may be only a few percent of relevant energy use. Rajkovich et al. (2010) offer a common myth of ZNE debates: "Once people know how much energy they use, they will [necessarily] reduce their consumption." As research continues, the ability to provide influential feedback will no doubt improve. Yet, the questions of just how this feedback might fit into the daily lives of building users in the long run, and with what repercussions, remain unknown. In particular, the users of ZNE buildings have no necessary interest in achieving ZNE performance, and typically have many other priorities that can interfere with managing energy use.

Feedback in Residential Settings

Many reviews on energy use feedback in residential settings are available (e.g., Darby 2006; Fischer 2008; Ehrhardt-Martinez and Laitner 2010; Ehrhardt-Martinez 2012). These reviews identify different types of feedback, provide quantitative summaries of the results of feedback interventions, outline design and program factors that seem to contribute to savings, and speculate on prospects for expanding feedback. The average savings from residential device-based feedback range roughly from 4% to 12%, but some studies show no savings. Reviews have found that feedback should be based on actual consumption, be given frequently, involve interaction and choice for households, involved appliance specific data, be given over a long period of time, involve historical or normative comparisons, and be presented in an understandable and appealing way. The design, interface, device placement, and level of disaggregation in feedback data presented can have a large impact on the level of savings achieved (Froehlich, 2009). The statistical quality of these experiments and programs is often poor (perhaps necessarily so) and there is little evidence on persistence. Nor is there much information on what households are doing to achieve any energy savings. Feedback devices tend to be aimed at a certain domestic demographic, nuclear families in detached homes paying the full bill for their energy use (Dillahunt and Mankoff 2012).

Little has been published on feedback results specifically for ZNE and similar houses. In some test cases, sophisticated performance feedback has been shown to be crucial in getting a household to achieve ZNE performance, but only with the (pre-existing) dedication of the occupant (Doiron et al. 2012). In some production low-energy buildings in Europe, occupants showed little interest in logging onto a web site to retrieve energy use and performance feedback. New directions in feedback and control such as "learning" technology and automated control, together with smart meter or sensor data, may provide a sweet spot for occupant engagement for certain types of users and buildings (Kibert 2012).

Feedback in Commercial Buildings

Occupant-oriented energy use feedback in commercial buildings is usually provided at a building or zone level, with an emphasis on group behavior and comparison. There is much less published experience in this kind of commercial energy use feedback than there is for residences (Lopes et al. 2012). Results to date often rely on short study periods of a few weeks or months, commonly in university settings, such as energy savings competitions across dormitories or campus buildings. But competitions may not be appropriate in all situations (Melton 2011).

Simply displaying quantitative energy use information may signal to occupants that somebody in the organization is paying attention to energy use. It has little salience unless compelling comparisons are invoked or there are accompanying efforts addressing energy use. The form of information and accompanying rationales can matter a great deal. A four-month study testing the efficacy of building-level feedback in a university setting reported modest decreases in energy use by e-mail based energy use feedback (8%) compared to peer educational efforts (4%), both of which were more effective in reducing energy use than an information-only campaign (Carrico and Riemer 2011). There are several upcoming or on-going efforts directed to using energy use feedback to commercial building occupants, testing how to harness social influence (Lehrer and Vasudev 2011), or competition (e.g., selected Starbucks in Washington State), but results are not yet available. Lucid Design group produces a Building Dashboard® designed in conjunction with competition programs as well as other commercial building and residential feedback devices (see, e.g., deCoriolis 2011).

There is little published information on the effects of feedback in ZNE commercial buildings, though most have some sort of energy use dashboard displaying energy consumption from on-site solar as well as conventional sources. Even in ZNE buildings, feedback alone does not necessarily motivate occupants to reduce energy consumption (Rajkovich et al. 2010), and cybersecurity concerns can complicate or prohibit use of energy sub-metering and dashboards (Metzger et al. 2011). We did not review feedback directed toward operations and facilities staff, though Granderson et al. (2011) provide a useful summary and suggest that some of this feedback might usefully conveyed to occupants as well.

11.1.6 Effects on Occupants

Houses and buildings designed for ZNE performance may provide indoor environments that differ from those in conventional construction. This can change the occupant experience, whether positively and negatively, with potential effects on health, well-being, occupant satisfaction, and productivity. Research on the health effects of ZNE residential buildings is in its infancy (Hesmath et al. 2011). Even less attention has been paid to indoor air quality in ZNE commercial buildings, and to effects beyond air quality. There is a risk that ZNE construction could inadvertently degrade occupant well-being and productivity, possibly damaging the overall reputation of ZNE. Buildings that don't "work" for occupants will be modified by users in an attempt to improve them, which can increase energy consumption and hurt performance. Energy efficiency research and policy in general have not yet embraced the domains of building user environment, satisfaction and well-being. Addressing these overlaps in ZNE planning can help ensure that ZNE buildings add value beyond the energy benefits they may provide, and that the promised energy benefits are attained.

Rebound and Related Effects

Another dimension in which ZNE buildings can affect users is in the cost of energy services and in perceptions about the "green-ness" of ZNE construction. Occupants of a house designed to have lower energy bills may take the opportunity to use higher levels of energy services than they would have otherwise. Or they may have specifically chosen a ZNE-design home for the dampening effect it would have on bills. These effects may not be purely "rebound" in the economic sense, but on-site supply and high energy efficiency effectively reduce the marginal cost of energy services relative to some conventional alternative. Direct rebound effects are harder to make out in commercial buildings due to the overall relatively low salience of energy costs, but similar arguments may apply. Finally, in both residential and commercial cases, buying or occupying ZNE-design buildings can be seen as doing enough for sustainability, without paying attention to actual use (Cole and Brown 2009).

Rebound effects have been debated over two decades in U.S. and Europe, often in a highly politicized fashion. It is hard to disprove or prove much about them. Some argue that the effect can be major, even more than 100%, while others argue that it is minor (Maxwell et al. 2011). Most agree that the degree of potential rebound depends on the end use and occupant – e.g. heating in a low-income household vs. office lighting. Some European work on low-energy residences suggest that occupants may use these residences like any other house and in fact not achieve any reduction in energy use relative to conventional alternatives (Karresand 2012). One interview we conducted with an industry member suggested than in production ZNE homes, on-site supply may be treated essentially as a bill offset, where long-term costs for energy have already been paid up front. It depends on the building, ownership and occupant characteristics, and how it is branded marketed. These examples points to a potentially critical difference between types of ZNE users, very engaged early adopters and prospective adopters under large-scale diffusion.

User Knowledge and Expectations

The technical characteristics of a building and how it the building is presented shape occupant expectations and potential use patterns. Expectations come from past experience as well as how a new building is presented (Mlecnik at al. 2012). User satisfaction is not a matter of physical conditions alone. Rather, building users adjust for context (Leaman and Bordass 2007). They may be more tolerant and forgiving of faults in green buildings if they philosophically support sustainable building efforts or if they have a relatively high level of knowledge about how systems are supposed to work (Brown and Cole 2007; Leaman and Bordass 2007). Still, green design does not necessarily equate with good performance, and users' tolerances for functional and design problems in green-design buildings do not erase all concerns or necessarily increase perceived comfort (Brown and Cole 2007). If occupants are not on-board with the green identity of a building or an organization, they may be less likely to engage with the building in ways that support sustainability, e.g., reduced energy use (Monfared and Sharples 2011). These results also highlight the importance of attending to design problems rather than presuming that users will be unwaveringly forgiving (Leaman and Bordass 2007).

There is little published work on occupant satisfaction with U.S. low-energy and ZNE homes. Even demonstration projects may not be closely evaluated or monitored as to user reaction (Mlecnik et al. 2012). User satisfaction evaluations available from European low-energy housing projects show mixed results, with generally favorable user reviews and some specific problems depending on the building (Bell et al. 2010; Hauge et al. 2011; Mlecnik et al. 2012; Schnieders and Hermelink 2006). Dissatisfaction with design and level of controls was often noted. There is even less published information on user satisfaction in ZNE commercial buildings. More attention to post-occupancy evaluation and user satisfaction assessment of both ZNE commercial and residential buildings could be very useful in getting ZNE buildings to work well, especially if results are openly shared with other designers and researchers.

11.1.7 Demand for ZNE

The behavior literature review was not intended to cover ZNE market issues in any depth. In any case, little has yet been published on this topic. In envisioning the future of ZNE houses and commercial buildings, and transitioning from early adopters to the high levels of diffusion envisioned in California's policy goals, it is well-worth debating exactly who is expected to buy, build, and occupy ZNE buildings, why they would do so, and how their experience affects market evolution.

Who Buys or Rents ZNE and Similar Houses?

In the energy efficiency literature, the basic consumer efficiency choice model assumes that people buy energy efficient products because they offer economic savings over a conventional and otherwise nearly analogous alternative. This manifests the Physical Technical Economic Model (PTEM) framing of energy efficiency (Lutzenhiser 1993). Many social and behavioral sciences researchers have pointed to serious limitations in this model (Alcott and Greenstone 2012; Lutzenhiser 1993; Shove 2010; Stern 2011; Wilson and Dowlatabadi 2007). It remains a standard perspective in mainstream energy efficiency literature (Lutzenhiser et al. 2009), sometimes augmented by introducing the notion of non-energy benefits that efficient products may provide (Ryan and Campbell 2012).

ZNE homes are generally assumed offer consumers the benefits of energy efficiency, lower energy costs, and sustainability, versus alternatives. This set of assumptions parallels the policy rationale for ZNE, but it may poorly reflect most consumer decision-making. There has been little investigation into exactly why people buy low-energy homes, or might buy them in the future. It is clear that receptivity to ZNE and interest in living in a ZNE home will be influenced by the *kind of ZNE* designs involved (e.g., autonomous vs. networked, simple versus complicated; aesthetics of appearance; normalcy vs. innovative; clustered in a 'place' e.g., a ZNE place vs. dispersed, integrated).

Goodwin (2011) summarizes basic findings for "green" housing purchases in general: that a green aspect is more important in new homes than in existing homes, that buyers over the age of 40 may find environmental attributes more compelling than younger buyers, and that higher income buyers may be less compelled than lower-income buyers. As to ZNE homes in particular, most work on ZNE buildings to date involves early adopters, who may often be particularly interested in achieving good building performance, zero net energy, and other sustainability objectives (e.g., for houses in an eco-village) or overall adopting a way of "living differently" (Lorenzen 2012).

Where the decision criteria of people who buy or rent ZNE or similar low-energy homes have been explored, energy savings and technical characteristics themselves have not been found to often be key motivators. European reviews found that house features, such as the house location or the presence of a porch, or sometimes the promise of low energy costs more generally, are often more important (Hauge et al. 2011; Mlecnik *et al.* 2012; Schnieders and Hermelink 2006). In summary, European studies "generally confirm that the decision to choose a nearly zero-energy house is usually based on a combination of different criteria, such as reflection on architectural layout, economic costs or benefits, various environmental arguments, interest in [Passive House] technology, the site of the house and the influence of consultants. Energy efficiency and the branding of the dwellings as nearly zero energy – currently often regarded as essential to their promotion – are in themselves not enough" (Mlecnik et al. 2012).

As low-energy homes transition from niche products oriented to very engaged occupants -- roughly 1970s through 1990s -- to a more mainstream population, occupants may have even less specific interest in the sustainability or zero net aspects per se (Jensen et al. 2012). So overall there is little evidence that "if you build ZNE, they will come," unless other aspects of the building are attractive. Presumably, the general performance reputation of ZNE-constructed houses will also influence buyers, which on-line reviews and other social media help enable (e.g., Yelp reviews).

Demand for ZNE and low-energy commercial buildings

There is virtually no literature on the characteristics of who builds ZNE commercial buildings. Work in economic sociology has helped address the question of why commercial office buildings are not more energy efficient, despite the theoretical potential. Commercial building markets are constituted by multiple major industry groups, including capital providers, developers, design and delivery firms, regulatory and community interests, real estate providers, users, and others (Biggart and Lutzenhiser 2007; Lutzenhiser et al. 2001). How the interests of these various groups align and conflict shapes what buildings get built, the role of energy efficiency in these buildings, and the type of innovations that are likely to take place.

11.1.8 Design and Policy Implications

Grappling With the Variability of Behavior in Households

Different households have very different ways of consuming energy. Behavior, and lifestyles may be the most important determinants of the energy consumption in many homes in California, as opposed to the building and technical systems (Lutzenhiser et al. 2012). Evidence from energy use behavior change research suggests that the programs can influence household energy use downward by only a few percent on average. Dramatic changes in energy pricing could lead to some energy savings, but evidence is scant. The variability applies both to specific end uses as well as total energy use, so it is relevant to both how energy efficiency is achieved (e.g., heating vs. cooling vs. water heating efficiency) and the capacity of the supply system. If behavioral variability in ZNE houses is comparable to that in conventional construction, a particular house could not achieve actual net-zero energy performance in practice for *most* potential occupants unless it is also substantially oversized for many of them.

ZNE definitions, designs, and policies will need to address this innate variability if they are to effectively support policy objectives (e.g., the net effect that future ZNE residences will have on greenhouse gas emissions). This is a challenge: there is little empirical data available on end use consumption and on exactly how variability is constituted, and there is little experience for expressing and accounting for variability in current policy and technology design. Advances in building energy simulation that incorporate the variability of occupant behavior in residences, and potentially supporting data measuring this behavior (e.g., from sensors or AMI data), hold promise, but research is in its infancy.

Grappling With Variability of Behavior in Commercial Buildings

There is much less detail on exactly how user behavior varies in commercial buildings. But the situation may be even more complex than for residential buildings, given the many different types of commercial building activities (e.g., educational vs. retail vs. Class A office vs. health care) and the fact that in addition to occupants, building operators and other parties shape this energy use. Building designers can only loosely predict what building users will eventually do within the building, and in any case these activities change over time. Education, social learning, usability improvements, and operating training may help, but as for residential buildings, there is limited evidence that behavior change programs and feedback will have a major effect on what occupants do. Recent work in building energy simulation has improved the ability to model occupant behavior in commercial buildings. Empirical data and the ability to generalize from case studies, however, remain weak. How should variability be treated in design, policy definitions, and building performance assessment so as to best support ZNE policy objectives (in addition to market penetration goals *per se*)?

Improving Industry Understanding of the Role of Occupants

Given the technocentric nature of building energy research and policy (Lutzenhiser 1993) and the fracturing of responsibility for building performance, what users actually do in buildings has often been treated as an end-of-pipe matter. Especially in buildings designed for low-energy buildings, occupants are often the explanation of choice when buildings use more energy than expected or otherwise do not perform as designed. But this assessment is not necessarily valid or constructive. Rather, a more sophisticated assessment of actual behavior versus building design assumptions is required (Lenoir et al. 2012).

One common response to the problem of user unpredictability has been to promote "intelligent" or otherwise highly controlled buildings that reduce the potential effect that occupants have on building energy systems. Another common response is to assume that occupants can be trained or otherwise convinced to behave in specific ways. Neither line of argument is completely wrong, but the literature review suggests that each must be approached with true caution and with a multi-disciplinary view of what buildings are supposed to do and what people are like. Particular attention should be paid to the consequences of mistaken assumptions about what people want, do, and will tolerate, how effective technological design is with respect to *actual* occupant behavior, and the limited ability and unintended consequences of trying to control and influence occupant behavior.

Keeping Construction Options Open

Two strategies are often contrasted in debates on lower-energy construction (Cole and Brown 2009; Cole et al. 2010). The "intelligent building" strategy envisions a highly-engineered environment with very energy-efficient components and high levels of automated control. The "intelligent people" strategy relies more on passive strategies such as less automation, less precise control, and more flexibility in how needs are defined. Any assessment of standards, policies, definitions, and related conventions should consider the implications of pursuing either the "intelligent buildings" or the "intelligent people" route, and the risks of selecting each method of framing. One size does not fit all. Different ZNE designs may require different kinds of user interactions and control (e.g. the sealed-off design vs. the open-to-nature approach; automated vs. hyper-simple). These different designs may be best served by different types of policies and programs.

Importance of Building Operations in Commercial Buildings

Building operators, related facilities and organizational staff are major determinants of how buildings perform and use energy. These users are often forgotten, and considered part of the technical apparatus of a building. There is almost no research on the social and behavioral milieu of building operations. There are many related questions for ZNE design and policy. What is the role of building operator training, and how can it better training be supported by policy? What assumptions do ZNE design and the technical components of ZNE buildings (e.g., Building Automation Systems, system sizing) make about operations, and how justifiable are these assumptions? What are the implications of various types of automation (e.g., programming, fault detection) for building operations?

Educating Building Occupants

To date, results on how occupants use systems in ZNE (and similarly designed buildings) are limited, but several major findings exist. First, occupants are often not very educated on how to use building systems, including and what to expect of the systems. Second, the usability of systems designed for occupant interaction may be poor, and the level of controls may not match what occupants want or think they need. Third, occupants with better knowledge about how to use building systems and what to expect of them may have experience higher level of satisfaction with the building. Fourth, educational materials must be well designed and accessible, and should not assume that occupants will make a great deal of effort to learn. Fifth, the reasons for undertaking particular actions should be compelling to occupants (e.g., increases comfort or amenities).

In early adopter ZNE buildings, there may often an occupant and operator educational component during commissioning. In most commercial buildings, however, there may be no party with clear responsibility (or talent) for educating occupants. s. Even building operators may get little training once the building is handed off from builders and contractors. These educational hurdles merit more attention. Who educates occupants and how? How do occupants actually behave? How are operators trained and supported? What is the overall quality of the building and systems usability?

Influencing Building Occupants

There are different opinions about the prospects for using feedback devices, information programs and rewards programs that target individual behaviors to reduce energy use. Some positive results have led to a great deal of enthusiasm. Upon closer inspection, the successes are modest and selective, and cannot be taken as representative of buildings and program potential overall. For ZNE policy and design, the working conclusion is that while some feedback and information programs lead to some level of behavioral change in some contexts, these programs are insufficient as a complete strategy to transform building occupants. The quantitative information provided by existing feedback devices and displays can be useful for communicating the importance of energy, helping diagnose potential waste, and for assessing whether zero net energy performance goals are actually being attained. Feedback itself is not enough, however. It does not necessarily provide sufficient motivation or information for behavioral change, especially for the casual (versus enthusiast) ZNE building occupant, and there is little reason to think that policy rationales for ZNE or changes in occupant behavior (e.g., “reduce the threat of climate change”) can be simply imposed on building users.

Tracking and Improving User Satisfaction and Indoor Environment

Without adequate post-occupancy evaluation and commissioning, commercial buildings designed for ZNE may not function well with respect to energy performance or how the building interacts with its users. Ideally, post-occupancy evaluation should be undertaken not only right after move-in, but after longer periods of occupation. This will help identify issues that arise over time, as well as to track how users and buildings mutually adjust and evolve. Ideally, these assessments would include an evaluation of user satisfaction with the indoor environment and the overall building. Quantitative assessments (e.g., of air quality) would also be valuable. Dissemination of these "lessons learned" among industry players and researchers could help the ZNE industry learns from experience.

There is much less tradition in commissioning residential buildings and in evaluating user satisfaction in residential buildings. Again post-occupancy evaluation and user satisfaction assessment can help address design problems, improve construction and design processes overall, and, presumably, in improving user satisfaction with ZNE-design houses (and thus their reputation on the market).

Looking Deeper As To Where Behavioral Assumptions Enter

Policy definitions of energy efficiency depend on largely-hidden assumptions about what people do and what conditions are needed, which are buried deep in models, test protocols, and construction traditions (Lutzenhiser et al. 2009; Moezzi et al. 2009). For example, a system that is designed to provide efficient operations for circumstances or needs that do not exist (e.g. an oversized chiller, an air conditioner where passive cooling would be more than adequate) may be technically energy efficient but highly inefficient in actual operations. Hidden assumptions also shape construction and design practices. The potential turn of construction practices spurred by ZNE goals creates a good opportunity for debating and improving these assumptions.

Green Technology Does Not Necessarily Have Green Results

Social scientists have argued that sustainable building performance cannot be achieved by technology alone (Cole and Brown Jensen et al. 2012; Lorenzen 2012). In pushing to mainstream sustainable building or in focusing on increasing the sales of "green" devices, it becomes easy to forget that it is *how these buildings and devices are used* that matters in regard to whether they are actually aligned with sustainability goals (Jensen et al. 2012; Lorenzen 2012). Relative energy savings does not necessarily lead to absolute energy savings or GHG emissions reductions (Moezzi and Diamond 2005). Rebound and related effects suggest that efficiency itself sometimes invites higher demand for energy services. These problems may threaten the effectiveness of ZNE construction, especially in mainstreaming efforts. In formulating ZNE policy, the fact that asset specifications do not necessarily imply any particular level of performance must be addressed.

Addressing the Design–Performance Gap

Commercial building researchers have pointed to the importance of a "credibility gap" between design expectations and actual fuel consumption in commercial buildings. They have argued that this gap is evidence of the need for performance-based assessment and design response. "Credibility gaps arise not so much because predictive techniques are 'wrong,' but because the assumptions often used are not well enough informed by what really happens in practice, because few people who design buildings go on to monitor their performance … To achieve genuine step-change improvements, [all parties will] need to engage much more closely with achieved performance" (Bordass et al. 2004). Neither ZNE design or ZNE policy are likely to be very effective if they are based primarily on modeling and paper assessments.

Supporting Social Learning

Constructing ZNE buildings is not purely technical and models have only a limited ability to predict how things will work in an actual context. Hence, it is important to find ways to *let experience speak* from many different quarters and to take this experience into account. In particular, building designers, technology designers, building contractors, managers, building operators, occupants and others can learn from each other. Of course there is a reputation risk in doing so, because discussions can expose problems and failures. However this learning could ultimately lead to much better technology, performance, and user satisfaction (Bordass 2004; Ornetzeder and Rohracher 2002). It may be useful to provide or facilitate peer education, training, community learning forums, and other social learning exchanges for types of users ZNE-design homes and buildings.

Many studies argue that a collaborative, integrated design (ID), process not only achieves better performing buildings, but also acts to break down rigid, "siloed" approaches to buildings systems and professional practices(e.g., Brown and Vergragt 2008; Managan 2012). European experience in Passive House and ZNE construction, evaluation, and policy, might also help inform US efforts (Retzlaff 2010).

Assumptions about Who Buys ZNE and Why

Even in current ZNE construction, achieving ZNE or wanting to be green are not necessarily the goals of those who buy, build, and use ZNE buildings. Evaluations of recent European low-energy houses, for example, suggest that the promise of low energy use and low-energy technology features may rarely have been a major attraction or even much of a consideration for current occupants. Under the scenario of wide-spread diffusion of ZNE houses in California, prospective purchasers of these future houses may be even less motivated by sustainability or interest in low energy use. Nor will green performance necessarily be a major goal of future builders and occupants of ZNE commercial buildings.

Questioning Common Assumptions

Like any other field or industry, the various groups involved in constructing, planning, and legislating future ZNE buildings develop common assumptions about what is true and what will be required in order to create these buildings. These "institutional facts" (Searle 1995) are often narrow and are not necessarily based on much evidence or sound logic, even though they have tremendous influence on planning and execution of policy goals. Rajkovich et al. (2010) identify ten "myths and modes of thought"—several of which are addressed in the findings above. Both the design and research fields would do well to explicitly identify, monitor, and question common and emerging assumptions about ZNE.

11.2 Key Findings from Literature Review on Role of Building Operations, Maintenance, and Occupants

If good ZNE homes and buildings are to be achieved relatively cost-effectively, and if they are to appeal to prospective buyers, building users need to be incorporated realistically, rather than focus on technology without examining assumptions about what users want or will do. This requires observation about how people use buildings and considering new ways to incorporate this information. The following areas stand out as especially important for research and policy attention:

- **Realistic behavior description and feedback to design**. Improve understanding and description of what occupants in homes and commercial buildings do with respect to energy. Improve how behavior and its variability are reflected in building and technology design, research, and policy development.
  Energy-using systems in homes and buildings may often not be used as designed or as assumed in policies. Improved descriptions of user behavior that better match actual use can lead to better design and performance. In conventional construction, designers and users may eventually adapt to each others' expectations, but this feedback loop is uneven and can take many years. Given the aggressive ZNE market goals and the likelihood of innovative systems used in ZNE construction, this process could be accelerated by ensuring careful assessment and feedback on actual use and potential improvements in design as well as occupant education. Not doing so can lead to sub-par energy performance and occupant/buyer dissatisfaction, with potentially adverse effects on market growth.
  Further, better acknowledgement of the innate variability of behavior can help build more realistic expectations of building performance, versus the current use of synthetic "averages" in building energy policies (codes, programs et all)

- **Building operations.** Address the human side of building management and operations. In commercial buildings, building operations and management are key determinants of building energy use, but are often forgotten in the focus on technologies and occupant actions. Understanding why buildings are operated as they are can help support more realistic ZNE designs and reveal ways to reduce energy waste, e.g., by better incenting such reductions.

- **Influencing building users**. Improve the quality and delivery of education and energy use feedback to building users.

  Providing information to building users will not necessarily have a major impact on what all building users do. But more attention to the process of helping occupants learn about using the buildings they inhabit, and continued work on developing more useful forms of energy use feedback for ZNE designs, taking realistic account of why users do what they do, can help reduce energy use and improve user satisfaction with ZNE homes and buildings.

- **Automation vs. manual control.** Use observation and experimentation to improve automation and balance automatic versus manual control strategies.

  In part because of the unpredictability of user behavior, the building industry overall has embraced automation as a means of reducing energy waste. However, development and evaluation of automation has not adequately accounted for building users' desire for control or the potential energy savings from manual versus automated control.

Better integrating the human dimension in designing and selecting automation in energy service provision can help lead to lower energy use as well as more satisfied users.

- **Occupant satisfaction and building evolution**. Track occupant experience in ZNE buildings.

  If policy is to promote ZNE construction, it is important to help ensure – rather than simply assume -- that policies do not make the prospective occupants of these buildings worse off, e.g., through poorer air quality, inhospitable acoustic conditions, poor levels of control, etc. This will require evaluation of user experience and indoor environmental conditions, e.g., through post-occupancy evaluation and satisfaction assessments. High occupant satisfaction in ZNE buildings can help bolster the market case for ZNE. Assessment should also track how building users change the building, e.g., what systems they override or replace, and what uses they add.

- **Market.** Pay attention to what current and prospective ZNE buyers and building occupants want.

  Who buys, who occupies, who builds, and why, and what can be learned about the nature of future markets for ZNE homes and buildings? Rather than assume that the benefits of ZNE promoted in policy, research, and industry are also the hooks for potential buyers, use research to better determine what appeals about ZNE construction, what does not appeal about ZNE construction, perceived risks among buyers, and how buyer and occupant experience feeds back to the market.

12. Appendix D: Residential ZNE PV Capacity Calculation

This section presents additional supporting documentation about the assumptions and calculations conducted to support the findings in Section 6.8.1 of the report.

12.1 PV Capacity Needed Under the Site Energy Definition

The site energy-based PV capacity calculation assumes that enough rooftop PV must be built to offset the total energy use of all new residential construction beginning in 2020. For each of the 16 California climate zones and residential building types (single family, multifamily low-rise, and multifamily high-rise, the PV capacity required by new construction in a given year is calculated using the following equation:

$$\text{PV Capacity [MW]} = \frac{(\text{EUI [kBtu/sqft}\cdot\text{yr]}) \times (\text{Avg. Square Footage [sqft/unit]}) \times (\text{\# of new units}) \times 3{,}412\text{MWh/kBtu}}{(\text{Avg. PV Capacity Factor [\%]}) \times 8760\text{hrs/year}}$$

The EUI for each building type and climate zone was derived from the hourly energy usage of "exemplar" residential buildings simulated by Arup for the Technical Feasibility study. The "exemplar" buildings were simulated in five of the 16 California climate zones and a mapping was used to approximate building performance in climate zones that were not simulated. The resulting EUI's and the corresponding climate zones are listed in Table 11.

Table 7. EUI's from the hourly energy usage of "exemplar" residential buildings simulated by Arup for the Technical Feasibility study

Climate zones	Representative climate zone	EUI (kBtu/sqft-yr)	
		Single Family	Multifamily
1, 2, 3, 5	3	17.25	18.98
6, 7, 8, 9, 10	10	13.44	18.47
4, 11, 12, 13	12	17.54	18.99
14, 15	15	12.98	19.38
16	16	19.72	21.10

Historical square footage data was obtained for new residential construction starts in the West from the US Census Bureau. This data is listed in Table 12 and shown in Figure 54. The square footage of new residential units from 1999 to 2011 shows a slightly upward trend, however recent decreases suggest that this upward trend may not continue through 2020. For this reason, the most recent 10-year average was used to approximate the average square footage for new units in 2020-2030.

