Pacific Gas and Electric Company

Zero Net Energy Program

California Zero Net Energy Buildings Cost Study

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Definitions

AB32	California Global Warming Solutions Act of 2006
ACI	Affordable Comfort Inc
AEDG	Advanced Energy Design Guide
AIA	American Institute of Architects
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BBEES	Big Bold Energy Efficiency Strategies
CARB	California Air Resources Board
CEC	California Energy Commission
CPUC	California Public Utilities Commission
DEG	Davis Energy Group
DOE	U.S. Department of Energy
EEM	Energy Efficiency Measure
EUC	Energy Upgrade California, a statewide program
EUI	Energy Use Intensity
GHG	Greenhouse Gas Emissions
HVAC	Heating, ventilation, and air conditioning
IES	Illuminating Engineering Society of America
LED	Light-Emitting Diode
LEED	Leadership in Energy and Environmental Design
NBI	New Buildings Institute
NREL	National Renewable Energy Laboratory
PG&E	Pacific Gas and Electric Company
PIER	Public Interest Energy Research
PV	Photovoltaic
PPA	Power Purchase Agreement
SMUD	Sacramento Municipal Utility District
TDV	Time Dependent Valuation
TOU	Time of Use
USGBC	U.S. Green Building Council
ZNE	Zero Net Energy

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1 Executive Summary

Zero Net Energy (ZNE) buildings combine energy efficient designs with renewable energy generation to zero out net annual energy consumption. These buildings constitute a very small but expanding segment of residential and commercial markets. Of the 143 buildings listed in the New Building Institute "watch list"[1] of ZNE commercial projects, over half are listed as "emerging" projects. Federal and state initiatives, as well as increasingly rigorous California energy efficiency building standards, have generated momentum that is moving designers, builders, and building owners toward ZNE buildings. In California, the passage of AB32 consolidated future statewide goals for reducing Greenhouse Gas (GHG) emissions. Subsequently, the California Public Utilities Commission (CPUC) adopted the Big Bold Initiative, which directed that all new residential and commercial construction be ZNE by 2020 and 2030, respectively. This aggressive policy has sought to nurture a nascent market in high-performance and ZNE building design as a strategy to reduce greenhouse gas emissions.

This study explored the cost-effectiveness of ZNE buildings in the current residential and commercial marketplace through a review of literature, case studies, and interviews with ZNE experts familiar with residential, commercial, and community-scale projects. Peer-reviewed research indicates steady development of high-performance buildings and subsequent ZNE design strategies over several decades. Many of the early residential and commercial examples achieved high levels of energy performance, but at significant additional cost. The falling costs of photovoltaics (PV), combined with advanced energy modeling capabilities that support integrated design processes, have expanded market awareness of ZNE and increased the pool of experts. In addition, changing social attitudes, public policies, and incentive programs has increased the demand for highly energy-efficient buildings.

Research and interviews revealed examples where commercial buildings achieved ZNE (or near-ZNE) status at little or no additional cost. However, the current data set of available ZNE projects is insufficient to allow for statistically-significant comparison of ZNE cost parity with non-ZNE buildings. In the commercial sector, incremental costs for analyzed buildings ranged from $0-23/ft^2, but many projects did not report incremental costs making comparisons difficult. . In the residential market, incremental costs for energy efficiency measures (EEMs)[2] ranged from $2-27/ft^2, after incentives or tax credits. Decreasing PV costs and power purchasing arrangements are altering the cost-effectiveness balance between efficiency and generation.

Interviews indicated that appropriate design strategies are critical to achieving high performance buildings. Establishing energy targets and utilizing an integrated design process facilitates meeting performance goals while also identifying efficiencies in construction. Successful design teams tend to be experienced and include architects, engineers, contractors, estimators, and building owners early in the design process. Ability to achieve cost effectiveness is still sector-dependent. In the residential sector, the cost for EEMs and PV is simply an incremental increase relative to the cost for standard market rate homes. In the commercial sector, building treatments and configurations vary widely, based on building function and owner preferences. Emerging ZNE commercial buildings often reflect dramatic changes in building design or highly integrated systems, for example utilization of heat recovery or use of passive heating and cooling strategies. This leads to a high variance in costs and complicates comparability analyses, especially given the small sample of projects that currently exist. In the public sector, schools and government buildings, which have established construction budgets based on standardized costs per square foot, can often approach ZNE at cost parity by the application of effective integrated design practices by experienced design teams. Thus, strategies to promote ZNE design and construction should vary by building sector and location.