Table 8. Average square footage of new residential units in West (US Census Bureau 2012)

Year	Single Family Buildings (sqft/unit)	Multifamily Buildings (sqft/unit)
1999	2234	1069
2000	2244	1073
2001	2317	1128
2002	2350	1128
2003	2387	1155
2004	2352	1144
2005	2434	1158
2006	2488	1233
2007	2524	1272
2008	2508	1238
2009	2434	1249
2010	2386	1107
2011	2457	1118
2002-2011 Average	*2432*	*1180.2*

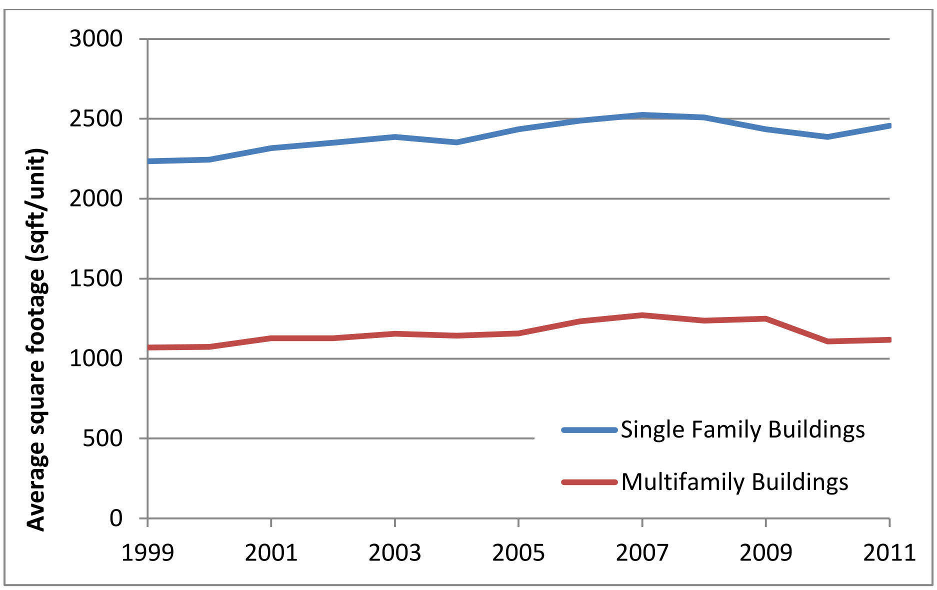

Figure 52. Average square footage of new residential construction completions in the West (US Census Bureau 2012).

The numbers of new residential construction builds by climate zone and building type in 2020 were taken from the CEC new residential construction 2020 forecast.

Table 9. Forecasted new residential construction by climate zone and building type in 2020

Climate Zone	Single Family Units	Multifamily High Rise Units	Multifamily Low Rise Units
1	903	0	102
2	2767	148	721
3	2785	1426	874
4	6307	1672	650
5	1225	167	284
6	2724	1631	1282
7	4960	1084	2014
8	4490	2311	1674
9	5156	2721	2053
10	21732	1146	2946
11	8035	93	943
12	23796	1872	2382
13	17200	275	2018
14	4018	0	802
15	4818	0	864
16	3680	0	646

The historical data indicates that the total number of new construction builds in California has varied significantly with business cycles. To approximate the uncertainty associated with these fluctuations, a baseline was calculated for the historical data using linear regression. The difference between the historical data and the linear trend was then calculated and the 10th and 90th percentiles of these differences, normalized by the baseline, were calculated in order to approximate the magnitude of the potential fluctuations away from a forecast for a given year.

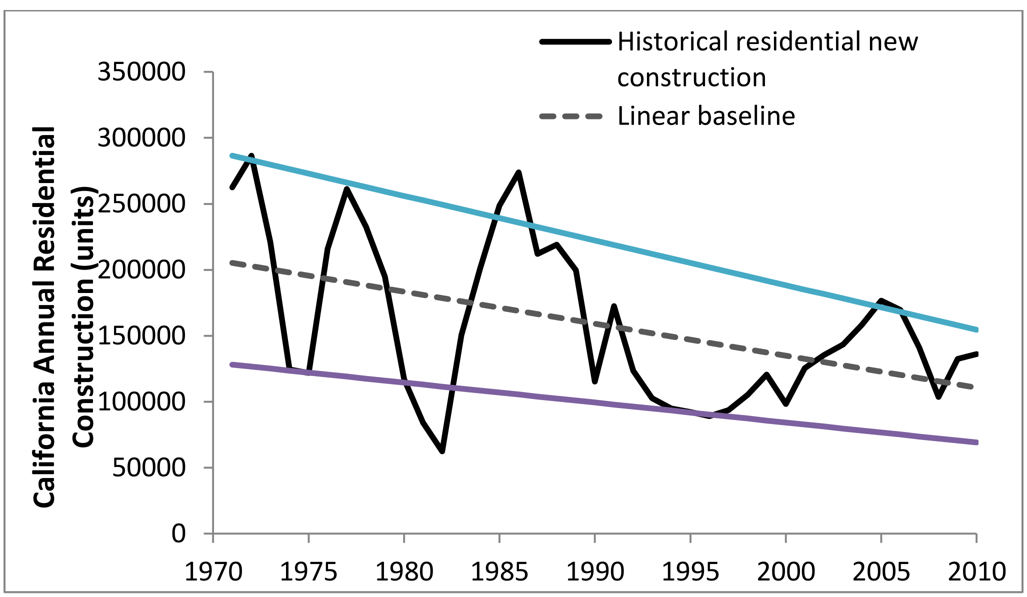

Figure 53. Historical fluctuations in new residential construction starts due to business cycles and the associated uncertainty bands calculated for the 2020 residential ZNE PV sizing problem.

This analysis indicated that business cycles can account for swings in the new residential construction starts from about 62% to about 140% of the baseline. This is a significant source of uncertainty in the 2020 analysis. Because the PV capacity is proportional to the number of new units, the error bars are used to reflect these swings. This implicitly assumes that the 2020 forecast tends toward the mean and does not capture business cycle fluctuations.

The PV capacity factors by climate zone were derived from hourly PV output profiles (kWh/kW-installed) from the CEC's PV simulation model. The resulting average annual capacity factors are listed in Table 14.

Table 10. Average capacity factors for PV systems in the California climate zones derived from CEC PV model output for the 2013 update to the Title 24 TDVs.

Climate Zone	PV Capacity Factor
1	15.3%
2	18.0%
3	18.2%
4	18.6%
5	19.5%
6	18.1%
7	19.0%
8	18.2%
9	18.8%
10	18.8%
11	18.3%
12	17.9%
13	17.7%
14	20.9%
15	19.1%
16	19.9%

12.2 PV Capacity Needed Under the Source Energy Definition

The source energy-based PV calculation is similar to the site energy-based calculation, but also requires the application of source energy conversion factors. In this definition, the primary energy consumption avoided by the PV output must equal the primary energy consumption of the building, including the primary energy consumed at the power plants to generate electricity. This method requires source energy conversion factors for both electricity and natural gas, which reflect the source energy consumption associated with a given amount of onsite electricity or gas consumption. The PV capacity required by new residential ZNE construction in a given year, according to the source energy definition of ZNE, is:

$$\text{PV Capacity [MW]} = \frac{\left(\text{EUI}_{\text{elec}} + \frac{k_{gas}}{k_{elec}}\text{EUI}_{\text{gas}}\right) \times (\text{Avg. Square Footage}) \times (\text{\# of new units}) \times \frac{3{,}412\text{MWh}}{\text{kBtu}}}{(\text{Avg. PV Capacity Factor}) \times \frac{8760\text{hrs}}{\text{year}}}$$

where the EUI is broken into the electricity gas usage components and the electricity and gas source energy conversion factors are k_{elec} and k_{gas}, respectively. For California electricity and natural gas, we have applied the source energy conversion factors of: k_{elec} = 2.45 and k_{gas} = 1.0 (Czachorski and Leslie 2009).

12.3 PV Capacity Needed Under the TDV-based Definition

Applying the TDV-based definition of ZNE requires a year of hourly electricity and gas usage for each building type by climate zone, as well as the electricity and gas TDV's for each climate zone. A home is considered ZNE by the TDV definition when:

$$\sum_t [(\text{Elec. Usage})_t \times (\text{Elec. TDV})_t + (\text{Gas Usage})_t \times (\text{Gas TDV})_t] = \sum_t (\text{PV Output})_t \times (\text{Elec. TDV})_t$$

For each climate zone and building type, the PV capacity required by new construction of ZNE homes in a given year is therefore:

$$\text{PV Capacity [MW]} = \frac{\sum_t [(\text{Elec. Usage [kWh]})_t \times (\text{Elec. TDV[kBtu/kWh]})_t + (\text{Gas Usage [therms]})_t \times (\text{Gas TDV [kBtu/therm]})_t]}{\sum_t [(\text{PV Power Output [kWh/MW]})_t \times (\text{Elec. TDV [kBtu/kWh]})_t]}$$

The TDV-based analysis relied on electricity and gas usage simulation results from the Technical Feasibility Study conducted by Arup (2012). One "exemplar" single family home and multifamily residential building were modeled in five of California's 16 climate zones. The rest of the climate zones were then mapped to these representative climate zones. In addition to the simulated hourly energy usage data, the TDV-based calculation relied on the residential construction forecast and average square footage data used in the site energy-based analysis and the electricity and gas TDV hourly factors used in the CEC's 2013 update of the Title 24 standards.

13. Appendix E: Greenhouse Gas Emissions

This section provides additional supporting details to information presented in Section 0 of the report.

13.1 Marginal and Average Emissions Rates of Electricity in California

There are two general approaches to calculating the carbon emissions associated with a building's electricity use, using either a marginal or an average emissions rate. Both approaches represent a ratio such as tonnes of CO_2 per megawatt-hour of electricity. Both approaches can either be calculated using historical data, or estimated using modeled data. Marginal and average emissions rates can be reported on an aggregate annual basis, time of use basis, or even on an hourly or sub-hourly basis. The definitions of these terms, and the tradeoffs between using a marginal versus an average emissions rate are described below:

- **Average emissions rate:** An average emissions rate is calculated based on the emissions of all the power plants that are operating in a given hour, including generation from zero-carbon power plants like nuclear, large hydroelectric and renewable resources. The average emissions rate for a given region will vary depending on how researchers classify which power plants are credited with supplying generation to a region.
- **When to use an average emissions rate:** The average emissions rate of electricity is appropriate to use in greenhouse gas calculations when estimating the total emissions associated with supplying electricity to a building, group of buildings or another entity. Put differently, the average emissions rate is useful for calculating the "carbon footprint" of a building. The average emissions rate is not appropriate to use when estimating the *change* in greenhouse gas emissions associated with a change in electricity demand. To estimate the greenhouse gas savings associated with energy efficiency, for example, a marginal emissions rate should generally be applied.
- **Marginal emissions rate:** The marginal emissions rate is generally calculated based on the emissions and generation of only those power plants that change their production due to a change in electricity demand. In general, only dispatchable or load-following power plants are treated as marginal sources of generation. The details of how different studies actually calculate the marginal emissions rate can vary significantly, depending on whether a short-term or long-term marginal emissions rate is calculated, and how the researchers go about determining which power plants are deemed "marginal".
- **When to use a marginal emissions rate:** The marginal emissions rate of electricity is appropriate to use in greenhouse gas calculations when estimating the change in emissions associated with a change in electricity demand. If a large and long-term change in electricity demand is projected, then it makes sense to use a long-term marginal emissions rate to estimate the carbon savings of this change. A long-term marginal emissions rate could reflect a change in the generation build decisions based on a sustained and significant drop (or increase) in electricity demand. If, for example, a reduction in demand led to a reduced need to build renewable generation to comply with the state's renewable portfolio standard, then the avoided renewable generation

could be included in the calculation of a long-term marginal emissions rate. On the other hand, if a relatively small or short-term change in electricity demand is projected, then it is appropriate to use a short-term marginal emissions rate to estimate the carbon savings. Short-term marginal emissions rates generally reflect changes in the dispatch of existing generation, rather than changes in the build-out of new generation.

Figure 54 below compares the projected 2020 average and short-term marginal emissions rates for California by time period. The marginal emissions rate in California reflects the fact that in general, natural gas power plants represent the marginal generation resource. Although it is true that in some hours of the year higher or lower carbon resources are on the margin, such as hydroelectric or coal generators, this occurs during relatively few number of hours per year, and does not significantly change the overall marginal emissions rate by time period.

Since California has a relatively large share of zero-emissions generation, the average emissions rate for the state tends to be about 30 percent lower than the marginal emissions rate, due to the fact that the average emissions rates includes California's zero-carbon generation resources such as nuclear, hydroelectric and renewable generation. Despite slight changes between seasons due to the availability of zero-carbon hydroelectric power, California's average emissions rate is fairly consistent across a given year. Likewise, the variations in marginal emissions rates between time periods are probably too modest to be factored into building design decisions.

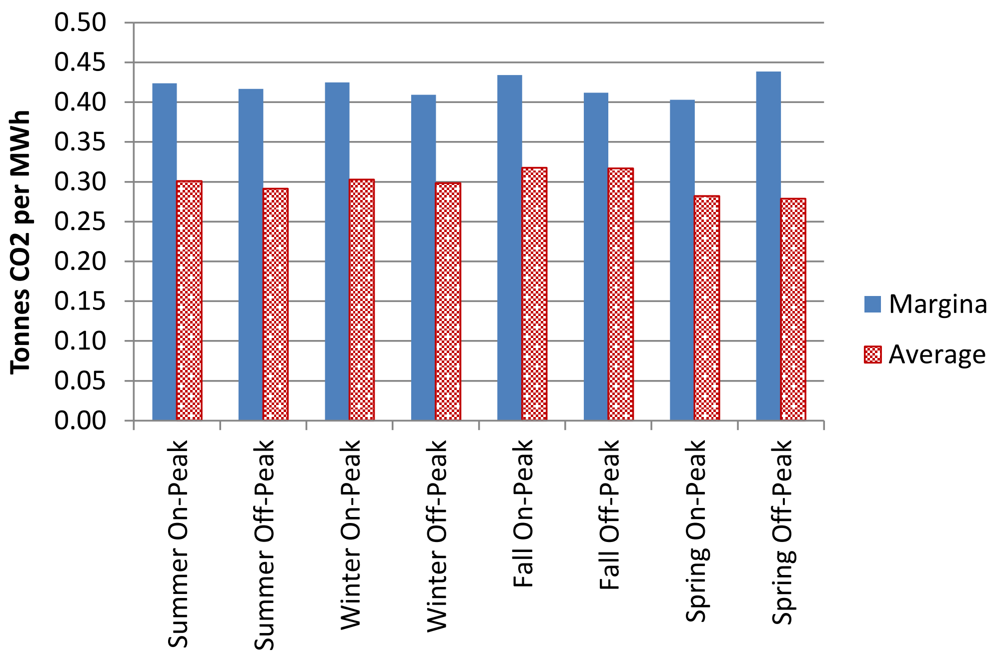

Figure 54. 2020 Forecast of California's Marginal and Average Electricity Emissions Factors by Time Period

In the figure above, we report average and short-term marginal emissions rates for California electricity generation, forecasted for the year 2020 by time period.[1] The emissions rate data are based on the summarized output of a production simulation model. The production simulation model used, PLEXOS, contains detailed information about nearly every generator in the Western Electricity Coordinating Council (WECC), as well as the transmission paths in the WECC. PLEXOS uses estimates of hourly load, fuel prices, and transmission constraints to estimate the least cost, constrained dispatch of generation in the West, and to estimate hourly CO_2 emissions for each generator.

The 2020 generation cases were developed by E3 as part of another project in 2008, and as a result use conservative assumptions about the future electricity mix in the state, assuming that the state meets only 20 percent renewable portfolio standard by 2020 and achieves relatively modest levels of energy efficiency. The emissions rates would be slightly lower (especially the average emissions rate) if updated today to reflect the achievement of a 33 percent renewable portfolio standard by 2020, changes to bi-lateral coal contracts with California utilities, higher levels of energy efficiency and lower load growth assumptions post-economic crisis. However, the overall patterns reflected in the chart would not significantly change.

In the figure above, the average emissions rate is calculated as the weighted average of the hourly average emissions rate, for each time period, of:

1. All generators operating within California's territorial boundary,
2. All out-of-state generators operating with known long-term, "specified" contracts with California retail providers and,
3. Electricity imports to California. Electricity imports are tagged with the average emissions intensity of all generators operating in the WECC in a given hour, excluding generators tagged for California.

In the figure above, the marginal emissions rate is calculated based on the difference in emissions between two different runs of the production simulation model for 2020. The marginal emissions rate is determined by evaluating the differences between a "base load" model run with normal electricity demand, and a "decremented" model run, where California's load is reduced by 500 MW in each hour. The difference between the generation dispatch patterns of the "base load" results and the "decremented" results reveals which generators are operating at the margin in any given hour in the model, enabling the calculation of the state's electricity marginal emissions rate. Here, the designation of in-state versus out-of-state generation is not important, since we care about which generators across the entire WECC increase or decrease their output in response to a small change in California's load.[2]

[1] Peak demand hours are defined as Monday through Friday, 6am to 10pm. Off-peak demand hours are weekdays 11pm to 5am, weekends and federal holidays.

[2] For more details about this methodology, see E3's report, "Developing a Greenhouse Gas Tool for Buildings in California: Methodology and User's Manual v.3," December 2010. The report was funded by the CEC PIER and is available for download here: http://www.ethree.com/public_projects/ghg.php

13.2 Lifecycle Greenhouse Gas Emissions

The greenhouse gas emissions associated with buildings are often calculated based simply on the building's direct (site) electricity and fuel usage, as is done in this report. However, it is possible to take a more comprehensive view of a building's greenhouse gas emissions. Some researchers have sought to estimate the "upstream" emissions associated with extracting, processing and transporting both electric and liquid fuel to a building.[1] Others have estimated the emissions that are embedded in the manufacture and transportation of a building's construction materials, as well as on-site construction practices and equipment, using a technique known as lifecycle assessment (LCA).[2] According to some estimates, the embodied environmental impacts of a building over its lifetime can be on the same order of magnitude as the environmental impacts associated with energy use in the building.[3] An even broader definition of a building's greenhouse gas emissions could account for the emissions associated with the land use choices associated with siting a building, the transportation emissions due to occupants commuting to and from the building, as well as the emissions embedded in processing and transporting water or other resources to the building site.

A better understanding of the lifecycle emissions associated with a building could be extremely useful in helping to inform low-carbon building design choices. However, it is difficult to obtain appropriate data to estimate lifecycle greenhouse gas emissions. An investigation of lifecycle greenhouse gas emissions from buildings is outside the scope of this report, but we bring it up here to simply note the importance of this issue and to highlight the need for more research into how lifecycle emissions data could inform better building design choices.

[1] See for example, Deru, M. and P. Torcellini, "Source energy and emission factors for energy use in buildings," NREL Technical Report 550-38617, Revised June 2007.

[2] Khasreen, M., P. Banfill, G. Menzies, "Lifecycle Assessment and the Environmental Impact of Buildings: A Review," *Sustainability*, 2009 (1) 674 – 701.

[3] Citherlet, S., "Towards the Holistic Assessment of Building Performance Based on an Integrated Simulation Approach," Swiss Federal Institute of Technology EPFL: Lausanne, Switzerland, 2001.

14. APPENDIX F: KEY ASSUMPTIONS FOR LEVELIZED COST OF ENERGY OF PV SYSTEMS

Section 5.5 demonstrates the relationship between all-in PV capital costs and the levelized cost of energy (LCOE). We compare two alternate options for financing a PV system. In the first option, PPA financing, the homeowner purchases electricity via a Power Purchase Agreement (PPA) from a third party commercial installer who owns and maintains the rooftop PV system. In the second financing scenario, the homeowner privately purchases the system and finances it with a home loan. (For a new construction home with solar PV already on the roof, the home loan could be a mortgage, or for an existing home that is retrofit for solar, the system might be financed with a home equity line of credit.)In both scenarios, we approximate likely conditions in 2020 by assuming that the federal investment tax credit is 10% of the total upfront system cost, we assume that REC's do not have a market value to the homeowner, and we assume that by 2020, existing state solar PV incentives, such as the California Solar Initiative or the New Solar Homes Partnership, are no longer available. The investment tax credit (ITC) is currently scheduled to fall from 30% of the upfront cost of solar to 10% starting in 2017, so these scenarios are consistent with a post-2017 view of solar PV costs.

The key differences between the two financing scenarios are related to cost of debt and tax considerations. In the PPA case, 40-60% of the PV system is financed with debt, while the remaining cost is purchased with equity. We assume a debt interest rate of 8% and an after-tax weighted average cost of capital (WACC) of 8.5%. In the home loan case, the system is 100% debt financed, the debt interest rate is 6%, and the WACC is equal to the tax adjusted debt interest rate, 3.92%. In both cases, the loan period is assumed to be 20 years.

Because the privately owned system is financed with a home loan, the interest paid is tax deductible. We assume the homeowner pays a 28% federal tax rate and a 9.3% state tax rate. In the PPA case, the commercial owner's debt interest is not tax deductible, but we assume a federal tax depreciation deduction (MACRS) for a 5 year term. The PV system's operating income is also taxable in the PPA case; we use a 35% federal tax rate and 8.84% state tax rate for the commercial owner.

These differences are summarized in the table below.

Table 11. Summary of 2020 forecasted differences between PPA financing and home loan financing

Input	PPA Value	Home loan Value
Percent of system financed with debt	40-60%	100%
WACC (after tax)	8.5%	3.92%
Debt interest rate	8%	6%
Debt period	20 years	20 years
Federal tax rate	35%	28%
State tax rate	8.84%	9.3%
Effective tax rate	40.75%	34.70%
Debt interest tax deductible	No	Yes
Taxable operating income	Yes	No
Depreciation tax deductible	5 year MACRS term	None

Some of the assumptions that are common across both financing scenarios are summarized in the table below.

Input	Assumption
REC Price	$0
Federal ITC	10%
Other rebates/incentives	None
O&M Costs	$30/kW, escalates 2%/yr
Inverter replacement cost	$0.393/W, replacement interval 10 years
Insurance cost	0.40% of CapEx, escalates 2%/yr
AC Derate Factor	85.5%
Performance degradation factor	1.25%/year

15. Appendix G: Nonresidential Building EUI Analysis

This section presents additional details in support of the information presented in Section 6.6.3 of the report.

15.1 Existing Building EUI Data

There are two primary sources of existing building energy performance data available to the team: the U.S. Energy Information Agency's Commercial Building Energy Consumption Survey (CBECS), and California's Commercial End-Use Survey (CEUS)[1]. Both of these studies select a sample of buildings from which to obtain energy consumption and building characteristic data, and then extrapolate energy consumption out to the state or national level. Energy consumption is typically reported as energy use intensities (EUIs), which is calculated by dividing total energy use by building area per year (kBTU/ft^2/year).[2]

Note that care needs to be taken when interpreting and applying the reported EUI data. Specifically, there are differences between whether EUI statistics are calculated on a per-building basis, versus an area-weighted basis—i.e., there is a significant difference between the "total number of buildings" with an EUI below a threshold versus the "total floorspace" below that threshold. Also, there is a difference between EUI statistics of the sample versus the entire population. Most of the end-use surveys use a variation of a "stratified random sample," where a statistically significant sample is selected for each minimum "strata group" (e.g., sample equal number of buildings for each climate zone/building type grouping), and different weighting factors are used to extrapolate this back to the entire population.

15.1.1 CBECS Data

The U.S. Energy Information Administration's Commercial Building Energy Consumption Survey (CBECS) is the DOE's primary commercial building energy end use study. CBECS obtains detailed energy consumption and building characteristic data for a sample of commercial buildings throughout the U.S. 2003 is the latest available study data[3].

[1] The team also investigated a number of other sources for additional EUI data, but for various reasons useful data wasn't able to be obtained. Energy Star Portfolio Manager contains historical energy performance data for a wide range of buildings; strict confidentiality requirements precluded access to this data. The University of California (UC), California State University (CSU), and Investor-Owned Utility (IOU) Energy Efficiency Partnership maintains databases on campus efficiency projects, which initially appeared to be a promising source of performance information but data was insufficient to provide consistent EUI calculations. LEED EB data was also explored but confidentiality requirements and other issues precluded its use.

[2] Note that some of the studies use slightly different definitions for EUI. This study consistently presents EUI data based on this definition.

[3] Note that the last (2007) survey was recently cancelled due to survey problems, and a new survey is currently being developed.

The 2003 CBECS is based on a sample of 5,215 buildings throughout the U.S. that are greater than 1,000 ft^2.[1] The CBECS is conducted in two data-collection stages: a Building Characteristics Survey and an Energy Suppliers Survey. The Building Characteristics Survey collects information about selected commercial buildings through voluntary interviews with the buildings' owners, managers, or tenants using Computer-Assisted Personal Interviewing techniques. Upon completion of the Building Characteristics Survey, the Energy Suppliers Survey is initiated for those cases that did not provide satisfactory consumption and expenditures information. This Suppliers Survey obtains data about the building's actual consumption of and expenditures for energy from records maintained by energy suppliers.

The CBECS data is available in two forms. The typical data set used is the final processed data, which extrapolates the underlying sample data to the entire population and presents total energy use, average EUIs and other statistics for the entire nation and select break-downs. This is valuable data, but has limited resolution. The EUI also makes available the underlying building sample data, which is useful for providing insight into the sample (i.e., what is the histogram of building EUIs in a certain climate zone for a specific building type), but is not weighted for the entire population. Both data sets are presented below.

Average Population EUIs

As discussed above, CBECS data is available in both processed form showing average population EUIs and other energy statistics[2], and the underlying raw sample data[3]. This section presents population averages. The most relevant population subset for which data is available is for CBECS climate zone 4 (<2000 CDD, <4000 HDD), which encompasses California Climate Zones 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, and 13 (refer to Table 16: Correlation between CBECS Climate Zones and California Climate Zones, for more details). Unfortunately, processed data is not available to further subdivide the data to only show data for the western census division. The average building EUI for CBECS climate zone 4 is 78.6 kBTU/ft^2, while the average EUI for buildings in climate zone 4 in the Pacific Census Division is 63.5 kBTU/ft^2, so the data in the following graphs will be higher than what is expected in California. Nevertheless, this data provides some insight and is of value to explore.

The following set of graphs present population-average EUIs, on an area-weighted basis, broken out by principal building activity, floor space, and year constructed. The graphs also show the percent of building floor area to total floor area for each category, read from the right axis. This data is from CBECS Table C10A, "Consumption and Gross Energy Intensity by Climate Zone for All Buildings, 2003"[4].

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[1] This is a multistage area probability sample supplemented by a sample of buildings drawn from special list frames. A sample of 6,955 potential buildings was initially selected, with 5,215 completed building interviews for a response rate of 82%.

[2] http://www.eia.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html

[3] http://www.eia.gov/emeu/cbecs/cbecs2003/public_use_2003/cbecs_pudata2003.html

[4] http://www.eia.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/2003set9/2003html/c10.html

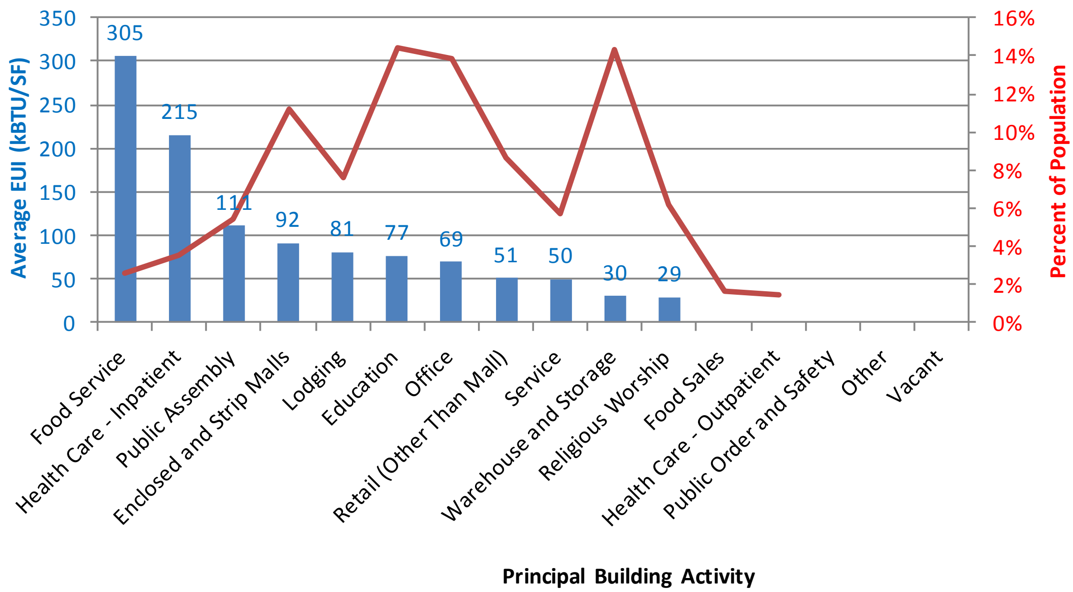

Figure 55: Population average EUIs by building activity for CBECS Climate Zone 4

(note: blank values represent insufficient data for meaningful statistics)

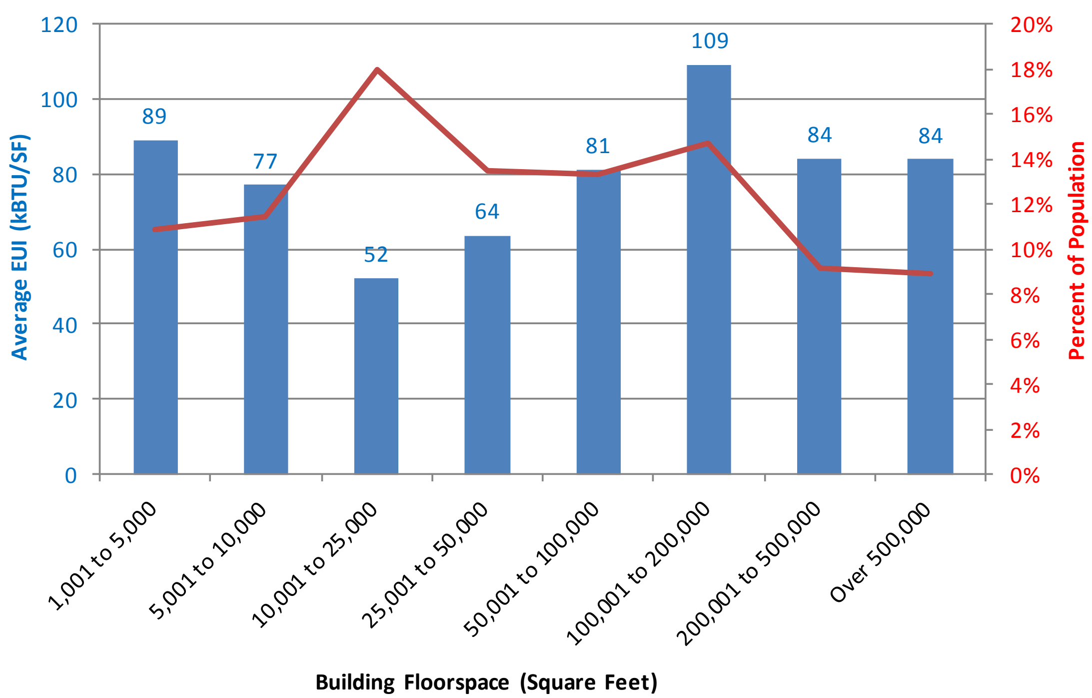

Figure 56: Population average EUIs by building floor space for CBECS Climate Zone 4

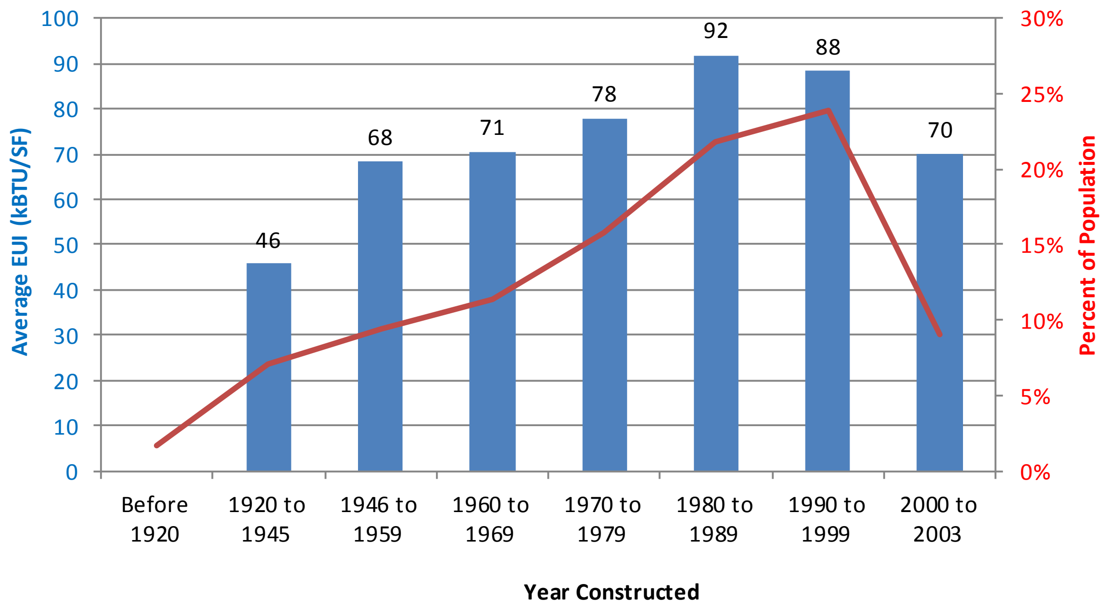

Figure 57: Population average EUIs by year constructed for CBECS Climate Zone 4

(note: blank values represent insufficient data for meaningful statistics)

CBECS Sample EUI Data

This section presents the underlying CBECS building sample data, which provides additional insight into the range of building performance and can help estimate the percent of existing buildings that have energy performance in the “ZNE Capable” range (i.e., an energy use index (EUI) of less than or equal to 30 kBTU/SF/year). Note that this data is an analysis of the underlying CBECS sample data, and is not extrapolated, or weighted to reflect the entire population of buildings represented by this sample. Also, the following statistics show average building EUIs, unweighted by building floor space.

The CBECS sample data was filtered to show building EUIs for the Pacific Census Region (which includes California, Oregon, Washington, Alaska and Hawaii), and then by CBECS climate zones 3, 4, and 5, representing the climate zones in California, as illustrated in the following table. While this data set contains buildings from other Pacific states with the same climate zone, it is nevertheless a useful dataset to benchmark existing building performance for California.

Table 12: Correlation between CBECS Climate Zones and California Climate Zones

CBECS Climate Zone	CDD / HDD	CA Climate Zones Contained	# of CBECS Buildings
3	<2000 CDD, 4000-5499 HDD	1, 16	82
4	<2000 CDD, <4000 HDD	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	391
5	>2000 CDD, <4000 HDD	14, 15	53

The following figure summarizes the percent of CBECS buildings, by building type and CBECS climate zone, that are “ZNE Capable” (i.e., buildings with an EUI ≤ 30 kBTU/SF), buildings in the “near” ZNE Capable range (EUIs between 30 and 40 kBTU/SF that potentially could reach ZNE with a larger renewable energy system and/or moderate energy efficiency improvements in the 10 – 25% range), and buildings with EUIs > 40 kBTU/SF which would be challenged to achieve ZNE. Buildings types where all buildings have EUIs ≥ 40 kBTU/SF are not shown (see the following tables for this data).

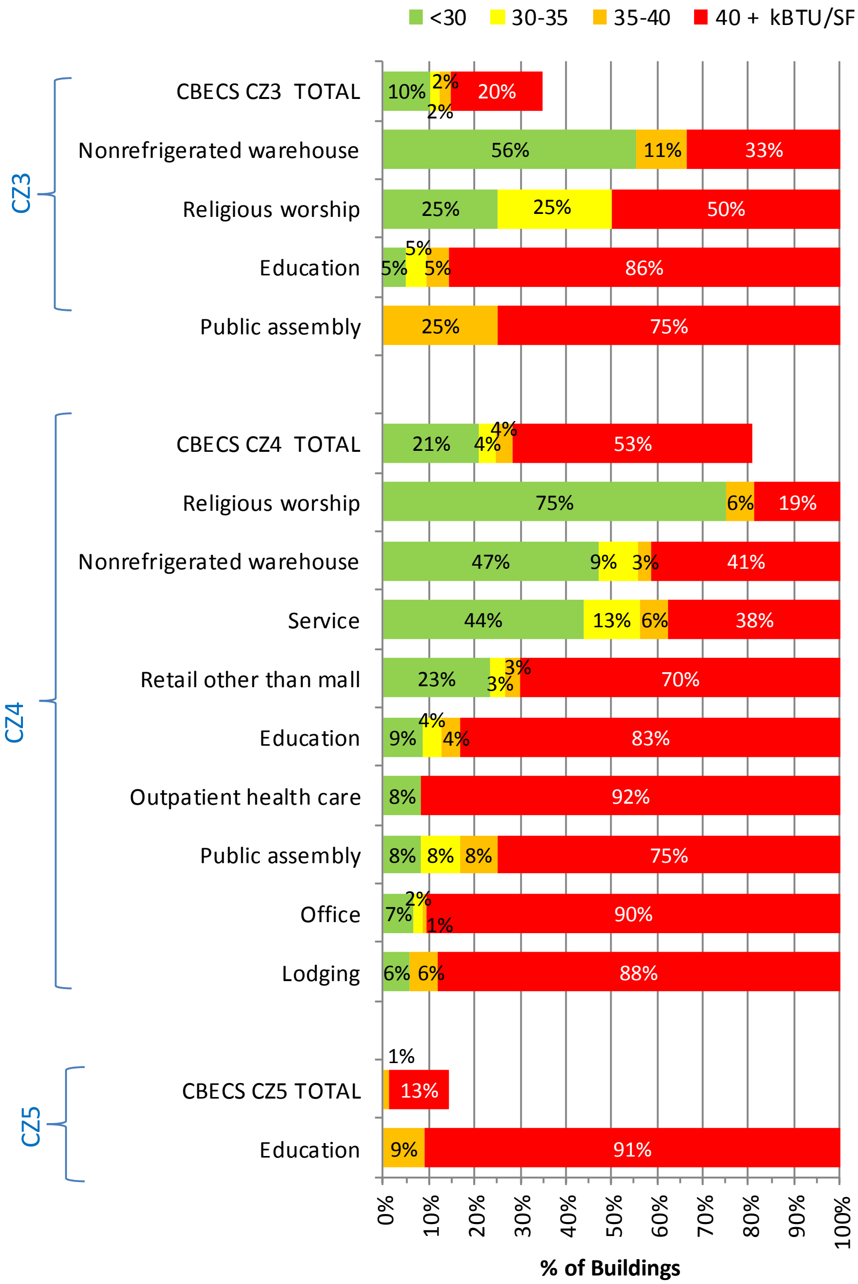

Figure 58: Percent of CBECS buildings achieving ZNE Capable and near-ZNE Capable EUIs by CBECS climate zone and building type

Overall, 13% of building square-footage has EUIs ≤ 30 kBTU/SF and are nominally "ZNE Capable". W[1]. An additional 6% have EUIs between 30 and 40 kBTU/SF, which are potentially within reach of ZNE with additional PV and/or efficiency improvements. 82% of buildings have EUIs ≥ 40 kBTU/SF, and are unlikely to achieve ZNE without significant efficiency improvement. CBECS Climate zone 4 (corresponding to the majority of the California climate zones) has the largest percent of buildings that are ZNE Capable (16%) and another 6% that are between 30 – 40 kBTU/SF.

There is significant EUI variation by building type. Considering CBECS climate zone 4 (encompassing the majority of California Climate Zones), religious worship has the largest percentage (75%) of buildings with EUIs below 30 kBTU/SF. A very large percentage of existing religious worship buildings could achieve ZNE right now by simply adding PV. This may be an important building class to target for achieving early-stage ZNE targets. In addition to the technical feasibility, the faith community plays an important leadership role in the community.

The following figure summarizes the EUI distribution by climate zone and building use type. The data is broken down by "ZNE Capable" buildings (buildings with an EUI ≤ 30 kBTU/SF), buildings in the "near" ZNE Capable range with EUIs between 30 and 40 kBTU/SF that potentially could reach ZNE with a larger renewable energy system and/or moderate energy efficiency improvements in the 10 – 25% range), and buildings with EUIs > 40 which would be challenged to achieve ZNE.

Table 13: CBECS EUI Distribution by climate zone and building use type

	EUI (kBTU/SF/Yr)			
Climate Zone / Building Use Type	**≤30**	**30-35**	**35-40**	**> 40**
CBECS CZ3 / CA CZs 1,16	**9%**	**2%**	**4%**	**85%**
Education	5%	5%	5%	86%
Food sales				100%
Food service				100%
Inpatient health care				100%
Laboratory				100%
Lodging				100%
Nonrefrigerated warehouse	56%		11%	33%
Nursing				100%
Office				100%
Outpatient health care				100%
Public assembly			25%	75%
Public order and safety				100%
Refrigerated warehouse				100%
Religious worship	25%	25%		50%
Retail other than mall				100%
Service				100%
Strip shopping mall				100%

[1] Note that this value is the average of the sample, and does not account for the fact that

Vacant				100%
CBECS CZ4 / CA CZs 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	16%	3%	3%	79%
Education	9%	4%	4%	83%
Enclosed mall				100%
Food sales				100%
Food service				100%
Inpatient health care				100%
Laboratory				100%
Lodging	6%		6%	88%
Nonrefrigerated warehouse	47%	9%	3%	41%
Nursing				100%
Office	7%	2%	1%	90%
Other				100%
Outpatient health care	8%			92%
Public assembly	8%	8%	8%	75%
Public order and safety				100%
Refrigerated warehouse				100%
Religious worship	75%		6%	19%
Retail other than mall	23%	3%	3%	70%
Service	44%	13%	6%	38%
Strip shopping mall				100%
Vacant	57%		14%	29%
CBECS CZ5 / CA CZs 14, 15			**2%**	**98%**
Education			9%	91%
Enclosed mall				100%
Food service				100%
Inpatient health care				100%
Lodging				100%
Nonrefrigerated warehouse				100%
Nursing				100%
Office				100%
Outpatient health care				100%
Public assembly				100%
Religious worship				100%
Retail other than mall				100%
Service				100%
Strip shopping mall				100%
Grand Total	**13%**	**3%**	**3%**	**82%**

The following table shows similar CBECS EUI data, but average EUIs (by building count) and related statistics are shown.

Table 14: Average CBECS EUIs by climate zone and building use type

	EUI (kBTU/SF)			
Climate Zone/Building Use Type	**Average**	**Std. Dev.**	**Min**	**Max**
CBECS CZ3 / CA CZs 1,16	**133**	**112**	**1**	**650**
Education	107	59	16	249
Food sales	290	n/a	290	290
Food service	362	278	96	650
Inpatient health care	402	75	349	455
Laboratory	245	n/a	245	245
Lodging	108	26	73	143
Nonrefrigerated warehouse	43	36	1	118
Nursing	268	n/a	268	268
Office	144	112	42	519
Outpatient health care	122	47	77	171
Public assembly	130	88	37	246
Public order and safety	112	52	52	150
Refrigerated warehouse	179	n/a	179	179
Religious worship	36	13	18	47
Retail other than mall	100	75	47	153
Service	69	13	59	85
Strip shopping mall	265	26	247	283
Vacant	231	n/a	231	231
CBECS CZ4 / CA CZs 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	136	144	2	1,207
Education	118	114	16	593
Enclosed mall	128	8	119	134
Food sales	267	114	97	460
Food service	410	231	67	702
Inpatient health care	312	168	102	727
Laboratory	269	116	104	441
Lodging	86	48	5	173
Nonrefrigerated warehouse	41	35	4	145
Nursing	206	89	89	302
Office	120	83	9	572
Other	301	221	173	557
Outpatient health care	189	120	26	355
Public assembly	112	169	3	836
Public order and safety	103	46	54	148
Refrigerated warehouse	73	n/a	73	73
Religious worship	26	17	2	57
Retail other than mall	100	75	3	286
Service	128	295	5	1,207
Strip shopping mall	158	65	82	346
Vacant	45	53	4	151
CBECS CZ5 / CA CZs 14, 15	**141**	**108**	**36**	**710**
Education	121	80	36	288
Enclosed mall	205	9	198	211
Food service	449	369	189	710
Inpatient health care	244	50	201	299

Lodging	123	77	49	270
Nonrefrigerated warehouse	54	16	40	76
Nursing	171	163	55	286
Office	134	63	66	226
Outpatient health care	147	n/a	147	147
Public assembly	65	38	42	109
Religious worship	53	8	47	58
Retail other than mall	119	35	95	143
Service	109	n/a	109	109
Strip shopping mall	159	46	100	212
Grand Total	**136**	**136**	**1**	**1,207**

15.1.2 California Commercial End-Use Survey (CEUS)

The California Commercial End-Use Survey (CEUS) is a comprehensive study of commercial sector energy use, primarily designed to support the state's energy demand forecasting activities.

There are two ways to look at the CEUS data. The original CEC report and Itron website with CEUS data[1] presents the data on an area-weighted basis, providing average EUI data for total building square footage[2]. This is useful for estimating total energy use and energy end uses at the state-level or other breakdown. It does not, however, present data about the total number of buildings in each category.

Lawrence Berkeley National Lab (LBL)'s Energy IQ program[3] has taken the CEUS data and presents the data on a per-building basis. The intent of this is to facilitate building owners compare how their building compare to other buildings, and provides insight into the range of building performance by building type and other factors.

Both sets of data present useful data, but caution should be used in interpreting the data. There is a significant difference between the average EUI of the population verses the average EUI of a typical building.

CEUS EUI Averages by Square-Footage

The original CEUS results are presented on a building area-weighted basis. This is useful for estimating total population energy use by building type or end use. For each utility service area, floor stocks, fuel shares, electric and natural gas consumption, energy-use indices (EUIs), energy intensities, and 16-day hourly end-use load profiles were estimated for twelve common commercial building type categories. The following figure shows the population average EUIs on

[1] http://capabilities.itron.com/ceusweb/

[2] i.e., individual "sample" building EUIs have been multiplied by the appropriate weighting factors to get the total square feet/energy usage represented by each sample.

[3] Lawrence Berkeley National Lab. "Energy IQ: Action-Oriented Energy Benchmarking". http://energyiq.lbl.gov/

an area-weighted basis for all building types. This data is statewide averages taken from the Itron CEUS website[1].

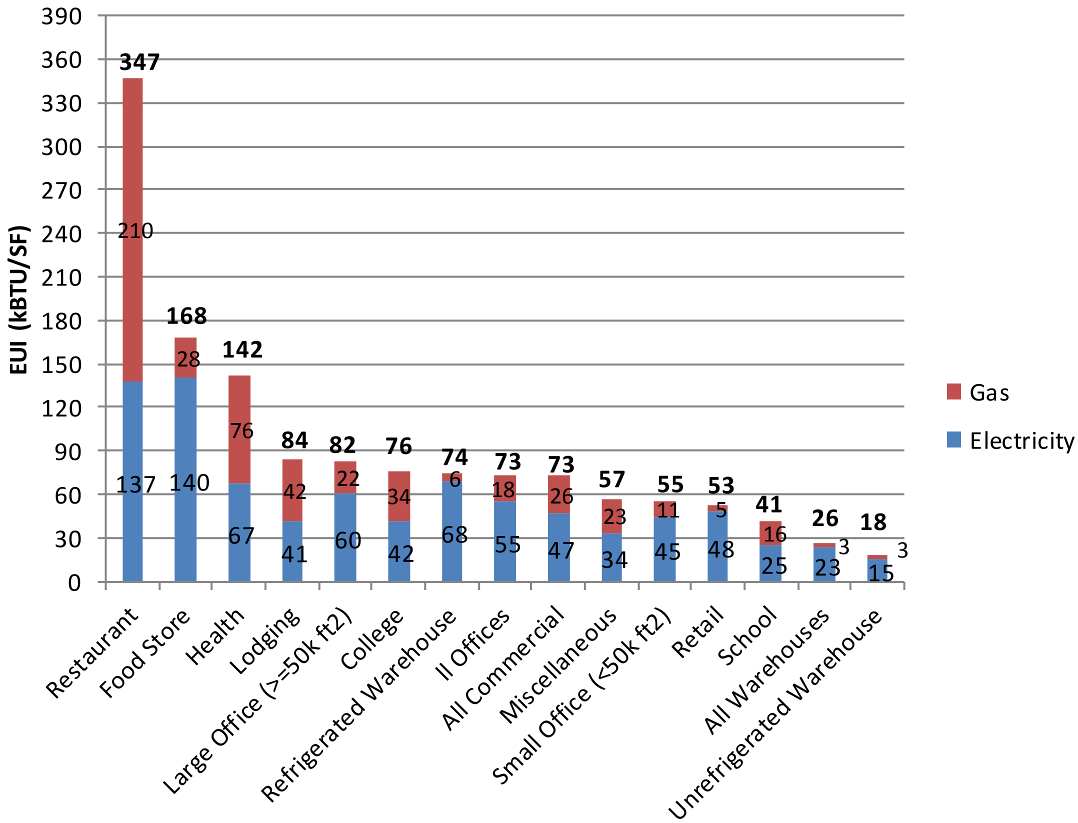

Figure 59: Population average EUIs (area-weighted) by building type (CEUS)

CEUS EUI Averages by Building Count

LBL's Energy IQ tool[2] presents the CEUS data on a per-building basis. The Energy IQ benchmarking tool was run to get EUI benchmark data for different building types at the state level. The following figure shows average EUI by building size. Note that for most building types, smaller buildings have significantly lower EUIs than larger buildings.

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[1] http://capabilities.itron.com/ceusweb/

[2] Lawrence Berkeley National Lab. "Energy IQ: Action-Oriented Energy Benchmarking". http://energyiq.lbl.gov/

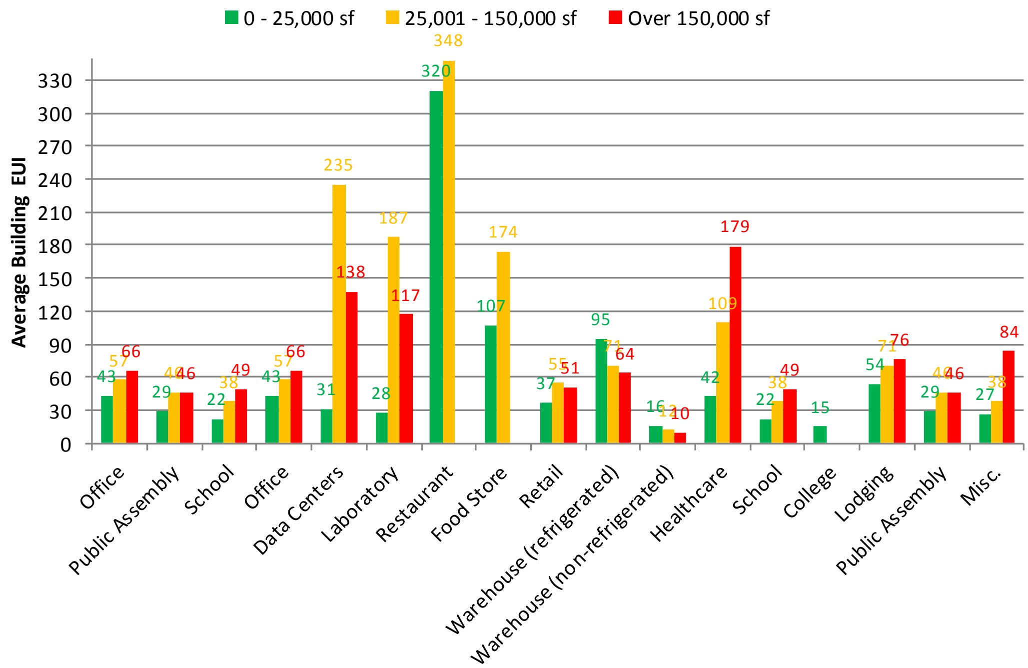

Figure 60: Average EUI by building size (CEUS data from the LBL Energy IQ Benchmarking Tool)

The following table shows the approximate number of buildings by size and type for PG&E's service territory[1]. This data is based on an analysis of the expansion weights in the CEUS final report[2]. Note that for all building types, the large majority of buildings are "Small". There are many smaller buildings with lower EUIs, which helps create the difference between the average EUIs by floor space.

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[1] Note that these size classifications are based on those defined in table 2-2 of the final CEUS Report, which vary by building type. This does not align with the LBL Energy IQ size breakdown in the preceding figure, but are illustrative of the issue.

[2] CEUS is a stratified random sample of 2,790 commercial facilities was collected from the service areas of Pacific Gas and Electric, San Diego Gas & Electric, Southern California Edison, Southern California Gas Company, and the Sacramento Municipal Utility District. The sample was stratified by utility service area, climate region, building type, and energy consumption level. Detailed building energy simulation modeling was used to develop the energy end uses and load profiles. The sample was then expanded to the total population by multiplying by appropriate "expansion weights" representing the number of buildings represented by each sample. Refer to the CEUS Final Report for details.

Table 15: Approximate distribution of buildings by size and type for PG&E's service territory

Building Type	% of Total Population	Percent of Buildings by Size		
		Small	Medium	Large
Miscellaneous	28%	75%	22%	2%
Small Office	22%	60%	26%	14%
Retail	16%	78%	20%	2%
Restaurant	13%	67%	29%	4%
Food Store	8%	80%	16%	4%
Unrefrigerated Warehouse	7%	78%	20%	2%
School	2%	60%	34%	6%
Lodging	2%	76%	21%	4%
Large Office	1%	59%	29%	13%
Health	1%	62%	30%	8%
Refrigerated Warehouse	0.4%	63%	29%	8%
College	0.3%	69%	26%	5%

When these EUIs are multiplied by the number of small/medium/large buildings, one gets a very different picture of the *number* of buildings with low EUIs, compared to the EUIs based on area-weighted averages.

The following figure summarizes the percent of buildings (by total building count, *NOT* weighted by square-footage) that are "ZNE Capable" (i.e., buildings with an EUI ≤ 30 kBTU/SF), buildings in the "near" ZNE Capable range (EUIs between 30 and 40 kBTU/SF that potentially could reach ZNE with a larger renewable energy system and/or moderate energy efficiency improvements in the 10 – 25% range), and buildings with EUIs > 40 kBTU/SF which would be challenged to achieve ZNE. The results are show much larger percentages of buildings that are already performing in the "ZNE Capable" range, compared to the floor space weighted EUI data. As discussed above, the primary drivers for these differences is that there are many more smaller buildings, and the smaller buildings have lower EUIs.

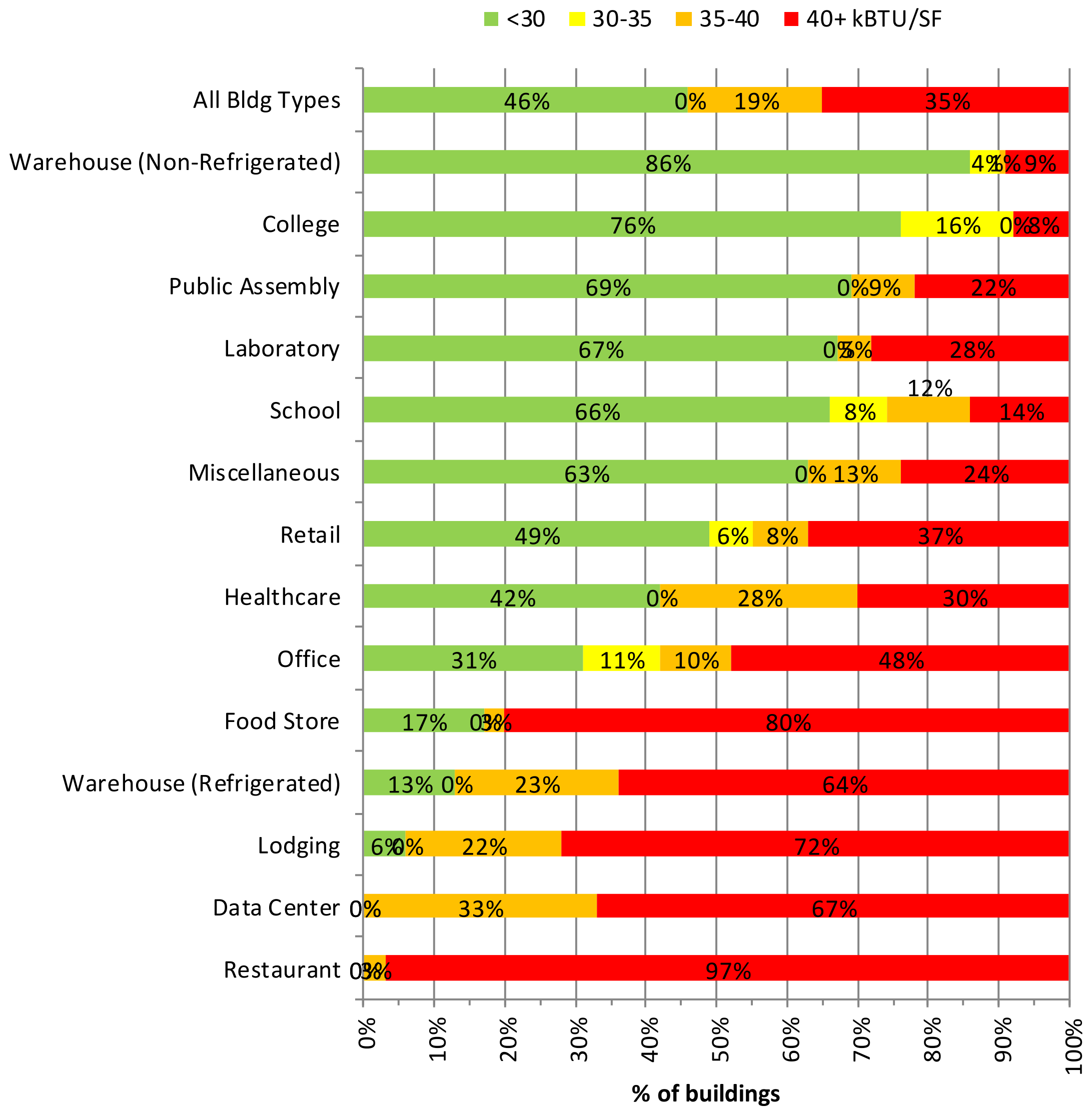

Figure 61: Percent of buildings by EUI category (CEUS data from the LBL Energy IQ Benchmarking Tool)

One driver of the low EUIs for smaller buildings is that a significant portion of the existing building stock does not have air conditioning, particularly for smaller buildings and older buildings. The two following graphs plot the percent of buildings with no cooling (or zero space cooling energy use per the Energy IQ data), broken down by building vintage and building size. Also plotted on these graphs (read on the right y-axis) is the median, 5th percentile and 95th percentile EUIs for each group.