[1] As of August 29, 2012

[2] Not including PV or solar thermal water heating

Project summary findings include the following:

General

1. The building industry (developers, builders, subcontractors, brokers, and appraisers) and the general public need more education on the costs, performance, and ancillary benefits of ZNE buildings. Case studies, brochures, and other media efforts, should include detailed substantiation of actual performance and costs. Passage of the SAVE Act would allow for energy cost savings of ZNE homes to be recognized in the appraisal process.

2. Innovative contracting processes, such as that employed at NREL's Research Support Facility 222,000 ft^2 office building, have been shown to be an effective method for contractually requiring a building to operate at a prescribed energy consumption level. In the early stages of ZNE commercial projects, this requires a detailed modeling effort to define the appropriate energy target. Many of the experts interviewed feel that this approach promotes efficiency in arriving at optimal performance/cost points for the key members of the design team.

3. The design community is still learning how to develop optimal ZNE packages that optimize the balance of EEMs and PV generation for different building types and climates. Dramatic changes in PV pricing over recent years and an ongoing evolution in cost and performance for some key technologies (e.g. LED lighting) factor into defining this balance point.

4. According to research compiled by experts who study commercial building rents and market premiums associated with green buildings and PV systems, green buildings and PV systems are valued more highly in the marketplace. It will be interesting to observe these current trends as the ZNE market expands to a broader community.

5. Developers of community scale projects indicate that the cost and complications related to regulatory requirements present a significant hurdle, particularly for the development of complex projects. Streamlining and simplifying the processes will benefit these projects, particularly multi-family projects where submetering rules complicate centralized plant and PV generation solutions that may offer both cost reduction and energy savings.

Residential

1. Conventional EEM upgrades to a code-compliant new home (e.g. improved windows and insulation levels; high efficiency space conditioning, water heating, and lighting systems) to achieve about 40% reductions in home thermal and lighting energy consumption will cost roughly \$2 - \$8 per ft^2 of conditioned floor area. More advanced design approaches that integrate advanced envelope components, efficient equipment and thermal delivery systems, passive strategies, and emerging technologies, currently may cost three to four times more. At this point, it is not clear whether these advanced approaches will "mature" to the point where they are competitive with falling PV costs (currently at about \$8 to \$10 per ft^2 of conditioned floor area in typical applications).

2. Innovative strategies for deriving value for the delivery of ZNE or ZNE-capable projects need to be tested and evaluated. A successful example is the Carsten Crossing subdivision in Rocklin, CA. During 2005 to 2007, 84 high performance LEED-certified homes were sold at the subdivision, with a sales rate 2.2 times that of competing neighboring subdivisions. The higher absorption rate significantly reduced the developer's carrying costs for the project. Early on, the developer had made the decision to price his homes at a comparable level to the competing subdivisions, despite the added costs associated with energy efficiency and 2.4kW_{dc} PV systems. The reduced carrying costs due to faster sales generated cost savings that were nearly five times greater than the incremental construction cost for these homes. Anecdotally, a limited sample of home resales (from June

through November 2012) in the Carsten Crossings subdivision (seven homes) as well as neighboring "comparable" subdivisions (fourteen homes) suggest a 12% higher per square foot market valuation for the Carsten Crossing homes.

Commercial

1. Industry experts suggest that it is possible to construct ZNE commercial buildings at little or no incremental cost. There is significant variability in the costs of both code compliant and high performance commercial buildings. ZNE commercial buildings put the focus on energy performance goals, while conventional buildings may focus on building amenities and treatments.

2. Commercial buildings offer greater opportunities for realizing cost tradeoff benefits which can reallocate construction cost savings from HVAC downsizing to other areas, such as architectural/envelope improvements, high efficiency lighting, and higher efficiency equipment. Maximizing performance synergies that reduce first costs and generate energy savings is a key part of the commercial building integrated design process.

3. Incorporation of precise and well thought out building energy use targets in construction contracts is widely recognized as an effective mechanism in focusing the design team's effort on an appropriate design solution. The electrical subcontractor from NREL's ZNE Research Support Facility building suggested that following this approach resulted in a several percent cost savings in their overall bid.