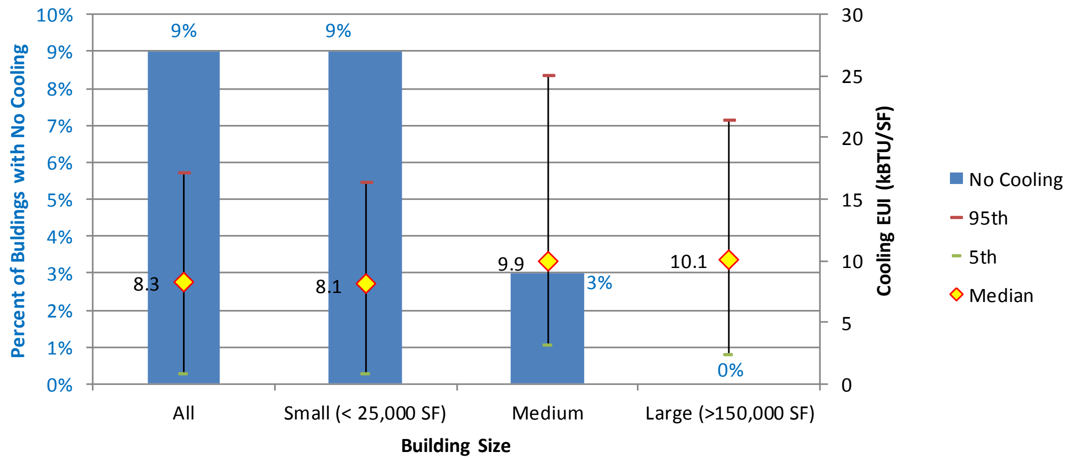

Figure 62: Percent of office buildings with no cooling and cooling EUIs, by building size

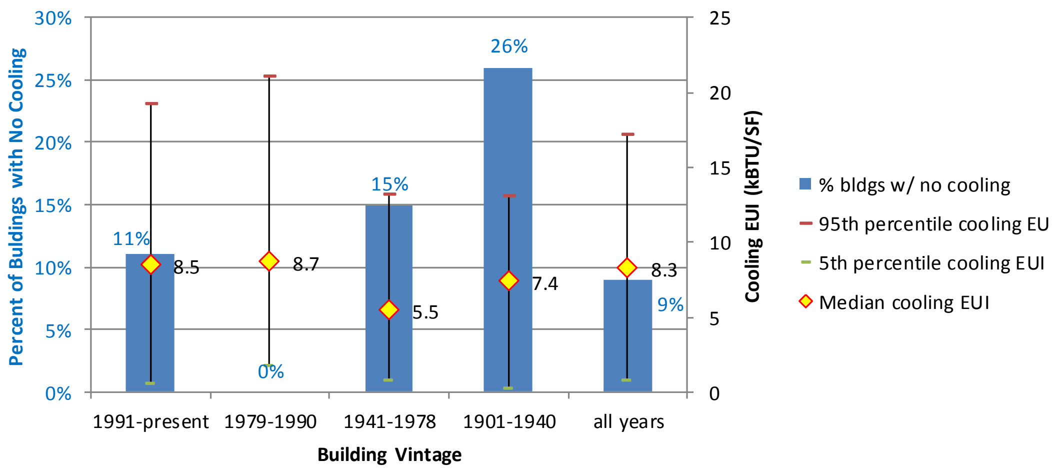

Figure 63: Percent of office buildings with no cooling and cooling EUIs, by building vintage

15.2 New Buildings – California LEED NC Rated Building Data

The team worked with U.S. Green Building Council (USGBC) to obtain access to modeled energy performance data for LEED for New Construction (LEED NC) certified projects in California. Specifically, the data contained in Energy and Atmosphere credit 1 (EAc1), "Optimize Energy Performance" submittals were obtained for projects utilizing the whole building energy simulation option and analyzed. Results are summarized here.

15.2.1 Methodology

Permission was obtained to use aggregated data for this report, with conditions that no individual building performance data could be released. Extracting this data required the development of custom programming tools to extract the data from the underlying PDF forms. The LEED Online project forms, implemented as Adobe Acrobat PDFs with editable form fields, provide users with a wide range of data input formats which results in a wide range of data output formats, thereby making the mass exportation of such data a complex process. A variety of search algorithms were created to intelligently locate the data within each text file based on parameters such as the data's expected position, length, or location in relationship to particular words. These general search techniques were then applied to extract specific data elements. Significant time was spent on quality control to ensure that the extracted data matched the original form data. Extracted data was placed in a database for analysis and processing.

Note that unless explicitly stated otherwise all energy use indices (EUIs) presented here are based on conditioned area and measured in kBTU/SF/year. Energy data is based on modeled data and does not represent actual building energy consumption. An effort was made to identify buildings that were both LEED NC and either LEED EB rated or were participating in the USGBC's Building Performance Partnership Program. This would have provided actual performance data for comparison between modeled vs. actual performance data. At the time of writing, overlapping projects have not been identified. It is possible that, due to different project ID's and project names, that there may be a few projects that overlap.

As discussed in section 5.5.1, "Design vs. Actual Performance", the New Buildings Institute (NBI) analyzed the energy performance for 121 LEED New Construction (NC) buildings[1]. They compared predicted verses modeled EUI. The results showed that while there is significant scatter for individual buildings, that on average the modeled results compare closely to actual results. Since this study has come out, the LEED energy modeling review process has increased in stringency with new quality assurance and review standards in place. It is believed (but not documented) that energy modeling quality has improved and that some of the project-level variation in modeled verses actual energy use has decreased. Based on this study, it is anticipated that the aggregate modeled EUI results reported in this study are representative of actual performance levels.

[1] New Buildings Institute. "Energy Performance of LEED® for New Construction Buildings." 2008. http://www.newbuildings.org/sites/default/files/Energy_Performance_of_LEED-NC_Buildings-Final_3-4-08b.pdf

15.2.2 LEED Building Performance Characteristics

California LEED NC rated building energy performance statistics are summarized below.

By Certification Level

A total of 415 LEED NC version 2.2 projects were extracted and analyzed. Over half of these buildings (52% or 216 buildings) received a gold rating, 31% received a silver rating, 10% were certified, and 7% received a platinum rating.

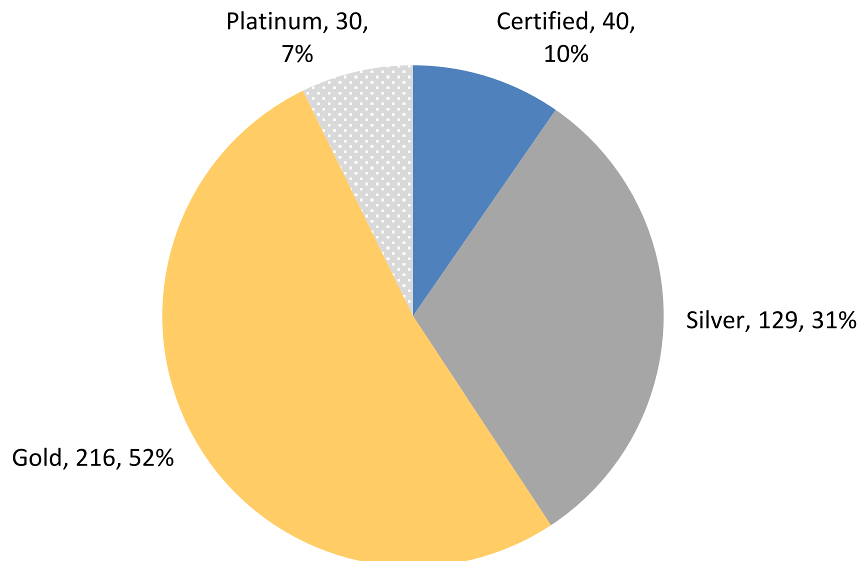

Figure 64: California LEED NC buildings by certification level

By Primary Building Type

The buildings were categorized into 21 specific building use types. The following figure shows the distribution of building use types. Offices were the largest category of buildings, followed by higher-education buildings, multi-family buildings, industrial buildings (this use category includes buildings with large process loads, such as data centers), public assembly buildings and K-12 facilities. Other uses are represented in smaller numbers. Note that EUI data for building types with only a single building are not shown.

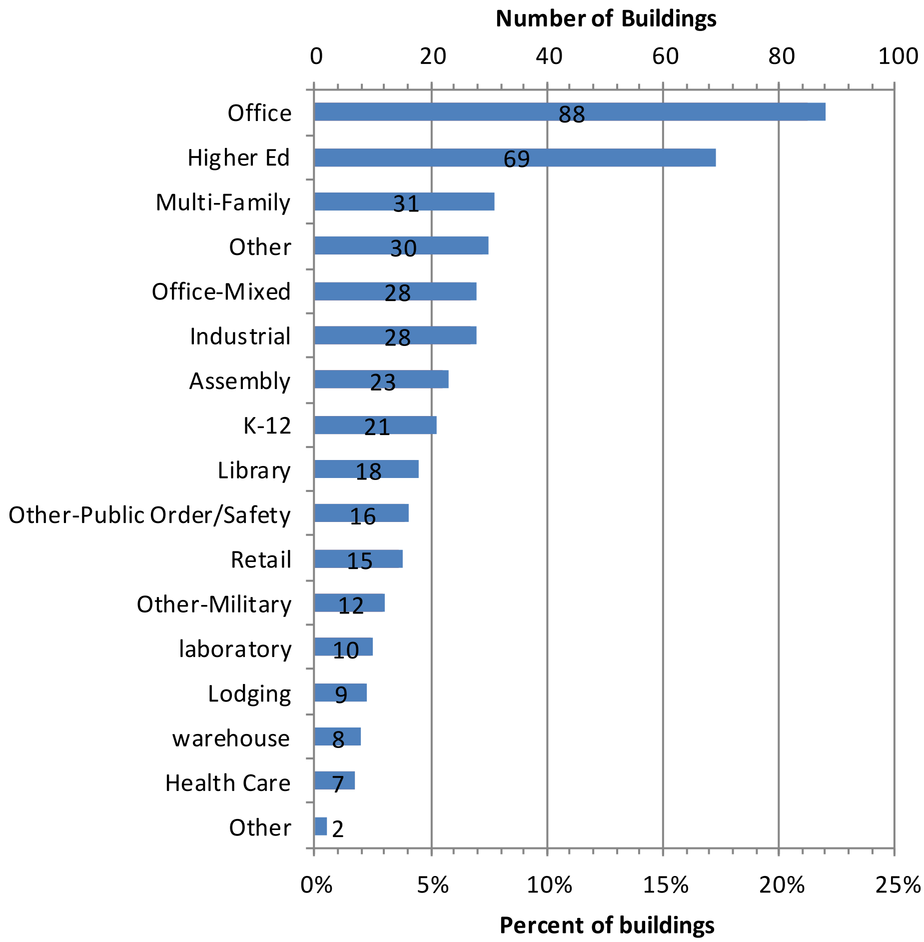

Figure 65: California LEED NC buildings by primary use type

The following figure plots building energy end use indices (EUIs) for each building use type. Individual EUIs are sorted from highest to lowest for each building use type (i.e., a histogram). While it is a little busy, this graph provides a quick summary of building energy performance by building type, shows how many buildings are in each category, and the range of distribution of EUIs. The yellow line represents 30 kBTU/SF, which is the highest EUI reported in the New Buildings Institute's Zero Energy Building list[1], and represents the approximate energy performance level for "ZNE Capable" buildings (although 25-30 kBTU/SF is a more likely target goal for ZNE Capable buildings. LEED NC buildings below the yellow line represent buildings that are currently performing at the ZNE building efficiency level. While there are not a lot of buildings with an EUI below 30 kBTU/SF, there are currently buildings being built to this level. As a reminder, the EUIs cited in this section are all modeled EUIs.

[1] New Buildings Institute. "Getting to Zero 2012 Status Update: A First Look at the Costs and Features of Zero Energy Commercial Buildings." March 2012. http://www.newbuildings.org/sites/default/files/GettingtoZeroReport_0.pdf

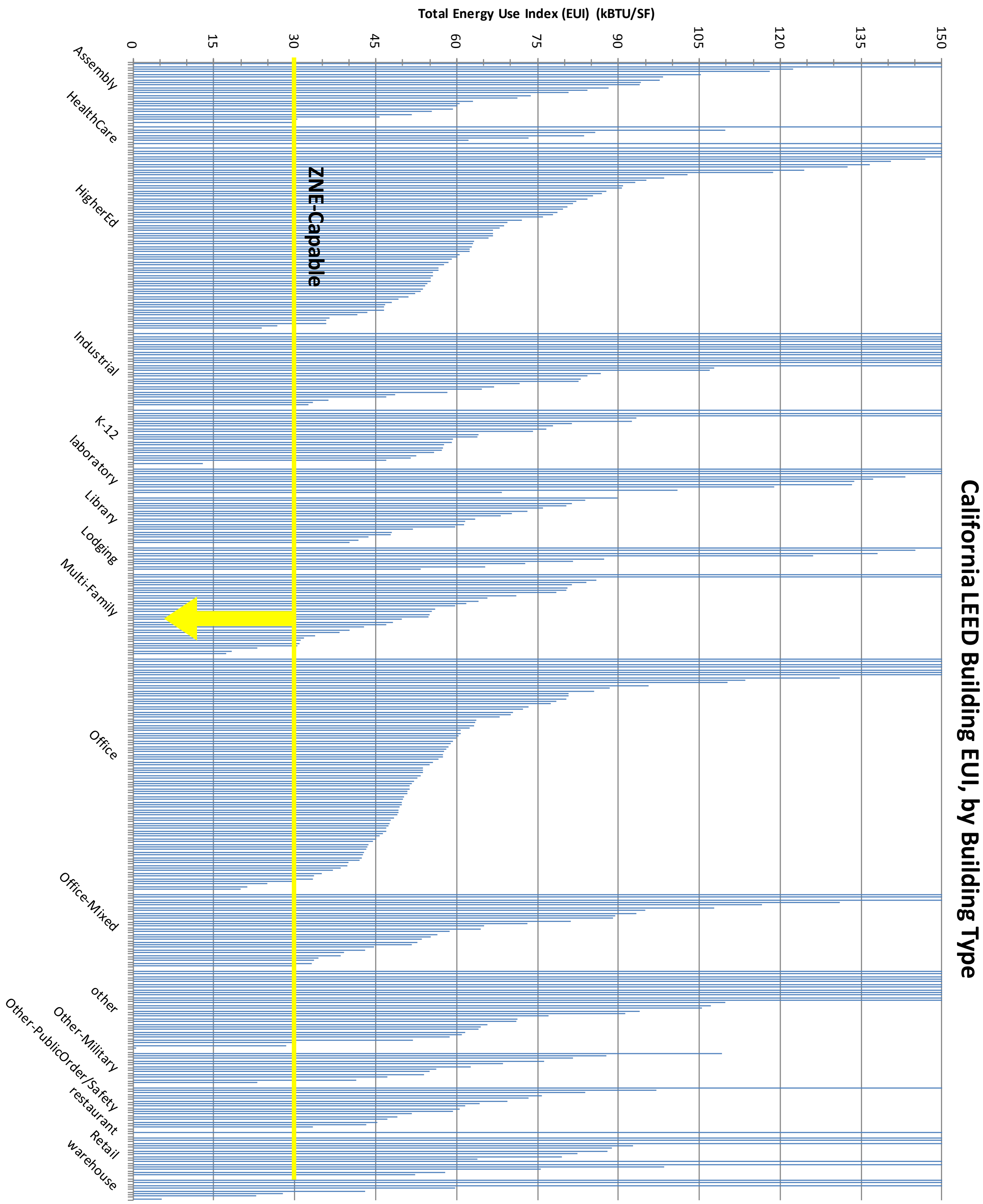

Figure 66: Histogram of LEED NC Building EUI distribution by building type

There are a total of 34 buildings with EUI's at or below 35 kBTU/SF/year that are performing at "ZNE Capable" levels. Refer to section 14.2.3 for further details.

The following table summarizes average EUI data by building type. EUI breakouts are shown for regulated (i.e., HVAC, lighting and DHW loads) and process/plug loads, and for electricity and natural gas.

Table 16: EUI summary data by building type

				EUI (kBTU/SF)													
				Proposed Building						Base-Case Buildng							
Building Type	Count	% Above ASHRAE	Avg EAc1 pts	Total	Regulated	Process/Plug		Electricity	Natural Gas	Total	Regulated	Process/Plug		Electricity	Natural Gas
Office	88	29%	6.2	85	43	42	51%	67	17	111	69	42	62%	87	23
Higher Ed	69	26%	5.4	78	54	24	69%	54	20	96	72	24	75%	68	24
Multi-Family	31	26%	5.4	65	45	20	69%	39	25	81	60	20	75%	50	29
Other	30	25%	5.3	620	324	296	52%	588	33	986	690	296	70%	937	49
Industrial	28	31%	6.8	1,717	155	1,561	9%	483	1,234	2,554	334	2,220	13%	686	2,380
Office-Mixed	28	24%	4.8	88	48	40	55%	59	27	106	65	40	62%	70	34
Assembly	23	25%	5.0	84	58	26	69%	60	23	112	86	26	77%	79	33
K-12	21	32%	7.0	96	77	20	80%	55	41	127	107	20	85%	75	52
Other-Public Order/Safety	16	25%	5.0	68	52	16	76%	40	15	90	74	16	82%	50	22
Other-Military	12	29%	6.4	64	40	23	63%	51	12	87	63	24	73%	68	19
laboratory	10	26%	5.3	170	102	68	60%	134	24	213	145	68	68%	168	29
Library	10	23%	5.0	59	43	16	73%	47	13	75	59	16	79%	61	15
Retail	9	28%	6.1	132	79	53	60%	100	32	168	115	53	68%	130	38
Lodging	9	22%	4.2	109	65	44	59%	46	59	129	84	45	65%	61	64
Library	8	26%	5.5	69	50	19	72%	52	16	98	77	21	78%	74	24
warehouse	8	32%	7.3	398	110	288	28%	391	7	571	223	348	39%	557	14
Health Care	6	21%	4.0	124	88	36	71%	92	32	165	129	36	78%	111	54
Retail	6	29%	6.2	130	53	77	41%	77	53	160	82	78	51%	99	73

By Climate Zone

The following table summarizes the California LEED buildings by California climate zone.

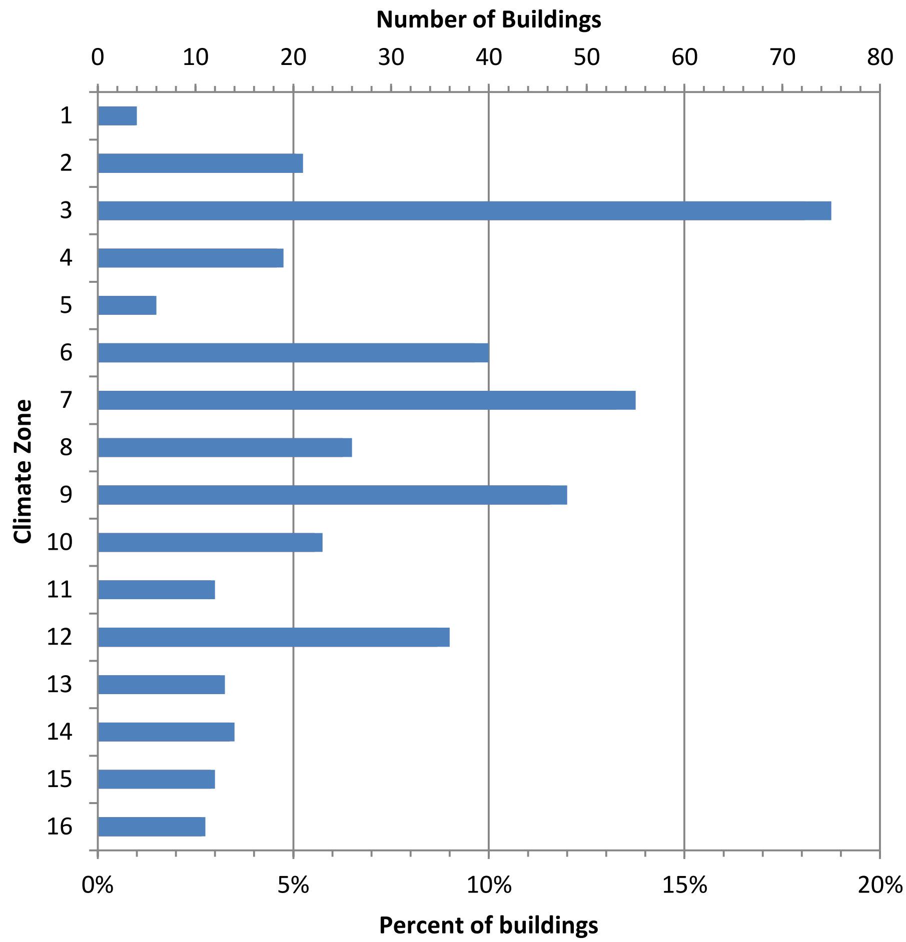

Figure 67: California LEED NC buildings by climate zone

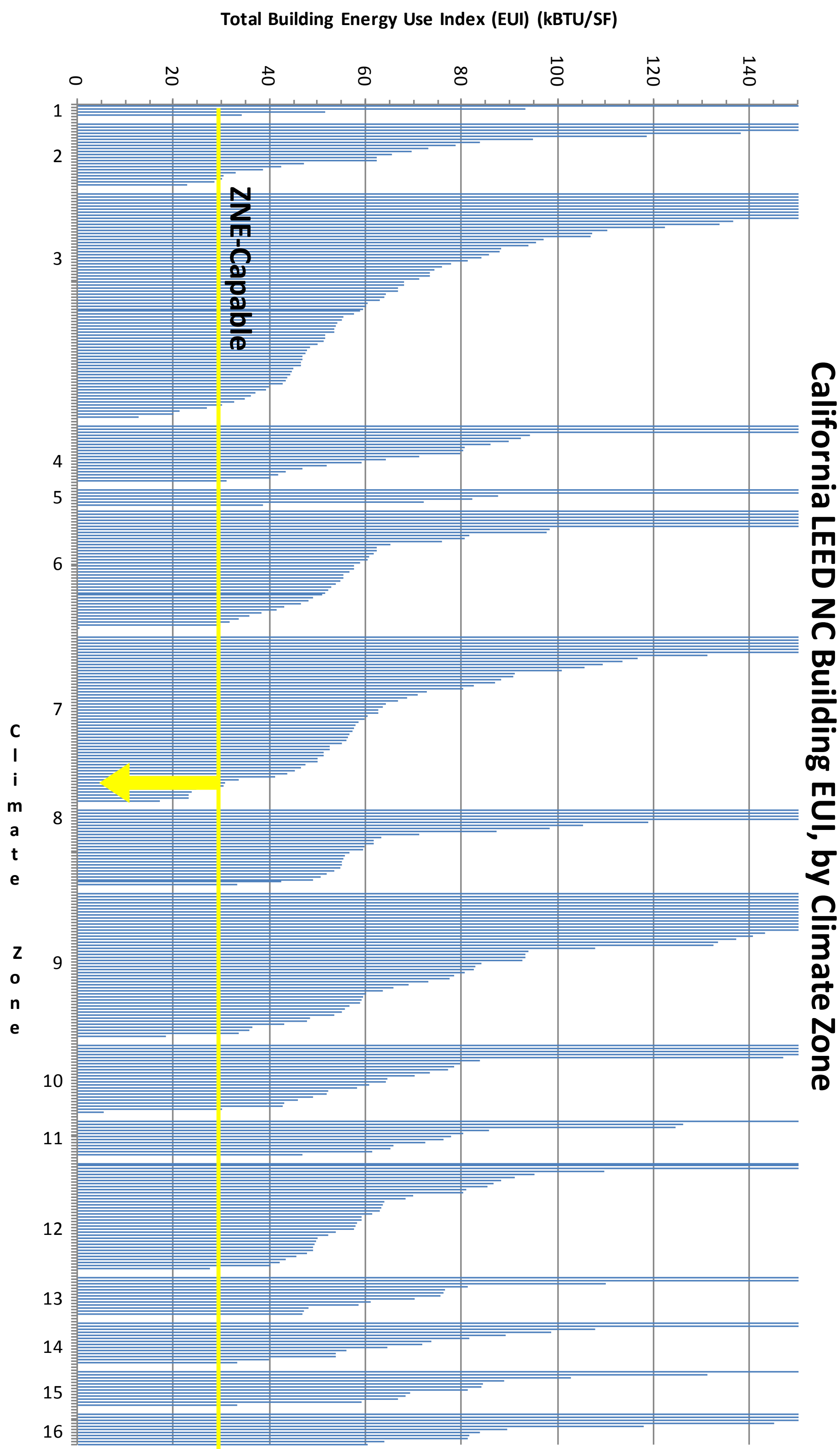

Figure 68: Histogram of LEED NC Building EUI distribution by climate zone

By Building Type and Climate Zone

Histograms for building EUI, grouped by climate zone are provided for the three most common building types (office, higher education, and multi-family).

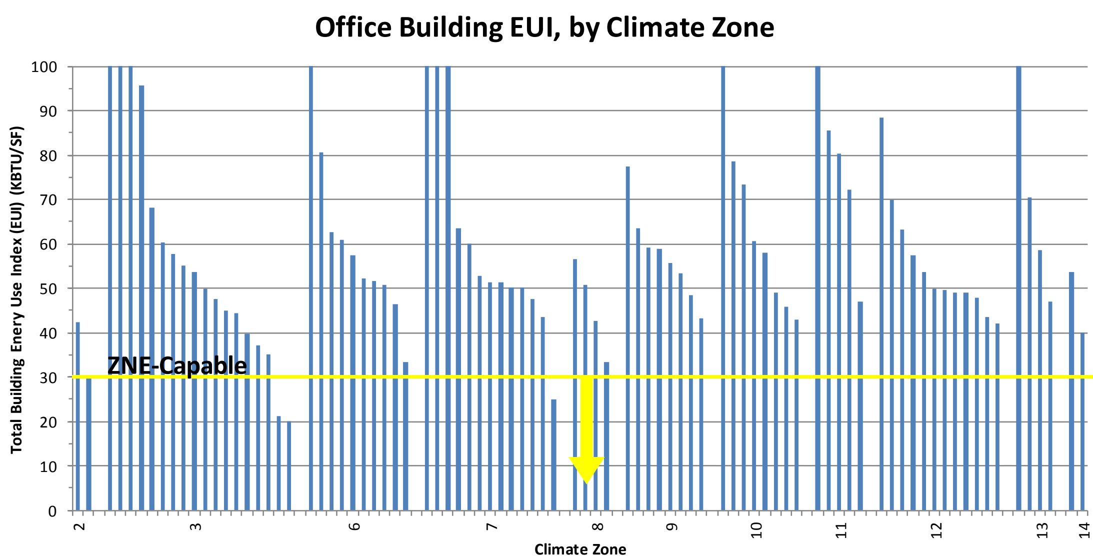

Figure 69: Histogram of LEED NC Office Building EUI by Climate Zone

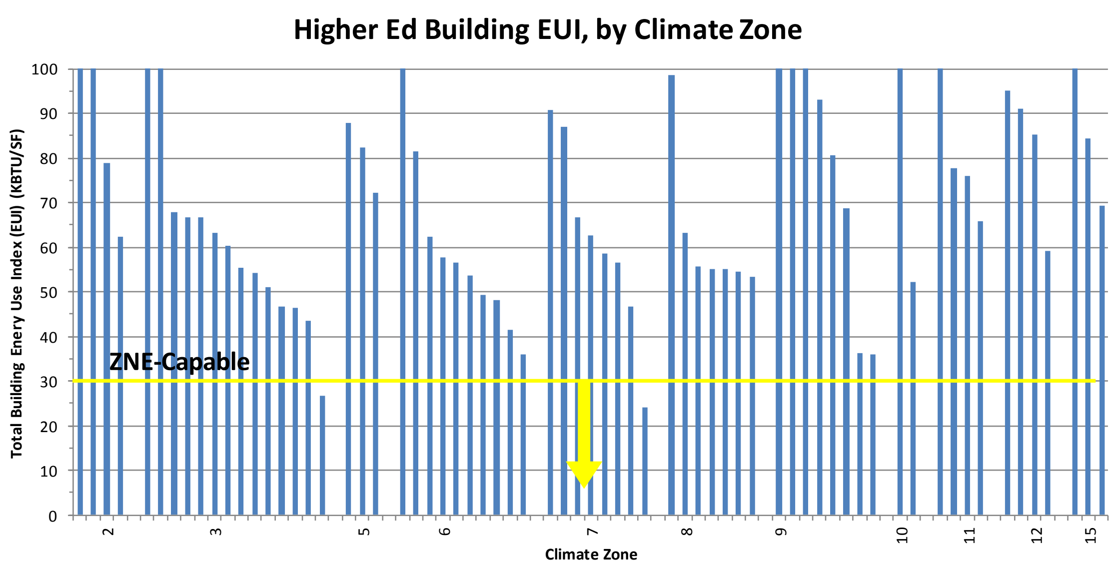

Figure 70: Histogram of LEED NC Higher Ed Building EUI by Climate Zone

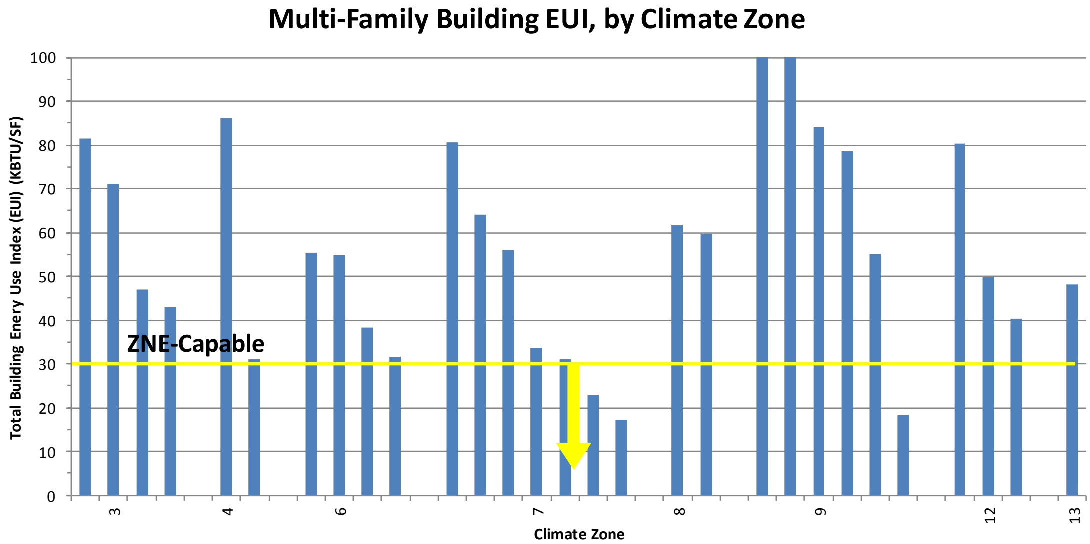

Figure 71: Histogram of LEED NC Higher Ed Multi-Family Building EUI by Climate Zone

Energy End–Use Analysis

The following section presents various energy end use statistics of California LEED NC projects. Note that the industrial, restaurant, warehouse and other building use types are excluded from the following graphs for clarity, since their EUIs are very high. This is primarily due to either large process loads, or large amounts of unconditioned space (EUIs are calculated from conditioned space).

The following two graphs explore the split between fuel types, with the first graph showing EUIs by fuel type. The second graph shows the percent of total energy met by electricity. Electricity consumption ranges from a low of 43% of the total energy consumption for lodging, to 81% for military.

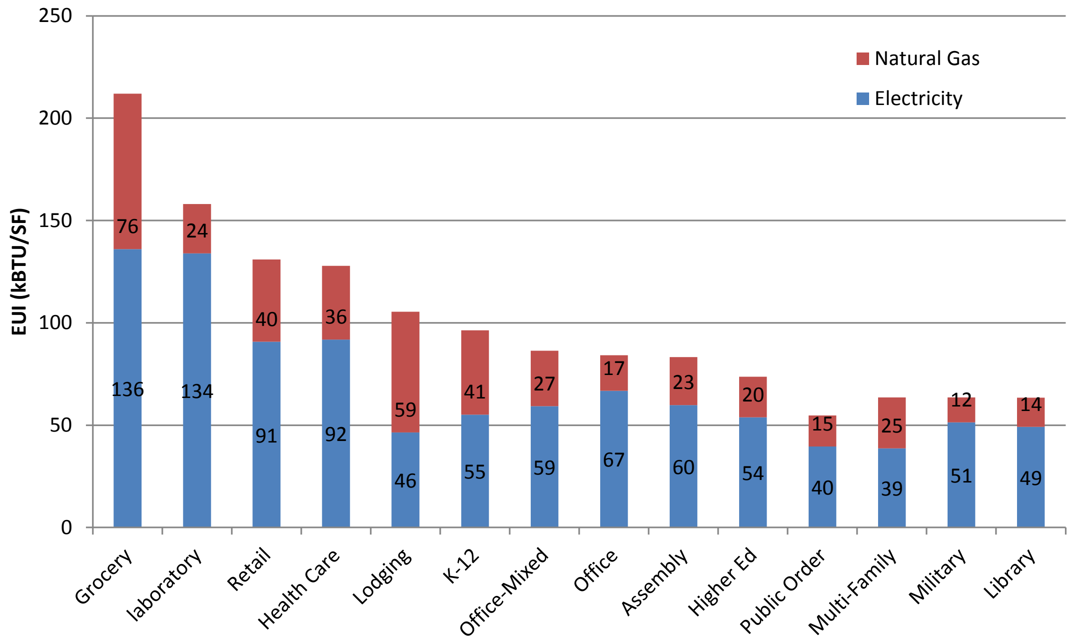

Figure 72: EUI by fuel type for LEED buildings

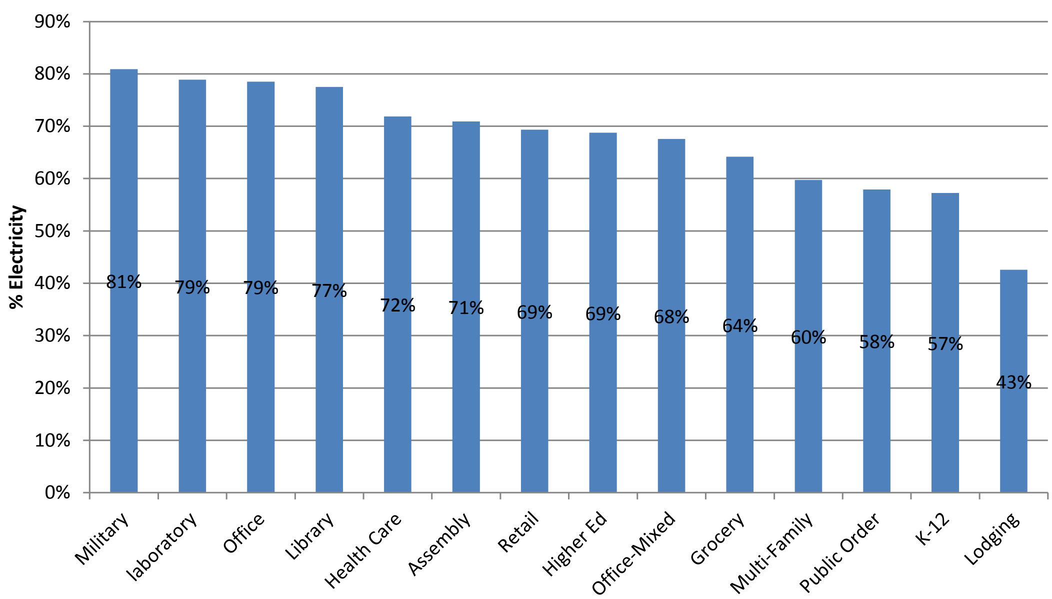

Figure 73: Electricity as a percent of total energy use

The next two graphs explore the ratio of regulated loads (e.g., HVAC, lighting and DHW) versus unregulated loads (e.g., plug loads, task lights and process loads). The first graph presents the data by EUI, sorted from largest regulated load to smallest. The second graph presents the data by percent, sorted by percent of the total load made up of unregulated power. Note that the two sort orders are different. One key implication for ZNE buildings is the wide variation in the percent of unregulated versus regulated loads. The magnitude of process and plug loads ranges from 16 kBTU/SF (public order/safety buildings) to 73 kBTU/SF for grocery stores. They represent from 20% of the total energy use in K-12 schools, to just under 50% in offices and retail buildings. Building codes generally have limited ability to address the unregulated loads. Furthermore, building control systems generally have limited control over these loads; occupants are the primary controllers of these loads. This points to the need for ZNE buildings to focus on reducing the unregulated loads, and developing effective occupant engagement strategies for effective control of unregulated loads. The percent of unregulated loads is very high for offices. This may be partially due to the way process and plug loads are modeled using the LEED for energy and atmosphere credit 1 (EAc1) methodology, and is an area that will merit further research and comparison to actual performance data.

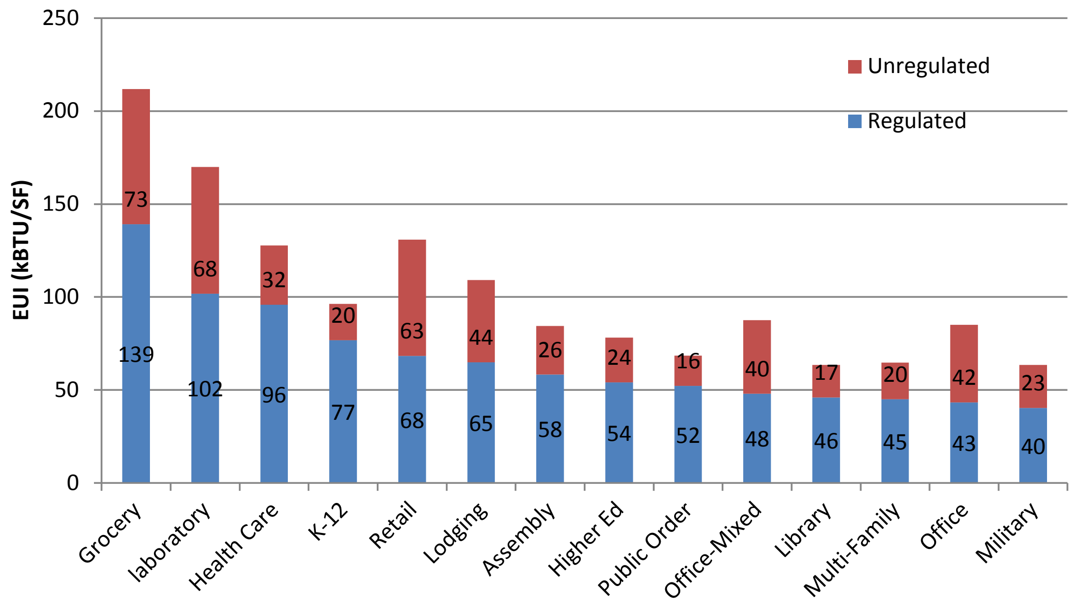

Figure 74: EUI distribution of regulated vs. plug/process loads for LEED buildings

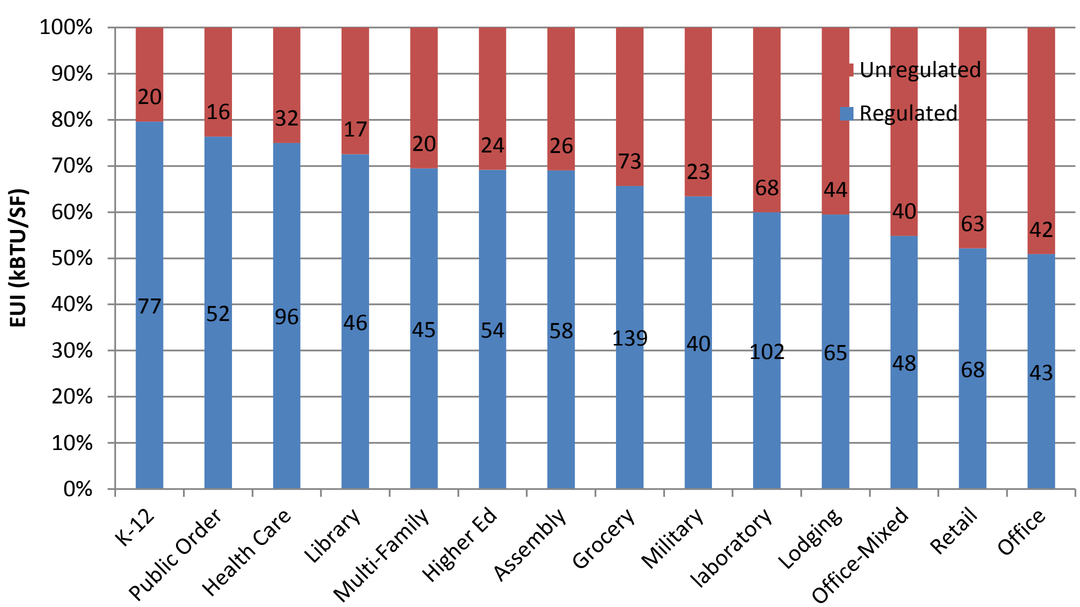

Figure 75: EUI percent distribution of regulated vs. plug/process loads for ZNE Capable LEED buildings

EUI Savings

The following figure shows the modeled EUI savings for LEED buildings compared to the base case, minimally code/standard compliant building. EUI savings are shown on the left axis, and percent savings shown on the right axis. Savings are typically in the 22% ± 5% range.

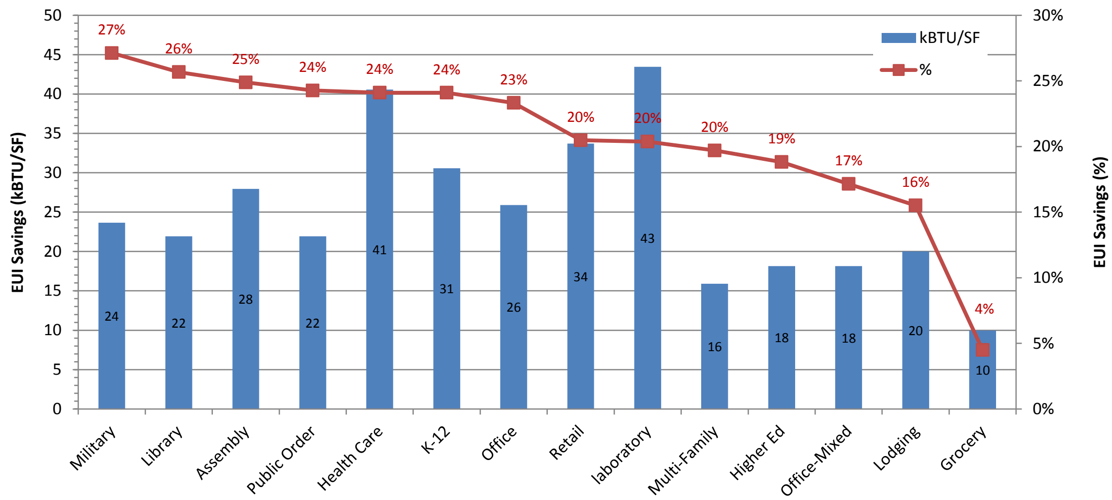

Figure 76: EUI savings from LEED NC projects

The following figure breaks down savings potential by major end use category. While there is some variability, HVAC, followed by lighting, and then DHW hold the largest savings mechanisms. Note that minimal process/plug load energy savings are reported. This is primarily due to the LEED energy modeling methodology which focuses on regulated building loads and holds most process/plug loads constant between the base-case and design-case building energy models.

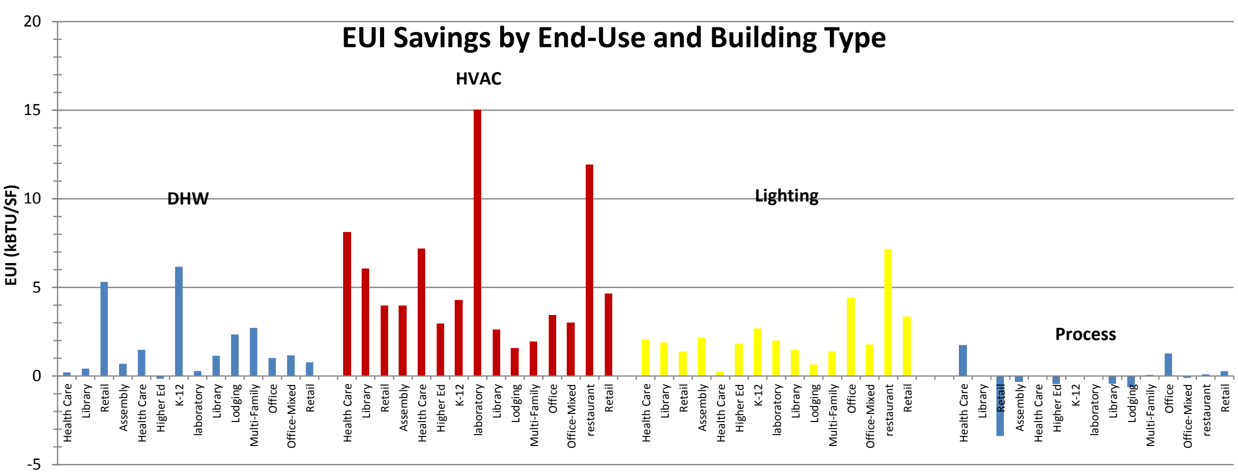

Figure 77: End use EUI savings by building type

15.2.3 "ZNE Capable" Building Performance Characteristics

The New Buildings Institute's "Getting to Zero" report [1] defines a "ZNE Capable" building as a building operating at or below 30 kBTU/SF/year. This is the highest EUI reported in their Zero Energy Building list. There are 34 California LEED NC buildings that have modeled EUIs performing at the "ZNE Capable" level. These ZNE Capable building characteristics are summarized below.

By Certification Level

The following figure shows the distribution of ZNE Capable buildings by certification level. The distribution is surprisingly similar to that of all LEED buildings (refer to Figure 68), with the exception that there are fewer certified projects (which in turn increases the other categories by approximately equal amounts). Achieving ZNE Capable performance levels does not necessarily require LEED platinum or gold ratings.

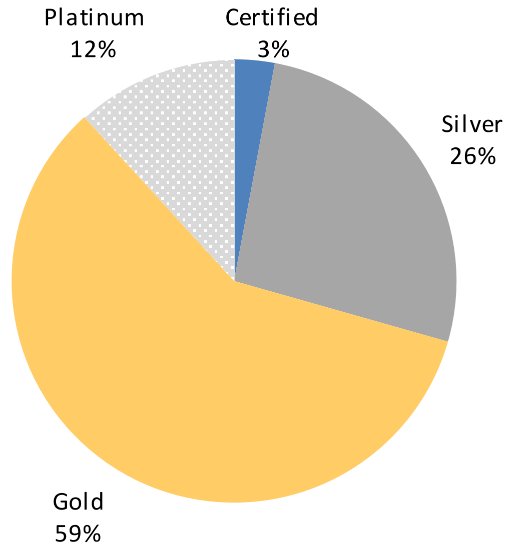

Figure 78: ZNE Capable LEED buildings by certification level

By Primary Building Type

The following figure shows a histogram, broken down by building type, of EUIs for ZNE Capable LEED NC buildings. This is analogous to Figure 70, but filtered for EUIs ≤ 30 kBTU/SF/year.

[1] New Buildings Institute. "Getting to Zero 2012 Status Update: A First Look at the Costs and Features of Zero Energy Commercial Buildings." March 2012. http://www.newbuildings.org/sites/default/files/GettingtoZeroReport_0.pdf

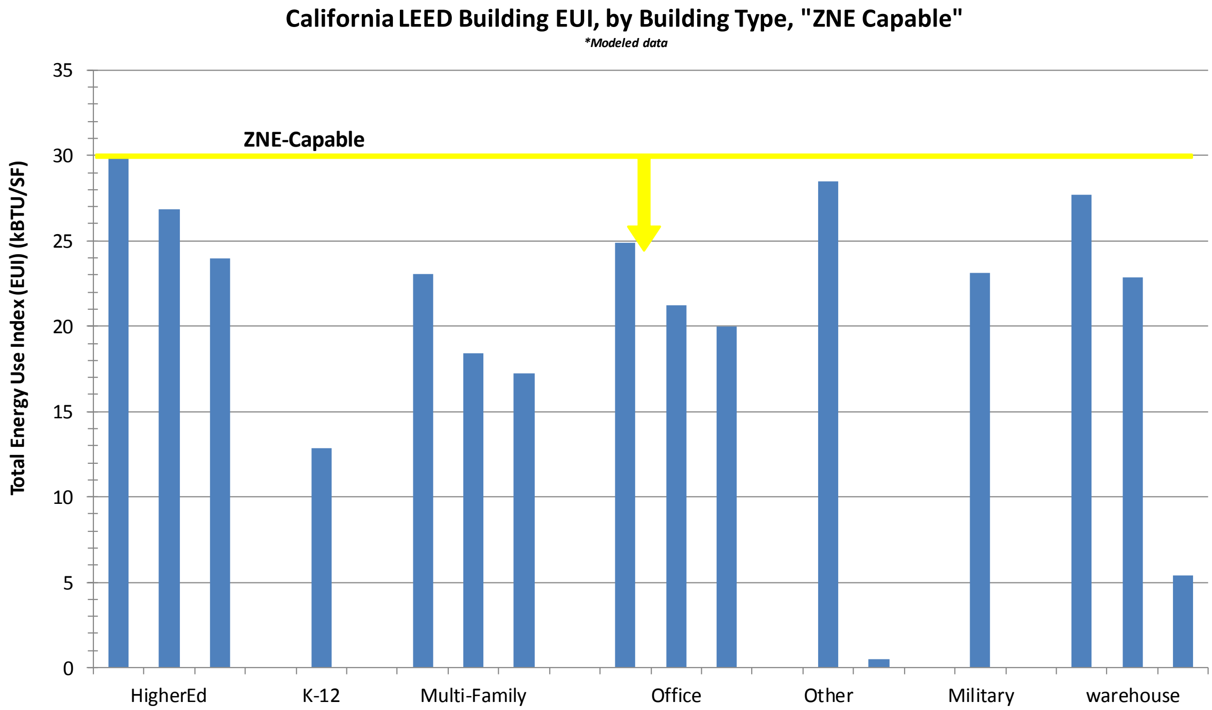

Figure 79: EUI Histogram of "ZNE Capable" California LEED Buildings

By Climate Zone

The following graph plots average EUI for ZNE Capable buildings by climate zone.

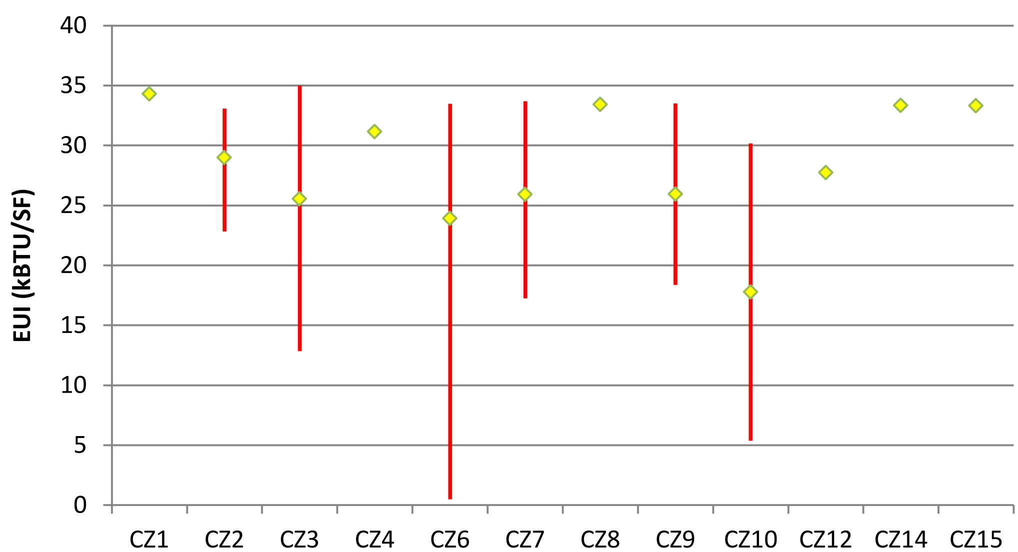

Figure 80: Average EUI for ZNE Capable LEED buildings by climate zone

(min, max & average values shown)

End Use Analysis

The following table presents details on ZNE Capable buildings by building use type, including a breakout of EUI by end use and fuel mix.

Table 17: Comparative statistics for ZNE Capable LEED buildings

							EUI (kBTU/SF)					
Building Type	Count	% Above ASHRAE 90,1	EAc1 Points	Conditioned Area (ft^2)	Un-Conditioned Area (ft^2)	Total Area (ft^2)	Total	Elec-tricity	Natural Gas	Regulated	Process/Plug	
Public Order/Safety	1	35%	8.0	78,133	3,656	81,789	33.3	33.3	-	33.3	-	0%
Industrial	2	32%	7.0	15,248	141	15,389	32.9	27.5	5.4	18.4	14.5	44%
Office-Mixed	4	30%	6.5	86,547	4,673	91,220	32.8	21.9	10.8	23.5	9.3	28%
Assembly	2	33%	7.5	31,095	2,543	33,638	30.2	27.5	2.7	19.1	11.1	37%
Office	7	40%	9.4	69,075	2,841	71,916	28.3	24.1	4.2	19.3	9.0	32%
Multi-Family	8	28%	6.0	221,012	104,786	325,798	27.1	20.6	6.5	18.8	8.3	31%
Higher Ed	2	28%	6.0	155,055	5,821	160,876	25.4	23.6	1.8	13.8	11.5	45%
Other-Military	1	28%	6.0	39,827	-	39,827	23.1	20.9	2.2	15.0	8.1	35%
Other	3	28%	6.0	22,395	1,647	24,043	19.7	14.4	5.3	15.7	4.0	20%
warehouse	3	33%	7.3	538,709	-	538,709	18.6	16.7	2.0	13.5	5.1	27%
K-12	1	32%	7.0	1,218,212	-	1,218,212	12.8	12.4	0.5	10.6	2.3	18%

The following figure shows the EUI breakout by fuel use by building type. Electricity is the predominant energy source.

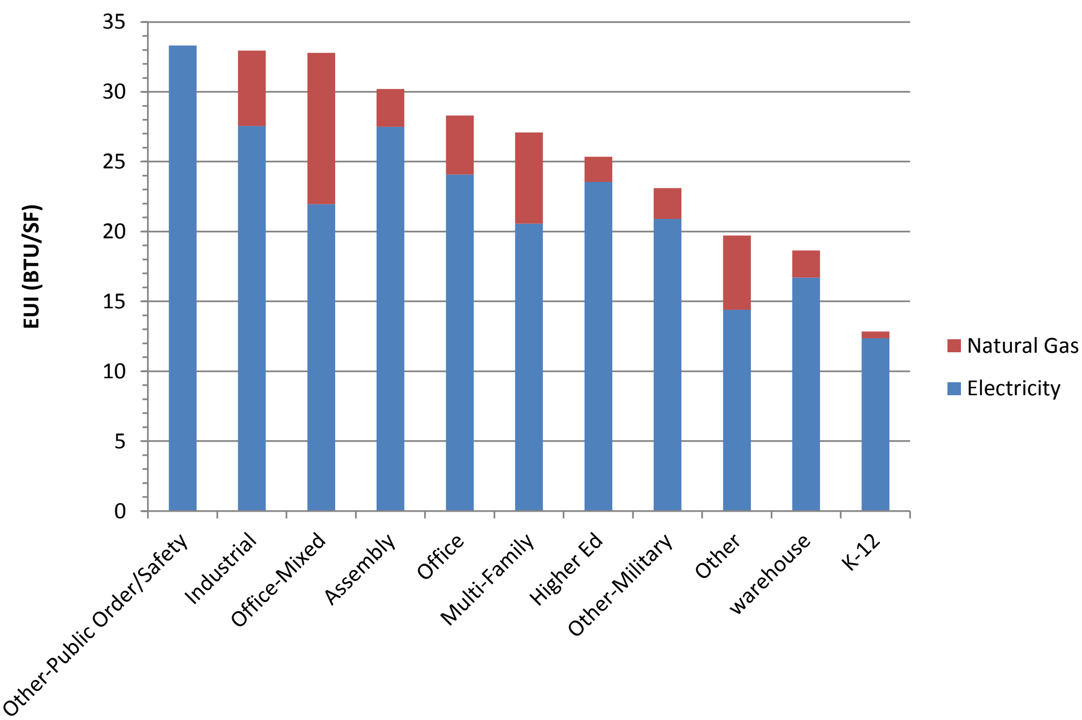

Figure 81: EUI breakout by fuel type for ZNE Capable LEED buildings

The following figure shows the breakout between regulated loads (i.e., HVAC, lighting, DHW) and unregulated (i.e., process and plug) loads. The data is sorted in by the magnitude of the regulated load. One of the insights from this graph is that the some of the key building types of interest (office, assembly, and multifamily), along with industrial buildings all have very similar EUI's for regulated loads, ranging between 18 and 20 kBTU/SF.

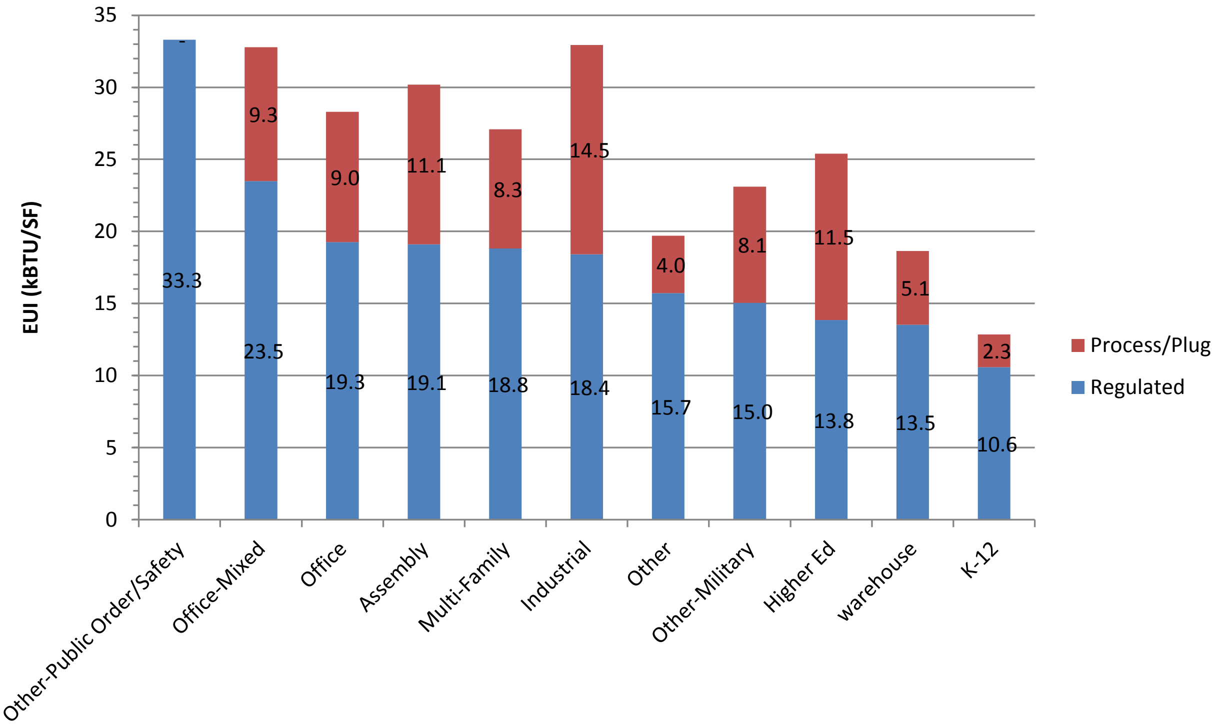

Figure 82: EUI distribution of regulated vs. plug/process loads for ZNE Capable LEED buildings

The following figure also shows the breakout between regulated and plug/process loads, but with the data presented in percent regulated vs. unregulated. There is an interesting difference in the percent of regulated vs. unregulated loads. One of the interesting implications of this is that the relative importance of managing the unregulated loads (e.g., through occupant engagement) varies with building use type.