2 Objectives

The primary objective of this study is to assess the incremental costs associated with Zero Net Energy (ZNE) buildings, with a focus on projects that have credibly documented performance. Since this work was undertaken for Pacific Gas and Electric (PG&E) as part of their ZNE program, the emphasis is on California projects, or projects that have climates offering comparability to California.

ZNE buildings combine energy efficient designs with renewable energy generation to reduce overall energy consumption to zero over the course of a year. ZNE or ZNE-capable[3] buildings have been around for many years, but many early projects were focused on demonstrating ZNE building as a viable strategy, rather than focusing on cost competitive building designs. Currently there is a growing push for ZNE buildings due to mandates by both the Federal government (The Energy Independence Security Act of 2007) and the state of California AB32 Global Warming Solutions Act of 2006. In response to AB32, the California Public Utilities Commission (CPUC) has developed a Long Term Energy Efficiency Strategic Plan that includes goals that all new residential buildings will be ZNE by 2020, and all new commercial buildings by 2030 (CPUC 2008). Currently these ZNE goals do not have supporting legislation, as the state is still exploring the exact definition of ZNE and the public policy steps needed to get there.

The scope of this project includes residential, commercial, and community scale projects that are connected to the electricity grid. For each of these sectors, a series of case studies documents and explores cost issues, design strategies, and lessons learned. The eight case studies (three residential, three commercial, and two community scale) are included in Appendix A and are intended to highlight projects that are well documented in terms of both demonstrated ZNE performance and cost. To gather the information for the case studies and the body report, the team began with a literature review and interview of key individuals to identify recent documented projects.

3 Introduction

Interest in ZNE buildings is increasing both in California and nationally. Federal initiatives include:

1. The Energy Independence Security Act of 2007, which requires new and renovated federal buildings to reduce fossil fuel use by 55% (from 2003 levels) by 2010, and 80% by 2020[4]; and

2. DOE's Building America and Challenge Home programs, which are focused on delivering highly efficient, ZNE-capable new homes.

In addition, the Affordable Comfort (ACI) 1000 Home Challenge[5] (target of >70% site energy reduction) and Architecture 2030[6] (carbon neutral buildings by 2030) are non-governmental efforts to promote ZNE. Combined, these initiatives have created an environment supporting the early development of ZNE buildings.

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[3] ZNE capable implies a high level of efficiency such that the introduction of renewable sources (or incremental addition of renewable sources) would allow the building to achieve true ZNE status.

[4] All new federal buildings must be carbon-neutral by 2030.

[5] http://www.affordablecomfort.org/content/1000-home-challenge-0

[6] http://architecture2030.org/

3.1 Statewide ZNE Influences

California has long led efforts for policy development and implementation related to energy efficiency and renewable energy. With its favorable climate, broad economic base, progressive policies, and strong technology sectors, the state is well-suited to pursue aggressive goals for development of high-efficiency buildings. Moreover, state agencies see energy efficiency as a vital component supporting continued state economic growth while also addressing air quality and other environmental concerns. Since 2000, the state has enacted a series of laws and policy measures to reduce energy consumption and promote cleaner generation technologies, which can in turn improve air quality by reducing greenhouse gas emissions and airborne particulate matter.

3.1.1 AB 32 and Other Legislation

California State Assembly Bill 32 (AB32), the *Global Warming Solutions Act of 2006*, was signed by Governor Schwarzenegger on September, 27, 2006. The legislation set forth a "comprehensive program of regulatory and market mechanisms to achieve real, quantifiable, cost-effective reductions of greenhouse gases", with oversight provided by the California Air Resources Board (CARB). CARB subsequently developed an AB32 "Draft Scoping Plan," which detailed a mix of market-based mechanisms (cap-and-trade), monetary incentives, and regulatory measures (GHG vehicle emissions reductions for cars and trucks and new building energy efficiency standards). The law called for a phased-in implementation period between 2007 and 2012, with all GHG rules taking effect by January, 1, 2012. Among other provisions, the CARB Scoping Plan for AB 32 established a target for statewide energy savings target of "at least 32,000 gigawatt hours and 800 million therms from business as usual projections for 2020" (CARB 2008).