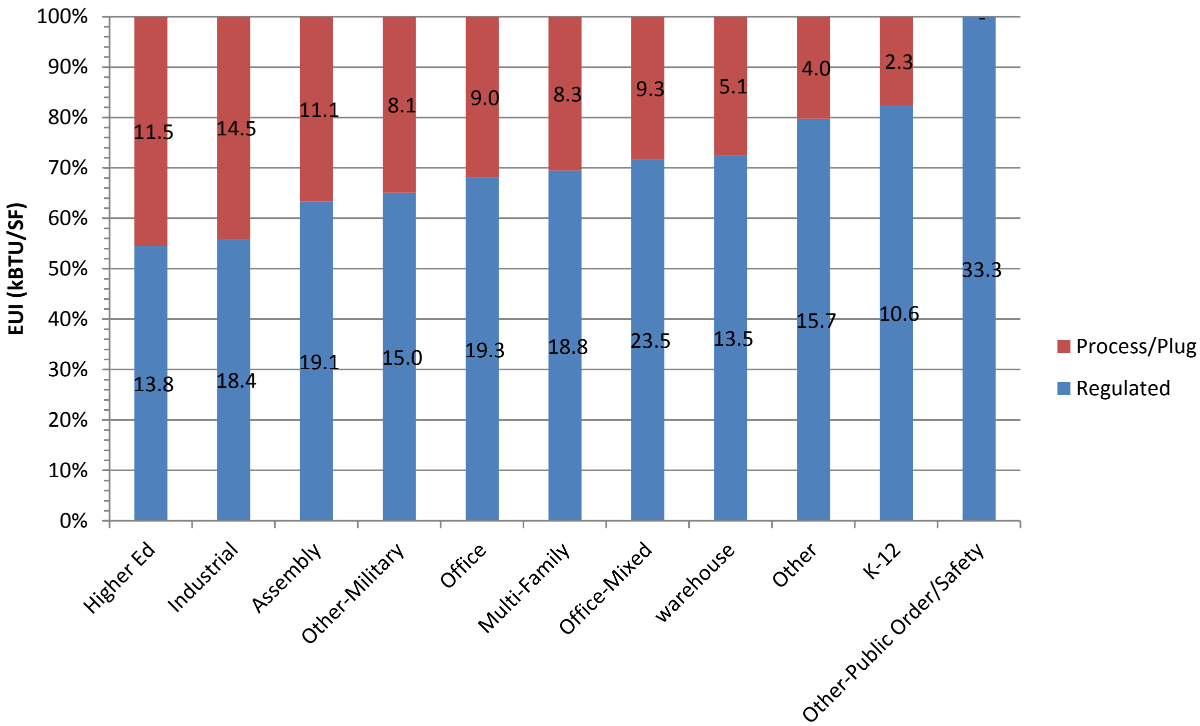

Figure 83: EUI distribution (%) of regulated vs. plug/process loads for ZNE Capable LEED buildings

EUI Savings

The following figure illustrates the EUI savings for the ZNE Capable LEED buildings compared to the base case (i.e., minimally code/standard compliant building). The left axis shows the savings in kBTU/SF, and the right axis shows the percent savings.

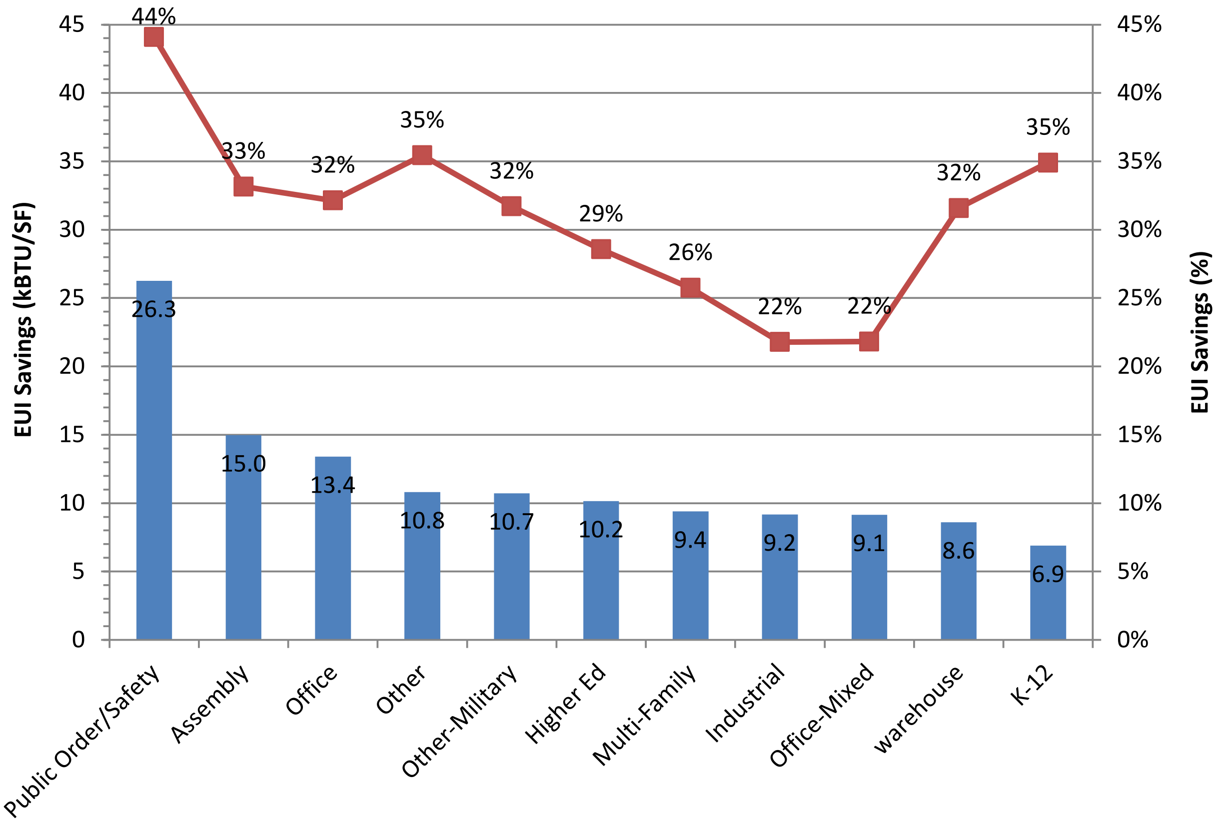

Figure 84: EUI Savings for ZNE Capable LEED buildings compared to 'base case" design

16. APPENDIX H: RESIDENTIAL EUI AND RASS ANALYSIS

This section provides additional supporting data for information presented in Section 6.6.3 Residential Energy Use Variability

To date, there are no clear EUI targets for residential ZNE buildings. There is significant variability in residential energy use and targets will vary by climate zone and buildings size. Based on our review, it is clear that further research is needed to define residential EUI targets.

16.1 Whole Building Energy Use

To explore the variability in residential energy use, we reviewed existing literature and analyzed data from the 2009 RASS. RASS provides a rich source of data to quantify energy end uses. Through the publicly available data, one can breakdown the average energy end uses by building type, service territory, and other building characteristics. While understanding average unit energy consumption (UEC) is a good starting point, the summary tables are limited in their ability to provide greater granularity compared to the raw data collected for the study. To inform ZNE goals, rather than just looking at average assumptions, we wanted to understand how these loads vary.

We analyzed data from over 20,000 anonymized samples from RASS to evaluate the variability in energy usage in the current building stock. Data from our market interviews and literature review suggests that most early adopters are targeting energy efficiency to the order of 50-66% beyond current code. The RASS analysis allowed us to compare these targets against the current building stock.

As seen in Figure 90, previous studies have estimated the statewide kWh and kW PV targets at varying levels of energy reduction compared to energy use of 'current new buildings' as defined in RASS (building constructed 2001-2008) (McHugh 2011).

Current new buildings	PV kWh	PV kW	PV Cost $/house	First Cost $ Million/yr
Site energy ZNE	17,501	11.7	$52,502	$5,250
Source energy ZNE	10,264	6.8	$30,791	$3,079
Societal Energy ZNE	8,056	5.4	$24,168	$2,417
(Elec) Grid neutral	6,645	4.4	$19,935	$1,994

48% reduction T-24 (4 cycles 15% reduction)	PV kWh	PV kW	PV Cost $/house	First Cost $ Million/yr
Site energy ZNE	11,581	7.7	$34,744	$3,474
Source energy ZNE	7,324	4.9	$21,972	$2,197
Societal Energy ZNE	5,835	3.9	$17,505	$1,750
(Elec) Grid neutral	5,195	3.5	$15,586	$1,559

66% reduction all end-uses	PV kWh	PV kW	PV Cost $/house	First Cost $ Million/yr
Site energy ZNE	5,834	3.9	$17,501	$1,750
Source energy ZNE	3,421	2.3	$10,264	$1,026
Societal Energy ZNE	2,685	1.8	$8,056	$806
(Elec) Grid neutral	2,215	1.5	$6,645	$665
Elec vehicle extra	3750	2.5	$11,250	$1,125

Figure 85: PV cost implications of different ZNE definitions with low PV price estimate ($4.50/W) (McHugh 2011).

Next we compared the 66% better than 'current' predictions for ZNE against the spread of energy use in existing building stock data from RASS. Figure 86 shows the overall distribution of whole building electric energy use for existing households, as well as the estimated household UEC in PG&E and SDG&E territories.

Next we compared the 66% better than 'current' predictions for ZNE against the spread of energy use in existing building stock data from RASS. Figure 26 shows the overall distribution of whole building electric energy use for existing households, as well as the estimated household UEC in PG&E and SDG&E territories[1].

Point estimates such as the 66% average reduction are useful to roughly understand how much of the building stock is currently reaching those targets. However, they do not differentiate by building type and climate zone, where there can be significant diversity. Further research is needed to identify climate zone specific targets.

Currently, RASS data is used to develop the HERS rating index which is an asset rating. Using the statewide or climate zone averages from RASS is appropriate in developing asset ratings. However, ZNE is a performance metric and the variability in energy use due to home size and other factors should be taken into account when developing EUI targets.

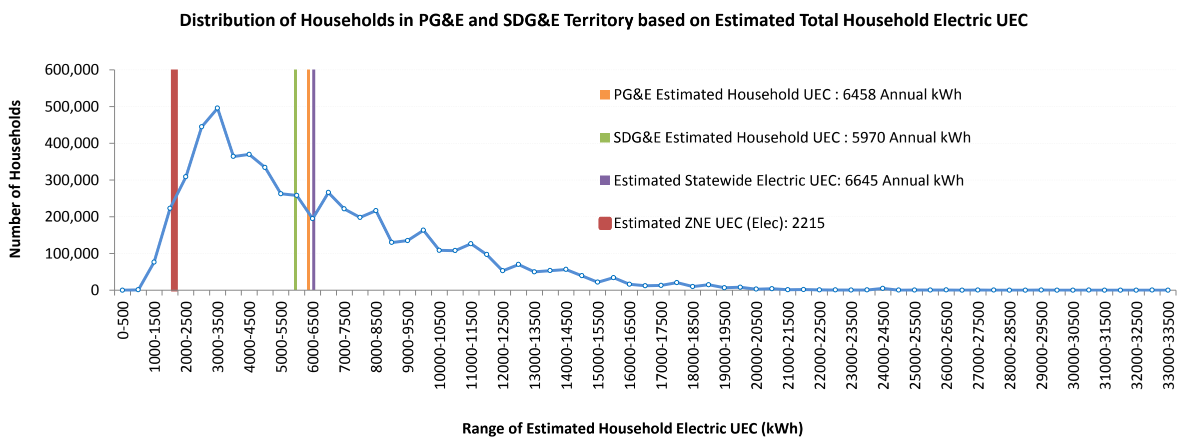

Figure 86: Distribution of Households in PG&E and SDG&E Territory based on Estimated Total Household Electric UEC

Figure 91 shows the electric UEC values for the range of homes in the RASS database served by PG&E and SDG&E. There is wide variation in UEC values but a sizable number of buildings use more energy than the average UEC for each utility or the statewide average UEC – while many use significantly less. Comparing UECs from RASS to the proposed UEC in Figure 85 for the 66% savings case points to the fact that a significant percentage of buildings have UECs well in excess of the target.

[1] Our study received anonmyzed data on residential building energy consumption data from PG&E and Sempra (SDG&E and SCG). This dataset scrubbed any building identifiable data such that we can run statistical analysis on the dataset.

In addition to understanding the overall range in UEC, we also analyzed how these varied by climate zone, building size, and construction year. Understanding the variability in EUI due to these factors will be important in defining appropriate EUI targets. The next sections summarize our findings.

16.2 UECs by Climate Zone

We looked at the breakdown of various end uses separated by climate zone to understand which ones would have climatic variability. Figure 92 and Figure 93 show estimated household electric and gas UEC by climate zone. While there is some variability in the total electric UEC, it should be noted that this includes electric uses that are not regulated by Title 24, such as the plug loads seen in Figure 94. In contrast, if you consider only the central AC UEC by climate zone, as seen in Figure 95, it is clear that significantly more electricity is used in warmer climates for this regulated end use. More on the breakdown of Title 24 regulated loads is included below in Section 15.5.

The variability in UEC by climate zone suggests that end use targets should be climate specific. However, these will vary significantly depending on which ZNE definition is chosen.

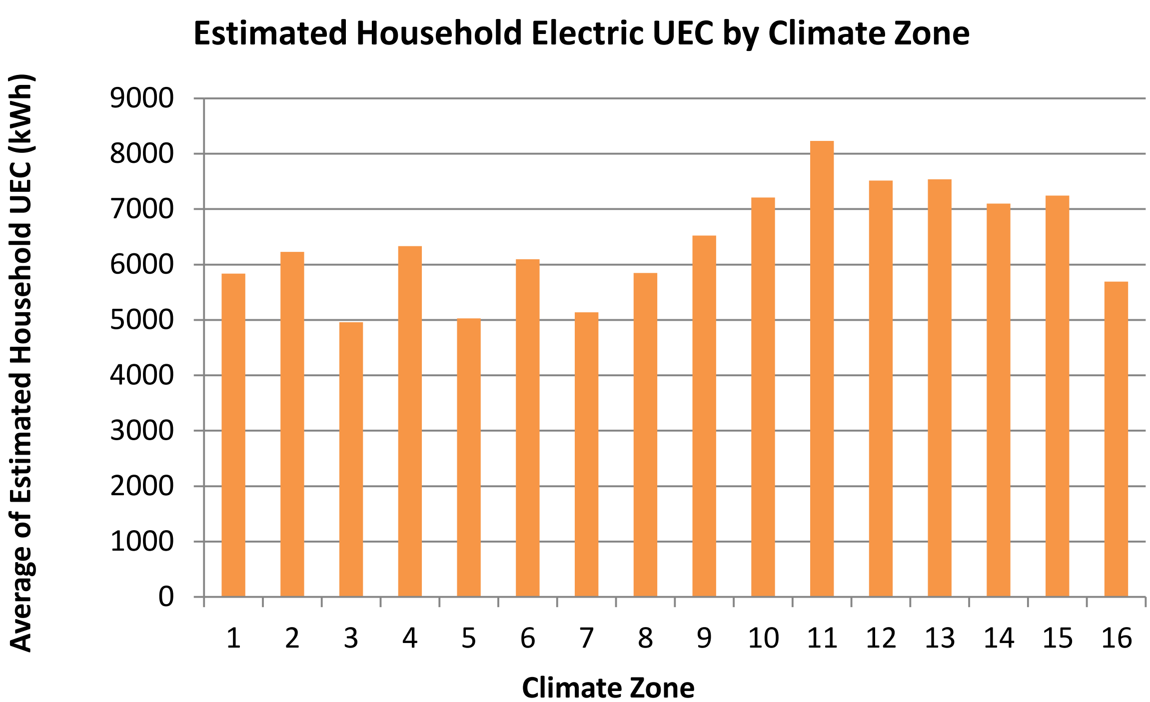

Figure 87: Estimated Household Electric UEC by Climate Zone

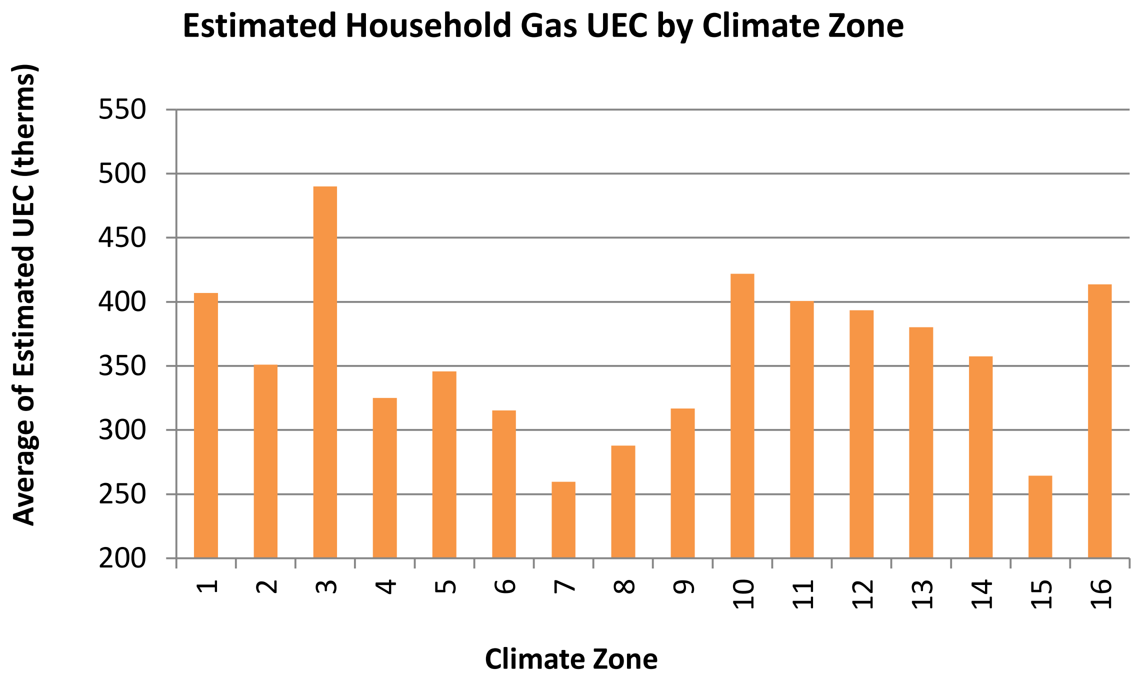

Figure 88: Estimated Household Gas UEC by Climate Zone

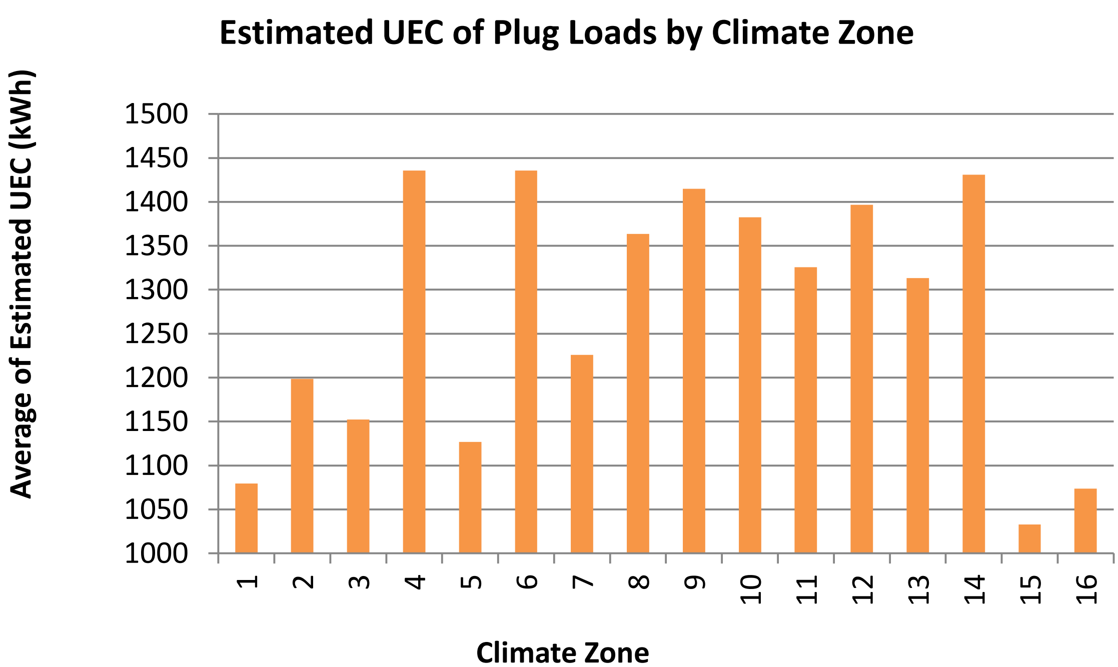

Figure 89: Estimated EUC of Plug Loads by Climate Zone

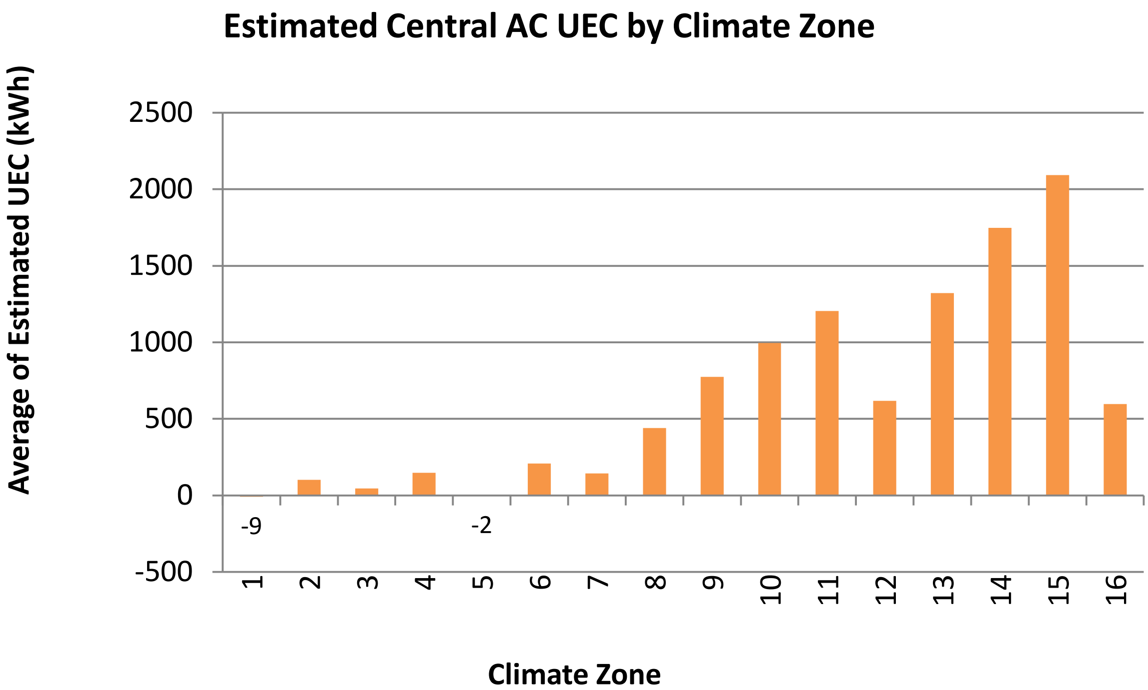

Figure 90: Estimated Central AC UEC by Climate Zone

16.3 UECs by Building Size

RASS developed UEC estimates for various building end uses and fuels. Through our analysis, we found that for all UEC estimates these four base variables were used to calculate the estimated UECs:

- Square footage of the livable spaces in the dwelling
- Age of dwelling
- # of residents
- Household Income

Since the estimated UECs in RASS use building area and number of people as variables, it's not surprising that they are strongly correlated. For example, Figure 96, Figure 97 and Figure 98 show the household electric UEC, household gas UEC, and plug load UEC as a function of the square footage of the living space and the shape of all three curves is very similar.

While we suspect that building size should be included in developing EUI targets, but more research is needed to accurately explore this.

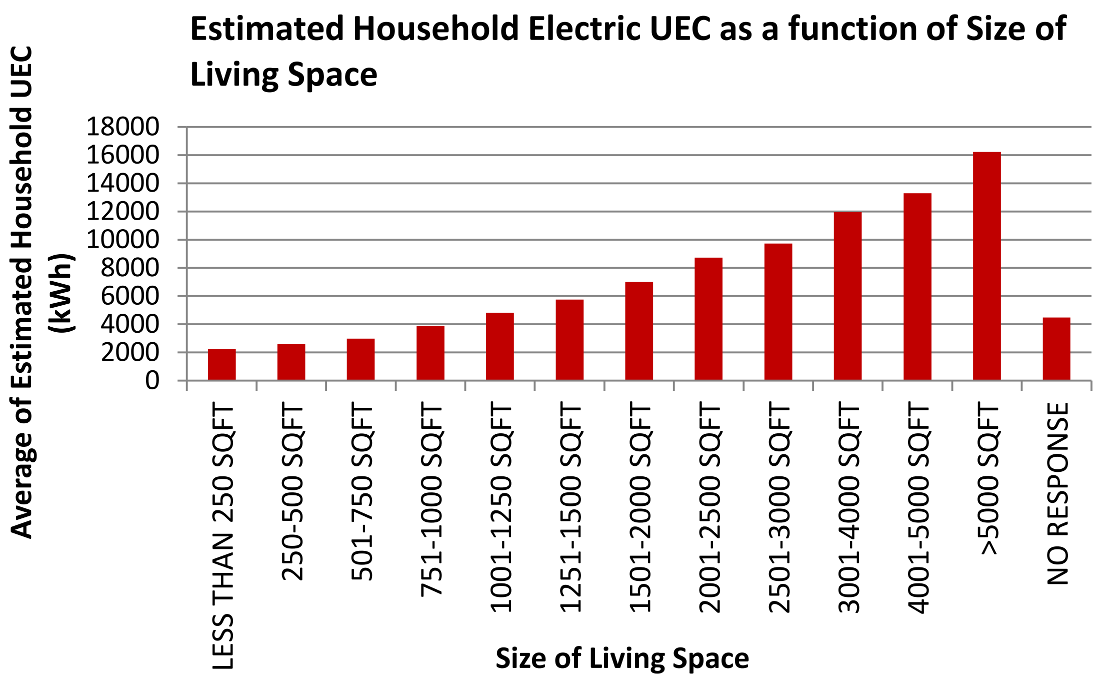

Figure 91: Estimated Household Electric UEC as a function of Size of Living Space

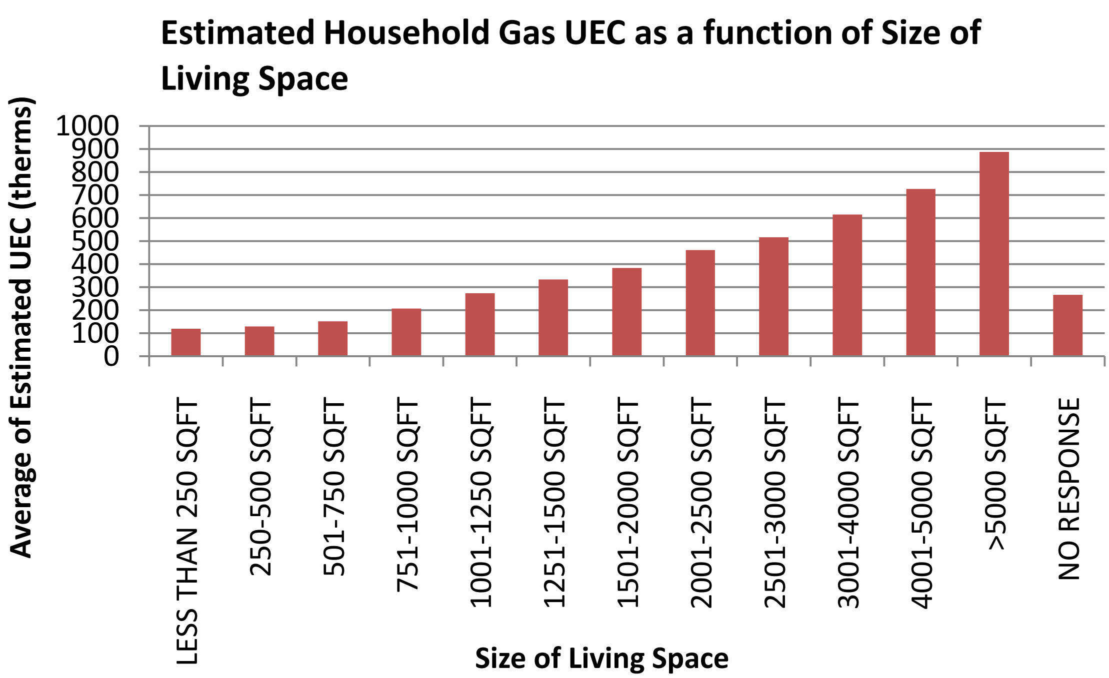

Figure 92: Estimated Household Gas UEC as a function of Size of Living Space

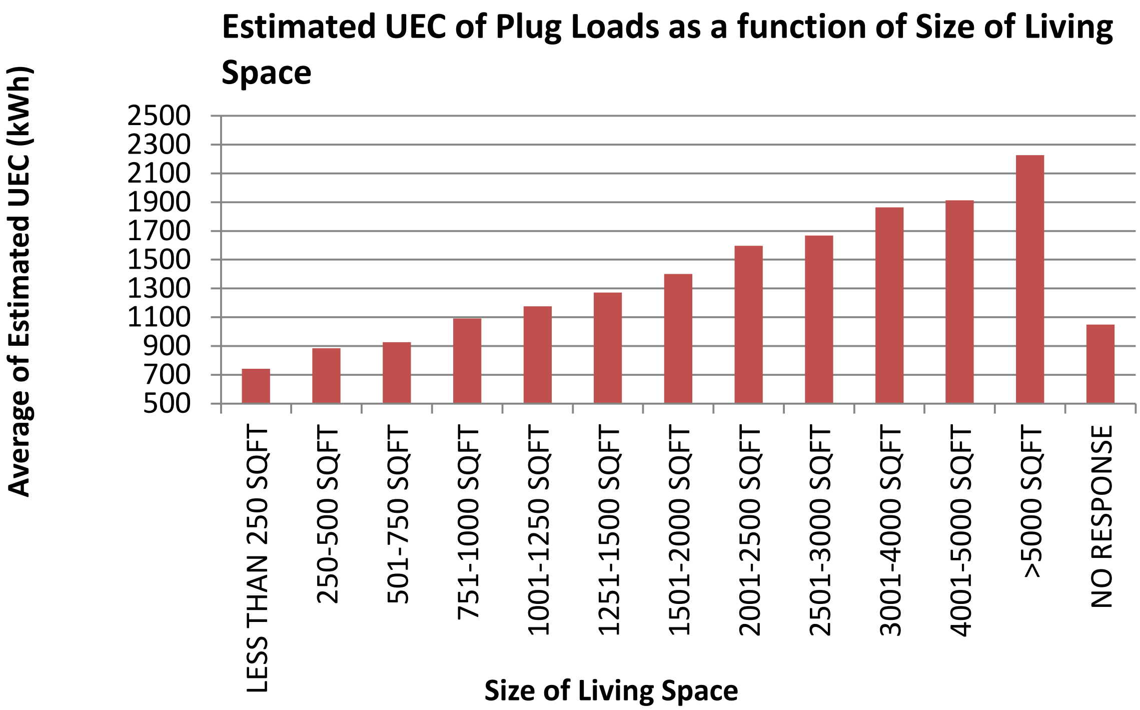

Figure 93: Estimated UEC of Plug Loads as a function of Size of Living Space

16.4 UECs by Construction Year

While energy use does vary by vintage it does not change significantly over the last twenty years on a whole building basis, but the plug load energy use reported in RASS does increase dramatically over the same period. However, as stated above, the age of the dwelling was used as an input to the estimated UECs, so further research should be conducted to accurately measure this variability.

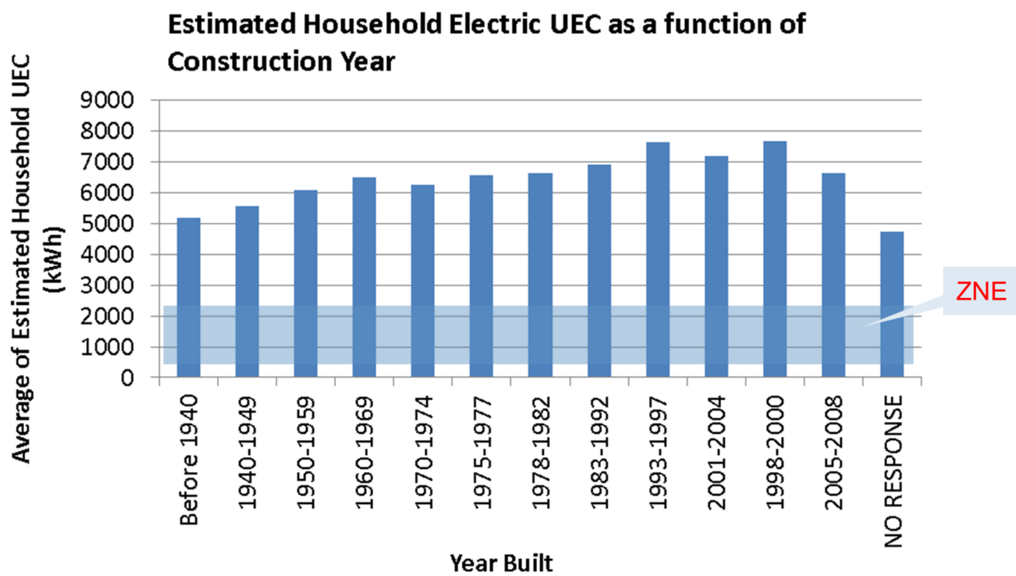

Figure 94: Estimated Household Electric UEC as a function of Construction Year

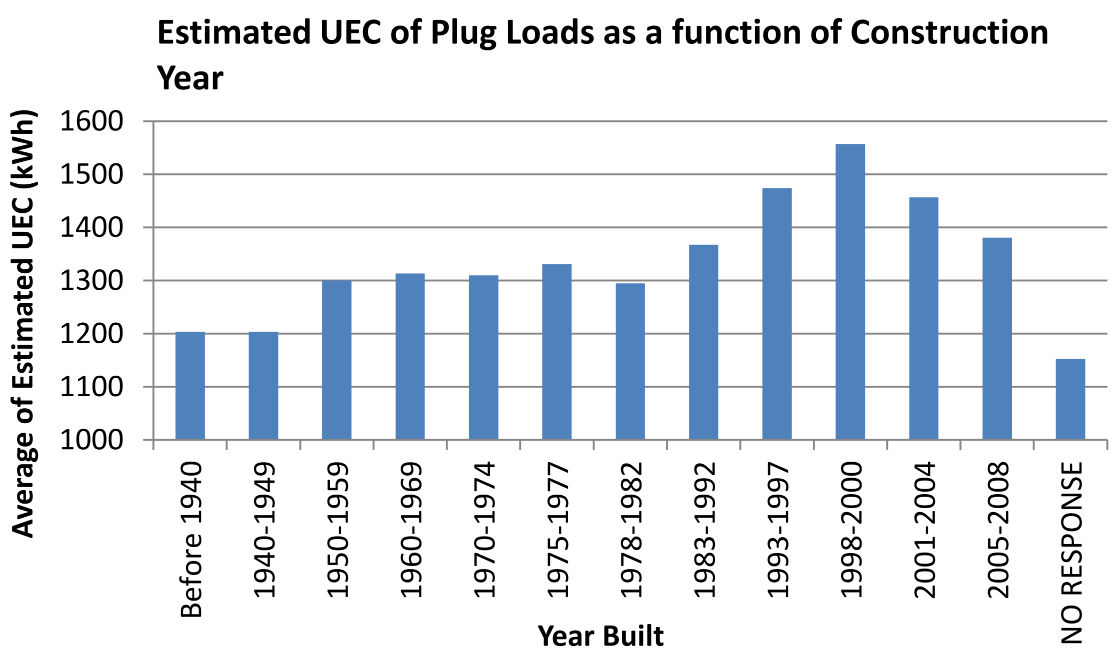

Figure 95: Estimated UEC of Plug Loads as a function of Construction Year

16.5 Title 24 Regulated Loads

It is important to note the differences in Title 24 regulated uses as opposed to whole building energy use, since Title 24 currently only covers 46% of the loads, as seen in Figure 101 (reproduced from Figure 10 above).

Over half of home electricity consumption not covered by T-24

End-Use	kWh/yr	
Not covered by T-24	**3,612**	**54%**
Dryer	187	
Clothes Washer	109	
Dish Washer	73	
First Refrigerator	707	
Additional Refrigerator	313	
Freezer	138	
Range/Oven	105	
Television	645	
Microwave	122	
Home Office Equipment	17	
Personal Computer	602	
Well Pump	28	
Miscellaneous	568	
T-24 + Preempted	**1,106**	**17%**
Conv. Space Heating	37	
Heat Pump Space Heating	13	
Aux Space Heating	0	
Central Air Conditioning	876	
Room Air Conditioning	47	
Water Heating	133	
T-24	**1,927**	**29%**
Furnace Fan	164	
Attic Fan	14	
Evaporative Cooling	43	
Solar Water Heating	0	
Pool Pump	234	
Spa	25	
Outdoor Lighting	284	
Spa Electric Heat	28	
Lighting	1,136	
Total	**6,645**	

End-Use	Therm/yr	%
Not Covered by T-24	**51.4**	**14%**
Dryer	16.2	
Range/Oven	31.7	
Miscellaneous	3.5	
T-24+ preempted	**309.0**	**83%**
Primary Heat	175.8	
Conv. Gas Water Heat	133.2	
T-24	**10.2**	**3%**
Pool Heat	5.6	
Spa Heat	2.9	
Auxiliary Heat	1.6	
Total	**370.5**	

Not Covered by T-24
Plug loads are installed after building inspection and are not covered by T-24

T-24 + Preempted
T-24 is preempted from requiring higher equipment efficiency but T-24 can impact the loads on equipment (envelope eff, controls etc.)

Covered by T-24
Loads and equipment efficiency can be regulated by T-24

Figure 96: Percent Residential Energy Use Covered by Title 24

Below, we analyzed the energy use of residential buildings through two code cycles. Figure 102, Figure 103, Figure 104, and Figure 105 show three sets of values – energy use for a building meeting the 2008 Title 24 standards, energy use for a building meeting the 2013 Title 24 standards and a third hypothetical data point for a building 66% better (lower EUI) than 2013 Title 24. Figure 102 shows this analysis in terms of TDV, while Figure 104 shows gas and electric EUI in kBTU/sf and Figure 103 show the electric-only EUI in kWh/sf.

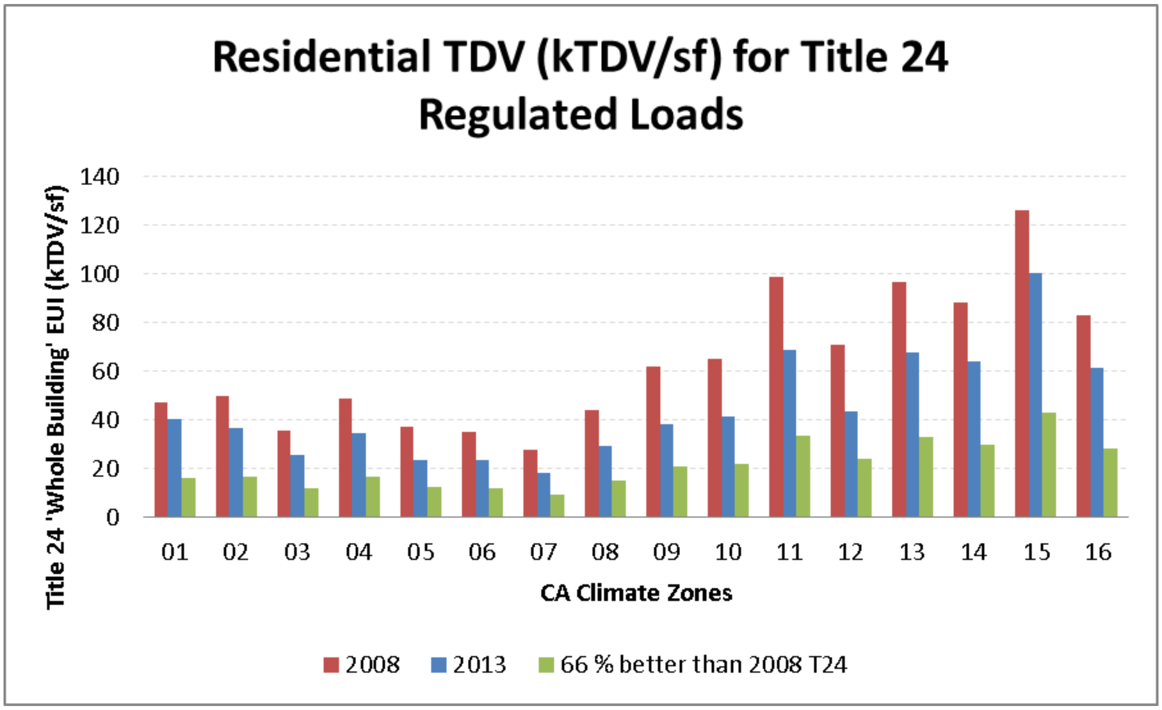

Figure 97: Residential TDV for Title 24 regulated loads.

Typically, when considering Title 24 regulated loads, we look at energy use in terms of TDV. From this lens, average EUIs at 66% better than 2008 Title 24 typically range from about 15-45 kBTU/sf. This represents a substantial savings as compared to 2008. From this perspective, climate zone 15, a cooling dominated climate zone, is the 'worst' performer and thus a target for codes and standards peak savings.

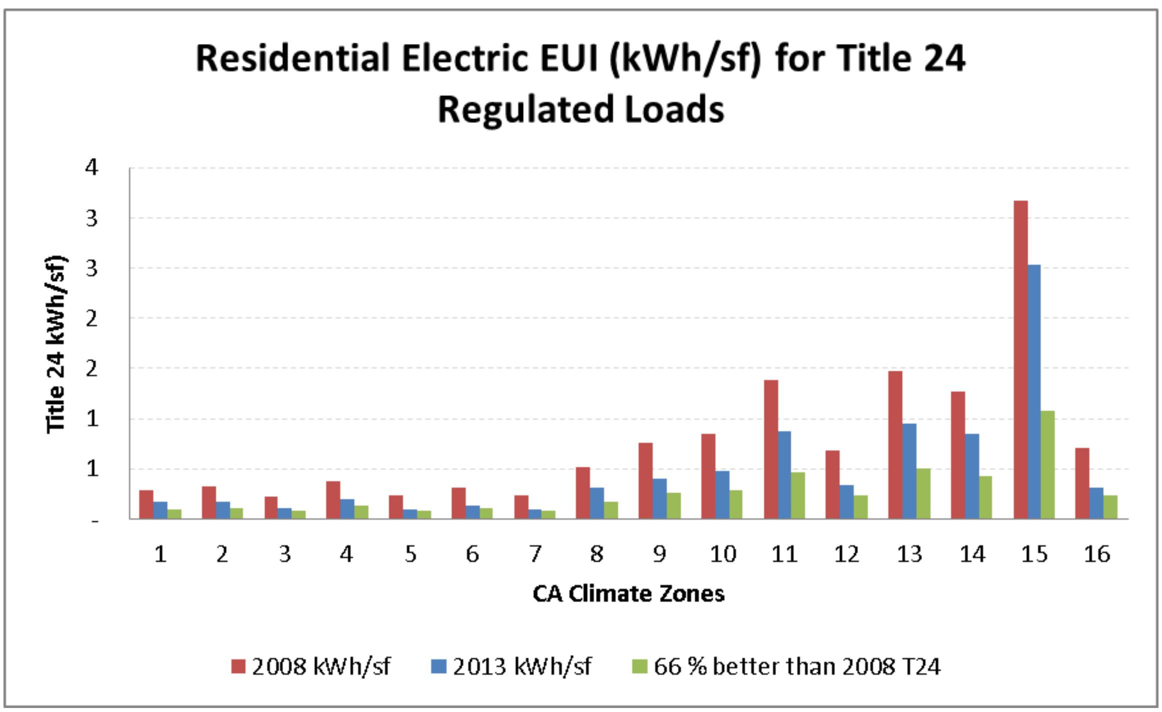

Figure 98: Residential electric EUI for Title 24 regulated loads.

Figure 103 shows the electrical use in the same set of buildings. This is closely correlated to the TDV analysis and again, climate 15 is the 'worst' performer.

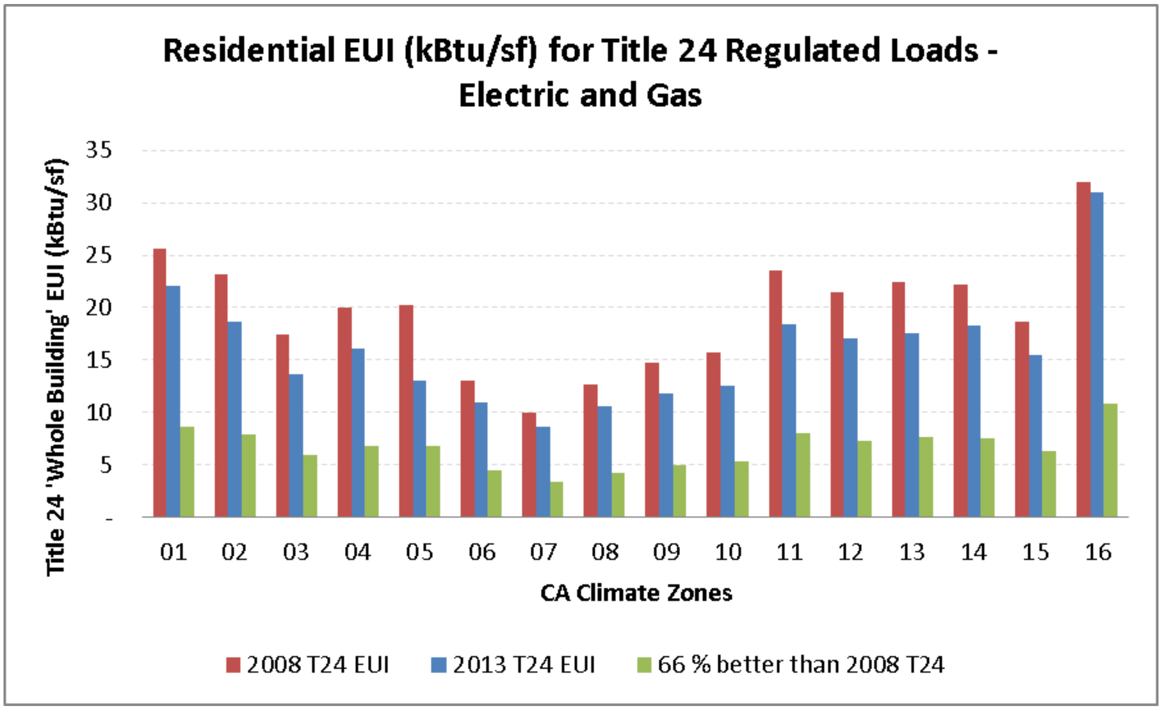

Figure 99: Residential EUI for Title 24 regulated loads.

However, if we consider site energy (looking at both electricity and gas use in total kBTU/sf) rather than TDV, the distribution looks significantly different. Here, climate zone 16, a heating dominated climate zone, has the highest EUI. From this perspective, codes and standards should also be targeting heating loads to lower the overall EUI.

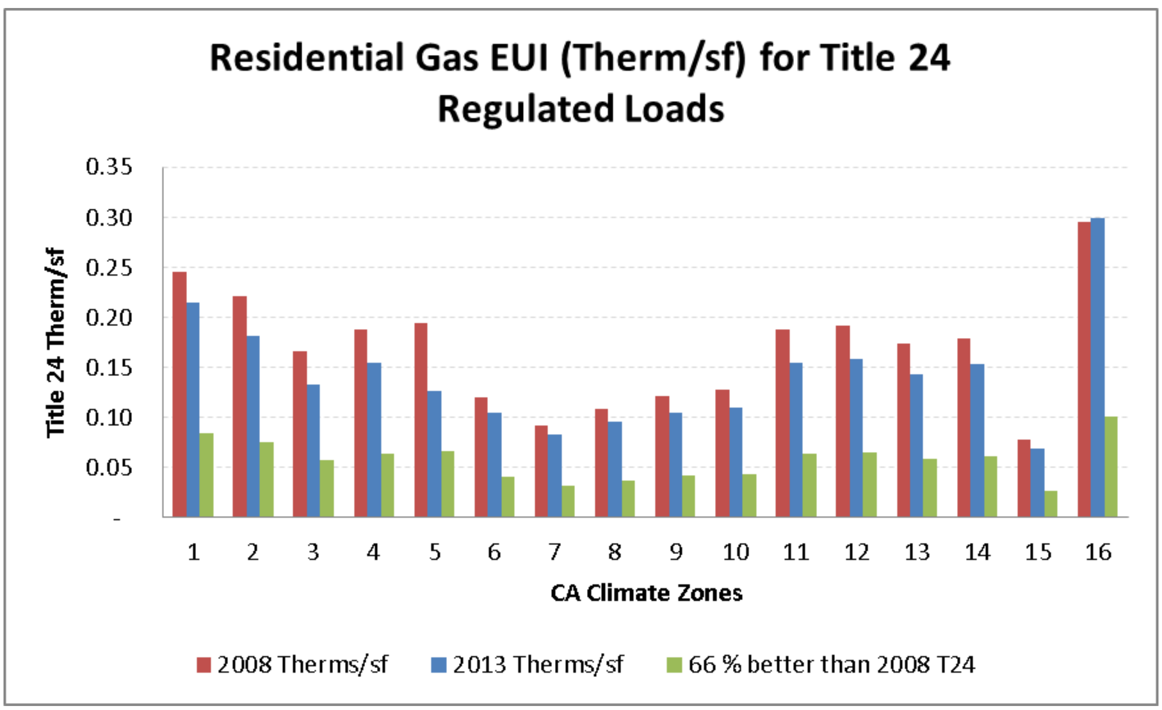

Figure 100: Residential gas EUI for Title 24 regulated loads.

Figure 105 shows the gas use for Title 24 regulated loads. These results closely follow the overall EUI seen in Figure 30 as opposed to the shape of the TDV results.

16.6 Unregulated Loads

As noted above, unregulated loads represent over half the energy use in residential buildings. However, there is a lack of good information on unregulated loads in terms of EUI or UEC.

One of the primary purposes of looking at RASS was to identify the differences in plug load energy use in various dwellings. However, data analyzed by HMG reveals that RASS is limited in its ability to provide data on plug load energy usage due to the way data was collected and sorted into categories. For example, the RASS survey provides bins of house size, rather than the actual square footage, so the data cannot be converted to EUI.

In addition, plug loads and lighting UECs were 'estimated,' not measured. These are calculated based on:

- Square footage of the livable spaces in the dwelling
- Age of dwelling
- # of residents
- Household Income

Further research should be completed to carefully look at the plug and appliance energy use assumptions in RASS to ensure that the numbers are not an artifact of calculations but supported through field measurements.

17. Appendix I: Building Rating Schemes and Initiatives

17.1 Asset Ratings

A number of asset ratings have been implemented or are currently under development. For example, the European Union, the US Department of Energy (DOE), the Massachusetts Department of Energy Resources (DOER), and the American Society and Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) have all been developing asset rating systems (Crowe, et al 2010). In California, the California Home Energy Rating System (HERS) is currently being used for residential buildings, while the California's Commercial Building Energy Asset Rating System (BEARS) is being developed by the California Energy Commission for commercial buildings.

17.1.1 California's Commercial Building Energy Asset Rating System (BEARS)

Under development by the California Energy Commission, the BEARS is an asset rating system that aims to improve energy efficiency in a wide range of commercial buildings. The scale used by BEARS is intended to provide for an intuitive scale that distinguishes between high and low performance buildings, capture the value of energy performance improvements and align well with California's policy goals. Given California's long term goals of reaching ZNE new construction the adopted scale is zEPI, a linear scale in which 0 denotes a TDV ZNE energy building designed by Architectural Energy Corporation (AEC). In this rating scale, 100 denotes a Title 24 compliant building, basically a Title 24 prescriptive version of the input building. The linearity of the scale makes it intuitive since energy efficiency improvements that result in a 20% energy consumption reduction will correspond to a 20% improvement in a building's score. This also makes comparing two buildings of the same building type simple. For example, a large hotel with a score of 70 consumes twice as much energy as a large hotel with a score of 35 (Crowe, et al 2012).

Figure 101: Presentation of the BEARS Rating (for a building with a rating of 123) (Crow, et al 2012).

17.1.2 California Home Energy Rating System (HERS)

The California HERS program utilizes an asset rating to compare efficiency measures between homes and allows owners to easily identify cost effective efficiency upgrades for both new and existing homes. Like BEARS, HERS also uses a zEPI scale. Again, in this scale, higher scores correspond to buildings that are likely to have higher energy use. A score of 100 is equivalent to a new Title 24 compliant home, while a 0 HERS score represents a ZNE TDV building.

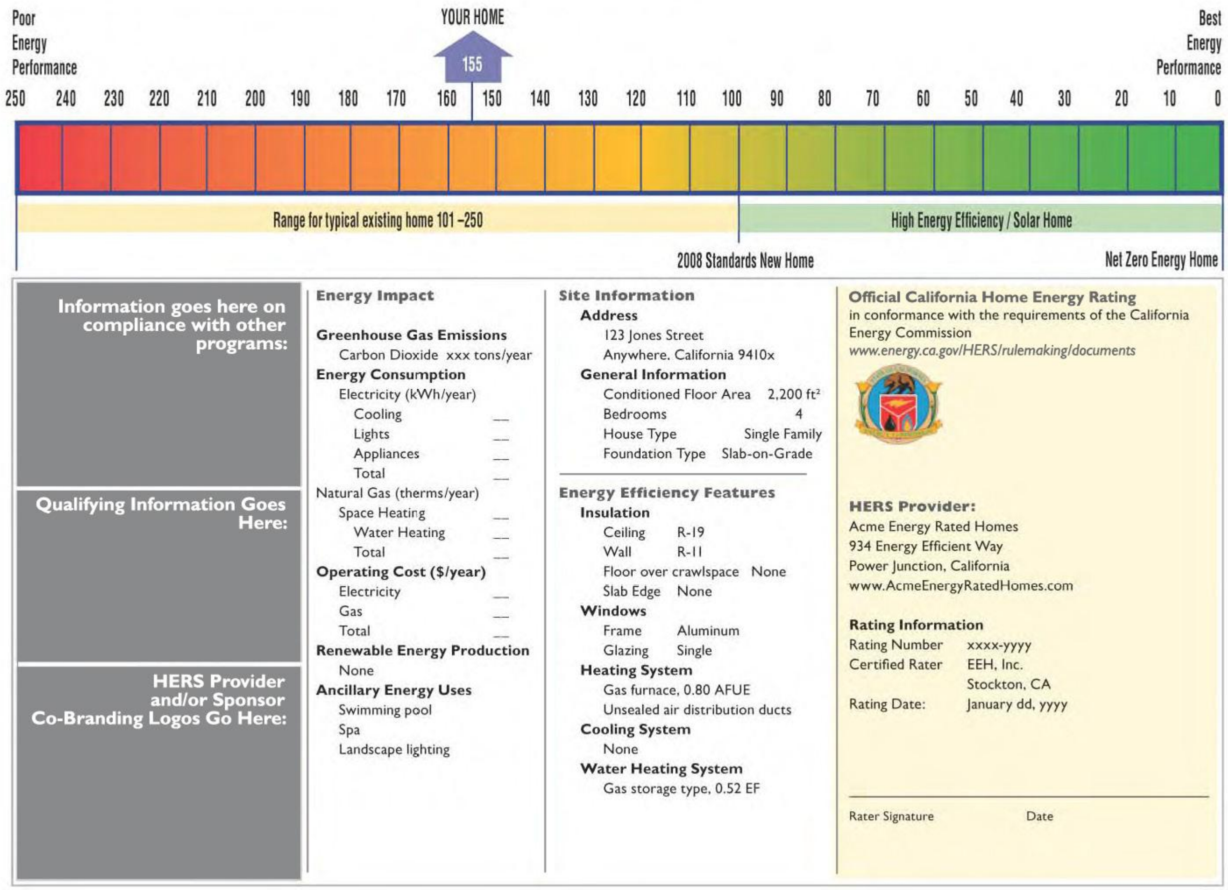

Figure 102: An example HERS Rating Certificate (CEC 2011).

17.2 Operational Ratings

In contrast to asset ratings, which measure the efficiency potential of a building, operational ratings are based on the actual energy use in a building.

17.2.1 Energy Star Portfolio Manager (ESPM)

Nationally, a commonly used tool to calculate an operational rating is the U.S. EPA's Energy Star Portfolio Manager (ESPM).The ESPM is a widely used, voluntary building performance tracking and labeling program. It tracks building's energy and water consumption and compares the building's source energy use to a national database of buildings with the same operating characteristic, usually the Department of Energy's Commercial Building Energy Consumption Survey (CBECS). The result is a rating on a scale of 1 to 100, with 100 being the most energy efficient building in its category. Note that the Energy Star Score is a statistical scale with the highest score representing the energy consumption of the most efficient building (not necessarily a ZNE building) and 1 representing the worst performing building. A verified score of 75 or higher (i.e., the building performs better than 75% of all similar buildings nationwide) qualifies the building for Energy Star certification.

Described below, EnergyIQ and Building EQ are other tools that also have similar features.

17.2.2 California Building Energy Use Rating Tool (CBEURT)

In parallel to the BEARS efforts, the California Building Energy Use Rating Tool (CBEURT) is also being developed to provide operational ratings for commercial buildings in California. "The CBEURT utilizes the same information as the ESPM to generate a rating that is based on California specific metrics and referenced to net zero source energy consumption" (Regnier 2012). In contrast to the ESPM rating, where higher scores are better, in the base rating scale of CBEURT, "an EUI of zero yields a rating of zero, while an EUI equal to the median value for a particular building type will always yield a rating of one hundred" (Regnier 2012). A statistical analysis of the California End Use Survey (CEUS) was performed to develop this scale for California building types.

Figure 103: Presentation of the CBEURT Rating (for a building with a rating of 123) (Regnier2012)

17.3 Building Labeling Initiatives

17.3.1 California Building Energy Labeling Initiatives

California Assembly bill (AB) 1103 (Soldana 2007), modified by AB 531 (Soldana 2009), and further modified by new proposed regulations to be released in October 2012[1] will require building owners to benchmark and disclose a building's Energy Star Portfolio Manager Score before a building is sold, leased entirely or refinanced. This applies to buildings larger than 50,000 ft^2, or owner occupied buildings greater than 1,000 ft^2. The upcoming regulations should postpone initial compliance to July 1, 2013.

17.3.2 Federal Building Energy Labeling Activities

Building performance labeling requirements have also repeatedly surfaced in various federal legislative efforts, including the Waxman-Markey bill , which had provisions for a performance, or "operational" rating based on actual utility use (likely based on the Energy Star rating); and a design, or "asset" rating based on building design features. The bill also had mandatory reporting and disclosure provisions. Some form of federal building energy labeling system appears likely in the future and would likely impact ZNE efforts. In general, federal building energy labeling should be positive, but there could be unintended effects, such as the preemption of a potentially more useful state building energy labeling system, a national rating scale with too low of a bar that inadvertently disincentives California buildings from exceeding minimum Title-24 performance , etc.

17.3.3 Voluntary Building Energy Labeling Activities

Voluntary building energy labeling standards are also under development. One of the most prominent efforts is the ASHRAE Building Energy Quotient, or "Building EQ" system[2], which incorporates an "as designed" and "in operation" rating, as illustrated below. They provide both a "label/plaque" and "dashboard" to visualize performance. The ASHRAE rating is based on an absolute performance scale (with a ZNE building representing the best score), which does not correlate to the Energy Star scale (which is a statistical scale with the highest score representing the energy consumption of the most efficient building, not necessarily a ZNE building).

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[1] An initial draft of these regulations, *Proposed Regulations, Title 20, Division 2, Chapter 4, Article 9, Sections 1680-1685,* "Nonresidential Building Energy Use Disclosure Program" is available online at http://www.energy.ca.gov/2010publications/CEC-400-2010-004/CEC-400-2010-004-SD3.pdf .

[2] http://buildingenergyquotient.org/

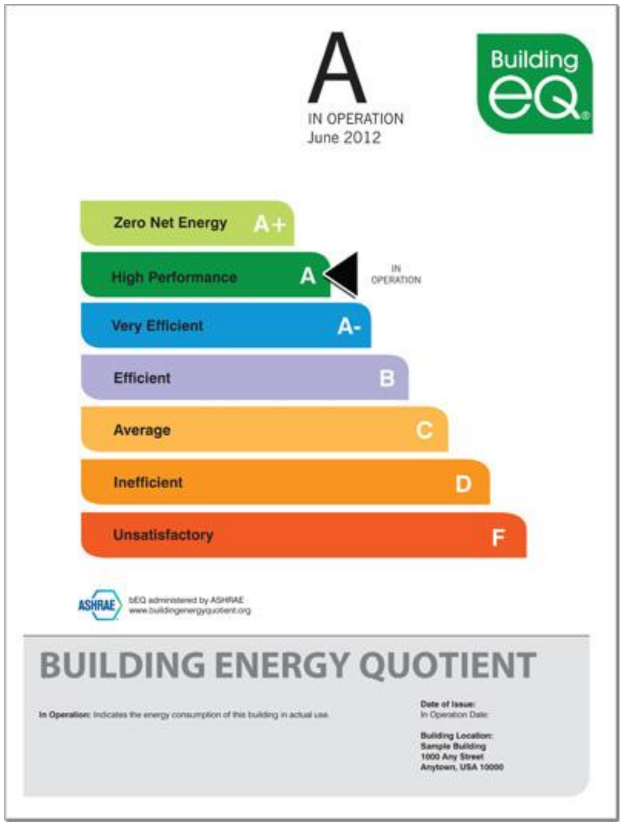


Figure 104: ASHRAE building energy use label/plaque (as designed and in operation)[1]

[1] Image from http://buildingenergyquotient.org/get-started-with-beq-to.html

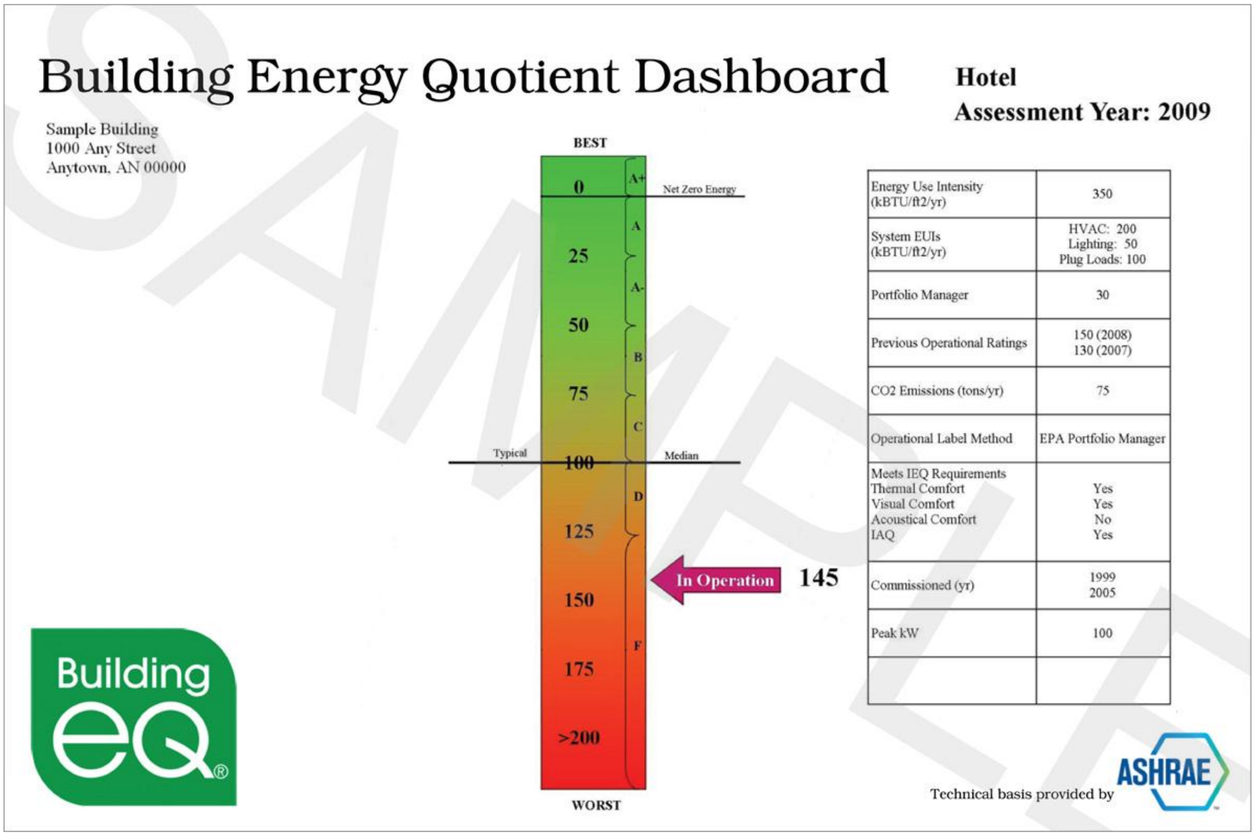
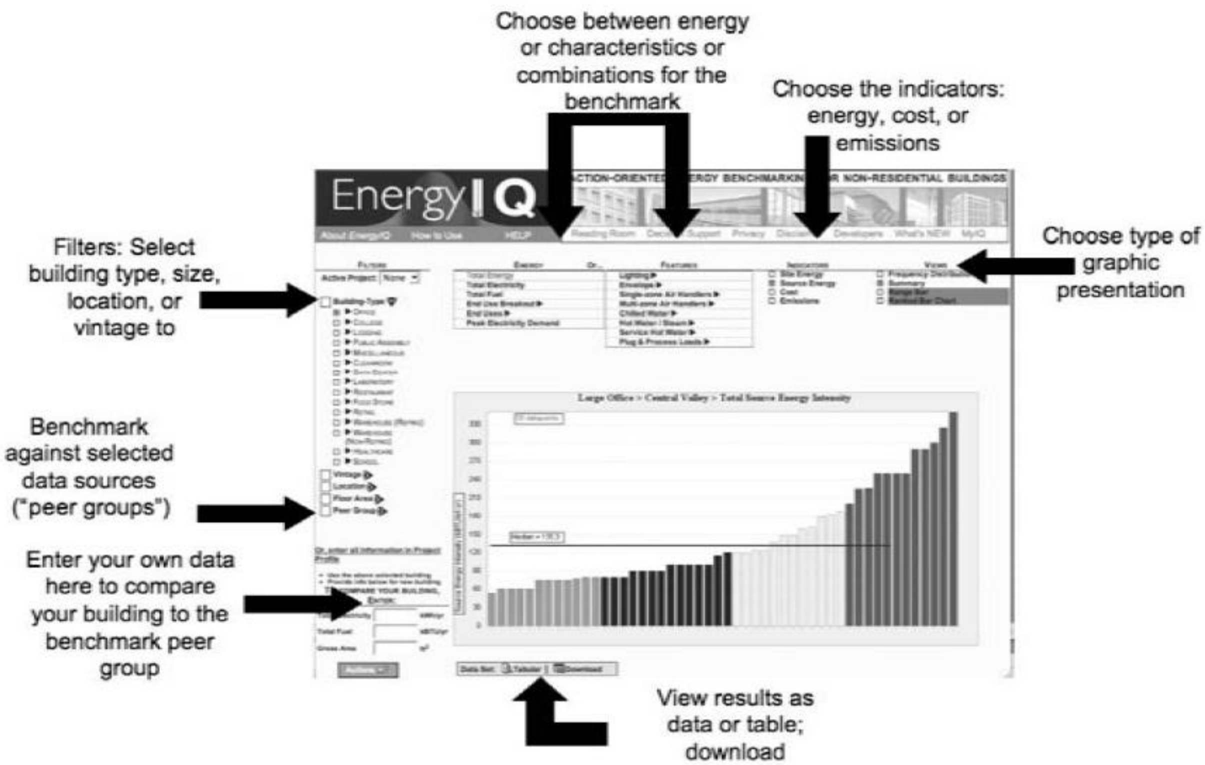


Figure 105: ASHRAE Building Energy Quotient Dashboard Sample[1]

In California, the U.S. Department of Energy's Lawrence Berkeley National Laboratory has been developing EnergyIQ, which also has asset and operational components. EnergyIQ is an 'action-oriented' benchmarking tool for non-residential buildings, enabling user-defined metrics and building peer group comparisons, as well as improvement suggestions/resources and performance tracking. Here, the benchmarking databases are CEUS and CBECS.

[1] http://buildingenergyquotient.org/images/sampledashboard.jpg


Choose between energy or characteristics or combinations for the benchmark
Choose the indicators: energy, cost, or emissions
Filters: Select building type, size, location, or vintage to
Choose type of graphic presentation
Benchmark against selected data sources ("peer groups")
Enter your own data here to compare your building to the benchmark peer group
View results as data or table; download
Energy IQ
Large Office > Central Valley > Total Source Energy Intensity

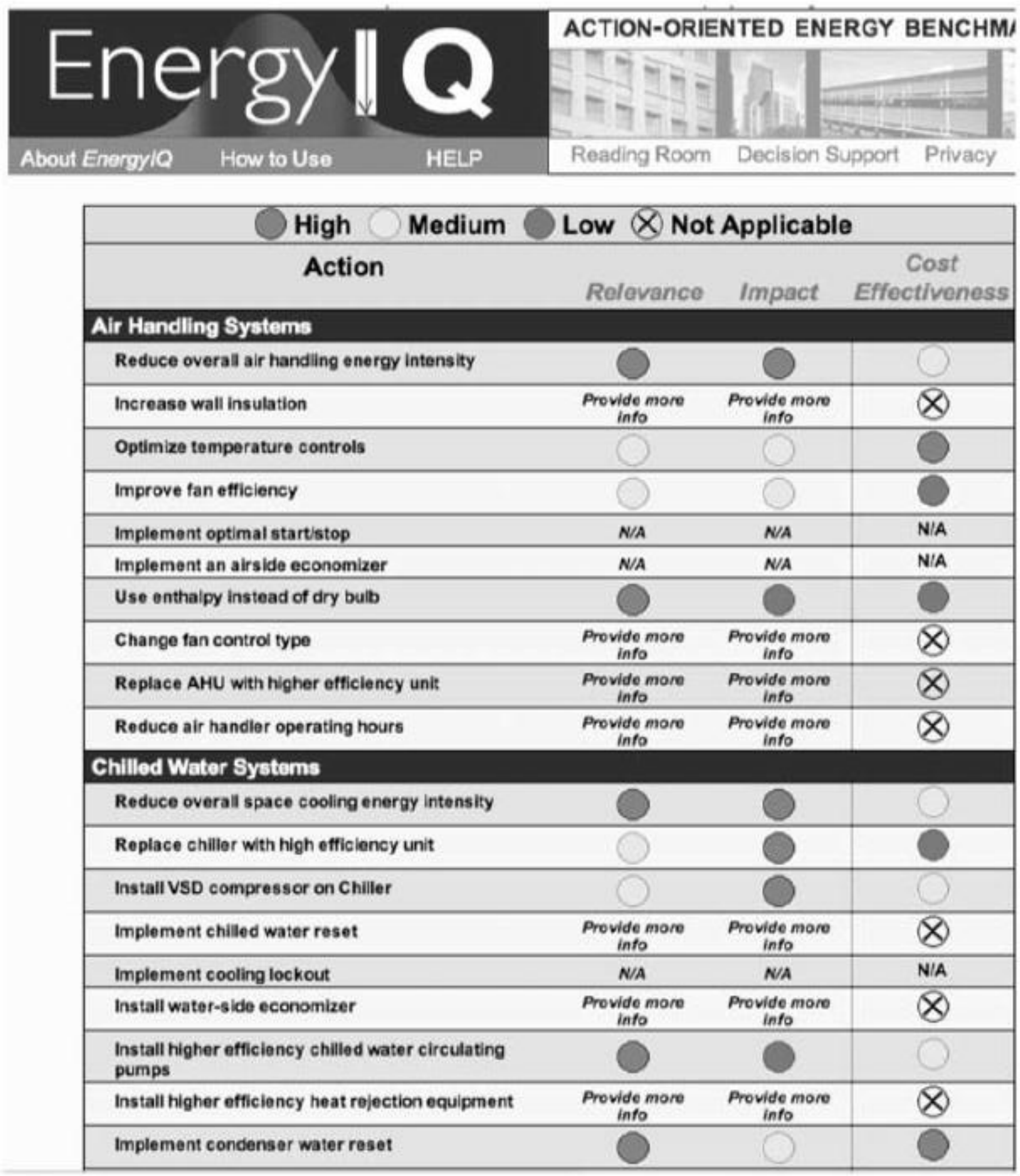


Figure 106: Screenshot of the EnergyIQ benchmarking interface (Mills, et al 2008).

17.3.4 Local Benchmarking, Labeling and Energy Auditing Regulations

A number of local jurisdictions are implementing their own local benchmarking and building labeling requirements as outlined in Figure 107. Two notable examples include New York City and San Francisco.

Jurisdiction	Benchmarking (Building Type and Size)		Disclosure					
	Non-residential	Multi-family	On public web site	To local or state government	To tenants	To transactional counterparties		
						Sale	Lease	Financing
Austin*	10k SF+	-	-	✓	-	✓	-	-
California	5k SF+	-	-	✓	-	✓	✓	✓
District of Columbia*	50k SF+	50k SF+	✓	✓	-	-	-	-
New York City*	50k SF+	50k SF+	✓	✓	-	-	-	-
San Francisco*	10k SF+	-	✓	✓	✓	-	-	-
Seattle*	10k SF+	5+ units	-	✓	✓	✓	✓	✓
Washington	10k SF+	-	-	-	-	✓	✓	✓

*Time based disclosure – there is a date certain for disclosure regardless of any triggering transaction

Figure 107: Commerical Benchmarking Laws' Size and Disclosure Requirements (Regnier 2012, adapted from Burr 2011).

San Francisco adopted an “Existing Commercial Buildings Energy Performance Ordinance” (added Chapter 20, Sections 2000 through 2009 to the San Francisco Environment Code). This requires nonresidential building owners to conduct ASHRAE level 1 energy audits for buildings ≥ 10,000 ft^2, or ASHRAE level 2 energy audits for buildings ≥ 50,000 ft^2 every five years. It also benchmarks building performance using the Energy Star Portfolio Manager and file annual energy benchmark summaries.

New York City has a similar effort, called the Greener, Greater Buildings Plan (GGBP), targeting energy efficiency in larger existing buildings. The program consists of four regulatory pieces supplemented with job training and a financing entity called the New York City Energy Efficiency Corporation (NYCEEC). The four regulatory requirements include: (1) large buildings must annually benchmark their energy performance (LL84), (2) local energy codes must be adopted (LL85), (3) every 10 years large buildings conduct an energy audit and perform retro-commissioning (LL87), and (4) that by 2025, the lighting in the non-residential space be upgraded to meet code and large commercial tenants be provided with sub-meters (LL88).

These requirements, specifically the requirement for ongoing benchmarking and periodic energy audits will be very beneficial to ensuring ZNE buildings continue to operate at ZNE. Policy makers will want to consider similar opportunities in California. This will not only benefit ZNE buildings, but the entire building stock population.

17.4 Green Building Rating Programs

There is a proliferation of green building rating programs. The most well-known program is the U.S. Green Building Council (USGBC)'s Leadership in Energy and Environmental Design (LEED) rating systems. Most of these programs target new construction (i.e., a design rating). The programs that focus on operational issues and related initiatives that bridge the design/operational gap are discussed below.

17.4.1 LEED for Existing Buildings: Operations & Maintenance

Increasing attention to the disparities between how buildings are designed to operate versus how they actually perform drove the creation of the LEED for Existing Buildings: Operations & Maintenance (LEED EB). LEED EB was the first LEED rating system to address the actual operating performance of occupied buildings. Buildings are required to demonstrate achievement of quantitative performance targets in: building exterior and site maintenance programs, water use, energy use, environmentally preferred products and practices for cleaning and alterations, sustainable purchasing policies, waste stream management, and ongoing indoor environmental quality. Energy Star Portfolio Manager is used to track energy performance. LEED EB was designed to provide a complement to LEED for New Construction (LEED NC), where a LEED NC rating represents the "asset rating" and LEED EB represents the performance rating, analogous to ASHRAE's Building EQ program and other programs with both asset and performance ratings.

17.4.2 LEED Building Performance Partnership

The U.S. Green Building Council's Building Performance Partnership (BPP) was established to create a comprehensive data collection and analysis infrastructure that will receive data from all LEED certified projects, including both commercial and residential, LEED NC and LEED EB. BPP is a step beyond LEED to improve building performance through active data collection. The initiative engages commercial, institutional, and residential LEED building owners and managers in a collaborative effort to increase the green building community's emphasis on tracking and reviewing building performance data. BPP is still in its infancy, and is being rolled out in two phases. The first phase, launched in April 2010, focuses on two key performance indicators, energy and water, and relies on the ENERGY STAR's Portfolio Manager tool to collect and store this data. It then combines these monthly level data with available LEED data, and generates reports which analyze and benchmark performance over time. In Phase 2 which is still in pilot, sub-meter data will be included for energy use, and other key performance indicators will be analyzed as well. Phase Two will also bring the unveiling of the building performance database. The BPP database will be able to receive both automated and manual data inputs and the USGBC will create a standard interface for data reception and communicate the specifications of the interface to BPP participants and providers. Automated inputs will come from sensors and meters through building management systems or data loggers. Manual data entry will be possible as well, through a direct interface with the BPP database hosted by USGBC.

17.4.3 Other LEED Initiatives and Future Direction

The LEED rating systems are routinely updated. The USGBC is focused on increasing performance-based approaches to the LEED rating systems, and has been working towards performance based ratings on a variety of levels. Future versions of LEED will be increasingly performance based, particularly for energy, water and other easily quantified impacts. There is ongoing discussion on where performance benchmarks should be set, including the role of ZNE. This clearly is a topic that ZNE policy makers should be coordinating with the USGBC on. The incorporation of ZNE requirements in a voluntary program could be a very important mechanism to help foster early adoption of ZNE buildings, and there will undoubtedly be many lessons learned as ZNE begins to penetrate the marketplace.

The USGBC is also very aware of the many issues relating to asset based ratings (e.g., LEED NC) and the challenges many buildings face in meeting the performance levels projected by the LEED NC asset rating. LEED EB (discussed above) was developed in part to address this issue. This will undoubtedly continue to be an issue that the USGBC will continue to explore and discuss. ZNE policy makers will want to coordinate with the USGBC on this issue as well.

Another issue that the USGBC is working on is improving building analytics, such as the Building Performance Partnership (see discussion above) and other initiatives. ZNE policy makers should be coordinating with the USGC on opportunities to leverage the building analytics to tie into related state initiatives, extract best practices, and other lessons learned.

A final point worth noting is the USGBC's interested in climate change, including both how green buildings can mitigate climate change, and how they will respond to climate change. One of the questions that the USGBC is interested in is the appropriateness of the weather files we used for building energy modeling and related building energy modeling issues. Chris Pyke, Director of Research for the U.S. Green Building Council notes, "We're designing tomorrow's buildings while looking through the rear view mirror of yesterday's weather and that's [a] fundamental problem.[1]" ZNE policy makers will likely find it useful to coordinate with the USGBC on this and related energy modeling issues. Since LEED is driving a significant portion of high performing building energy modeling, there is an obvious benefit to aligning building energy modeling efforts to the greatest extent possible.

17.4.4 Living Building Challenge

The Living Building Challenge is a green building certification program developed by the International Living Future Institute. Its goal is to define the most advanced measure of sustainability in the built environment possible today and acts to diminish the gap between current limits and ideal solutions. An integral part of the Living Building Challenge is achieving zero net energy and zero new water use. For projects that seek to achieve Net Zero Energy but may not be able to meet all the requirements of the Living Building Challenge, there is the option to earn the Net Zero Energy Building Certification. This certification is purely performance based and requires projects to demonstrate through documentation of metering and utility bills over a 12 month period that "One hundred percent of the building's energy needs on a net annual basis must be supplied by on-site renewable energy. The system may be grid-tied or off the grid. Note that no combustion is allowed, and 'green tags' or 'green power' purchases are not recognized compliance paths." ZNE policy makers will want to track the

[1] The Daily Energy Report. "UMich & USGBC Study Finds LEED Buildings Are More Resilient." Accessed 10/1/2012. http://www.dailyenergyreport.com/umich-usgbc-study-finds-leed-buildings-are-more-resilient/.

performance of Living Challenge building participants. There will be valuable lessons learned and best practices emerging from participating projects.

18. Appendix J: Roof Space Needed for Solar PV in Residential Single Family Buildings

Updated 2013 T24 now requires all single family residential homes to have a solar zone for future solar installations, and all new homes throughout the state should have adequate roof area appropriately oriented and free of shade to install sufficient PV to make the home ZNE or near ZNE. While there are exceptions for urban infill or other locations such as on hill slopes where shading from neighboring structure or landscape features make the roof less desirable for solar installation, it is anticipated these will be a relatively small percent of the total new housing stock based on current construction practices that favor greenfield developments.

The 2013 California Building Energy Efficiency Standards includes new mandatory requirements for solar ready buildings[1]. For single family homes, the minimum solar zone area is 250 ft^2. This equates to a PV size of approximately 4.4 $kW_{DC\ rated}$ for an efficient module array[2].

The residential solar ready requirements were developed as part of the "Solar Ready Homes and Solar Oriented Development" Codes And Standards Enhancement Initiative (CASE) study conducted in support of the 2013 California Building Energy Efficiency Standards by the California Utilities Statewide Codes and Standards Team. A complete study is available online[3].

The 250 ft^2 was determined to be the best balance between the need for a reasonably sized solar zone without unduly burdening or changing construction practices. The CASE Study performed detailed analysis[4] on the roof area available for a solar zone. Both a parametric analysis was performed of generic home geometry (e.g., area, number of stories, aspect ratio, roof configuration, etc.) and a sample of actual production homes were analyzed to develop 'test fits' for available solar zones that meet the required fire setback requirements. The focus of the test-fit analysis was to ensure that smaller, entry level homes have sufficient roof area to meet the requirements[5]. A variety of new production home communities throughout the state were examined, and representative homes from three typical new production home communities were selected for analysis. The homes selected for analysis include a range of locations and builders, and where the homes that could potentially have the most challenges meeting the solar zone requirements. All house plans examined have sufficient roof area to meet a 250 ft^2 solar zone requirement. The homes with more complex hip roofs perform better, in that they provide the required solar zone area on multiple exposures and are not constrained

[1] 2013 California Building Energy Efficiency Standards Title 24, Part 6, Section 110.10

[2] e.g., Sunpower E19/238 Solar Panels (http://us.sunpowercorp.com/), which are 19.1% efficient, have a rated power of 238 W, dimension of 31.42 in x 61.39 in = 13.4 sqft, and a power density of 17.77 W/SF. This analysis assumes optimal orientation and disregards other losses and inefficiencies.

[3] http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/2011-05-24_workshop/review/2013_CASE_ResSolarReady_SolarOrientedDevelopments_052011.pdf

[4] section 4.5.2

[5] Stakeholders expressed concern that the solar zone requirement could potentially increase roof complexity or not be able to be met on lower cost entry level homes, thereby making these homes more expensive and unaffordable.

on how they are placed in a development, compared to the gable roof designs which have more room but require more careful placement to meet the orientation requirements.

This analysis shows that a 450 ft^2 solar zone should be able to be accommodated on most roofs, including smaller production homes of 2 stories with moderately complex roofs. For the homes on which test fits were conducted, even smaller, 2-story homes with relatively complex roof designs have sufficient roof area to meet the 250 ft^2 solar zone proposal. The general conclusion of both roof area availability analyses is that there is sufficient roof area (excluding orientation concerns) to meet the proposed 250 ft^2 solar zone for up to two story buildings, even for small homes[1]. While the 2013 Standards provide a number of exceptions to the size of this solar zone area, it is anticipated, based on CASE study analysis and stakeholder input, that the significant majority of homes will be able to achieve this solar zone.

The 250 ft^2 solar zone can provide for a range of different solar system(s), for example: a ~ 4.4 kW PV system using efficient solar panels[2], a ~ 2.5 kW PV system using lower efficiency panels, a 50 ft^2 solar water heating system with 3.5 kW of efficient PV, etc. The solar zone orientation requirements enable annual PV TDV savings to be within 10% of the maximum savings.

While the PV size required to make a future home ZNE depends on many factors (e.g., house size, climate zone, future energy efficiency measures implemented, occupant behavior, changes in equipment and appliance efficiency, plug loads) the 250 ft^2 solar zone should be sufficient to make a typical 2,600 ft^2 home ZNE in all but three climate zones. The following table shows the PV size required to net out the TDV energy use of current energy consumption (both electricity and natural gas) regulated under Title 24 Part 6 for different climate zones and different house sizes. As can be seen, the 250 ft^2 solar zone (and in many cases significantly smaller area) can provide enough energy to enable homes to achieve ZNE in most cases. It should also be noted that this table analyzes PV only; solar thermal has a higher solar conversion efficiency and requires less space for comparable useful energy output and could also be used.

[1] Note that it is always possible to design a roof with enough complexity that the sufficient solar zone area is unavailable. However, this does not appear to be typical or common practice.

[2] e.g., Sunpower E19/238 Solar Panels (http://us.sunpowercorp.com/), which are 19.1% efficient, have a rated power of 238 W, dimension of 31.42 in x 61.39 in = 13.4 sqft, and a power density of 17.77 W/SF.

		Home Size (ft²)						
		1,000	1,500	2,000	2,700	3,200	3,700	4,200
Climate Zone	01	42	64	85	115	136	157	178
	02	43	64	86	116	137	159	180
	03	31	46	61	83	98	113	128
	04	41	62	82	111	131	152	172
	05	29	44	59	79	94	109	124
	06	36	53	71	96	114	132	150
	07	26	39	52	70	83	96	109
	08	47	70	94	127	150	174	197
	09	64	96	128	173	205	237	269
	10	69	104	138	187	221	256	290
	11	97	146	194	262	311	359	408
	12	71	107	142	192	227	263	299
	13	101	151	202	272	323	373	423
	14	76	113	151	204	242	279	317
	15	136	203	271	366	434	502	570
	16	76	114	152	205	243	281	319
	Statewide	56	85	113	152	180	209	237

Figure 108: Approximate PV size (ft²) to "net out" regulated household TDV