3.1.2 CPUC Big Bold Initiative

Achieving the GHG emissions reduction targets of AB 32 required state agencies to consider new regulations for the building sector. In response, the California Public Utilities Commission adopted the "Big Bold Energy Efficiency Strategies" (BBEES), also known as the Big Bold Initiative, to establish clear goals for California buildings over the next several decades. The Plan noted four key goals:

1. All new residential buildings in California will be zero net energy by 2020;
2. All new commercial buildings will be zero net energy by 2030;
3. Heating, ventilation, and air conditioning (HVAC) will be transformed to ensure that its energy performance is optimal for California's climate; and
4. All eligible low-income customers will be given the opportunity to participate in the low income energy efficiency program by 2020. California maintains a targeted program for low-income residents entitled the Low Income Energy Efficiency program, which provides no-cost energy efficiency and appliance testing, as well as repair measures, to low income residents.

Through this strategy, CPUC seeks to significantly improve building technologies and design approaches in order to meet greenhouse gas (GHG) reductions mandated through California legislation (see Section 3.1.1)

3.1.3 Title 24 Building Standards

Building energy efficiency standards play a key role in driving efficiency in new and retrofitted buildings. The California Energy Commission (CEC) is proceeding on an incremental path to achieve ZNE residential buildings by 2020 and ZNE commercial buildings by 2030. The recently adopted 2013 Title 24 Standards are estimated to reduce residential energy consumption, expressed in terms of *time dependent valuation* (TDV) energy (California Energy Commission 2002), by 25% and 30% for residential and commercial buildings, as compared to the current 2008 Title 24 Standards[7]. In addition, for the first time, the Title 24 Standards will be offering a credit for photovoltaic systems in certain climate zones, when the Standards take effect in January 2014. This approach will likely increase PV saturation in new homes, as builders value PV for various reasons including buyer recognition and consistent performance.

4 Literature Review

A literature review was conducted to identify existing research and documentation regarding ZNE design methodologies, performance results (both modeled and monitored), and costs for residential, commercial, and community scale projects. Notably, this arena is changing rapidly as the industry is transforming from initial demonstration and "statement" projects to more mainstream ZNE buildings.

4.1 Methodology

A literature review and series of interviews were conducted in order to research the question of cost-effectiveness for ZNE in the current marketplace. The literature review identified prior peer-reviewed and gray literature, as well as potential building case studies. The unique construct of the term zero net energy and its associated terms simplified identification of literature. Searches were conducted in *Google* and *Google Scholar* using the following terms:

- Zero Net Energy;
- Zero Energy;
- Zero Energy Buildings;
- Net Zero Energy;
- Near-Zero Net Energy;
- ZNE + Cost;
- Zero Net Energy + Cost;
- Integrated Design.

Subsequently, the research team used PG&E and their own network of contacts to identify key contacts for existing ZNE projects. Interviewees were asked for additional persons or literature relevant to ZNE buildings. A snowball survey approach, which is used to successively identify new sources through existing contacts and literature, was utilized to identify the extent of literature. The full list of interviewees is included in the acknowledgements section. A literature review summary completed as part of an interim project deliverable,can be found in Appendix B, with key findings integrated into this report.

4.2 Definitions of ZNE

As efforts move forward in promoting and documenting ZNE projects, there still remains the fundamental question of how to precisely define zero net energy. The primary variable amongst various definitions is the boundary conditions for measuring energy, including "site" energy, "source" energy, or other source energy definitions. For example, should source energy be based on a fixed ratio of Btu's to kilowatt hours that accounts for plant efficiency, transmission and distribution losses, and the mix of generation, as used in the Title 24 Standards prior to 2005? Alternatively, should a time dependent valuation (TDV) definition that

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[7] Improvement documented in terms of TDV reduction vs. 2008 Standards
http://www.energy.ca.gov/releases/2012_releases/2012-05-31_energy_commission_approves_more_efficient_buildings_nr.html

incorporates time of use impacts and other broader environmental or societal impacts, provide the framework for evaluating ZNE?

Even as the CPUC continues to clarify exact criteria for zero net energy, entities in academia, industry, and government are researching various definitions for characterizing a ZNE building. The following proposed definitions capture a broad range of these discussions related to defining ZNE. The National Renewable Energy Laboratory (NREL) developed the following four definitions that can be used to characterize ZNE building performance (Toricellini, Pless, and Crawley 2006):

1) Net-zero Site Energy: Building produces as much energy as it uses in a year when evaluated at the site level. For an all-electric building this approach is straightforward, but the addition of natural gas or propane at the site complicates the issue. A site ZNE definition is biased towards kWh, since the approach doesn't recognize the energy consumed at the power plant.

2) Net-zero Source Energy: Building produces as much energy as it uses on an annual source energy basis. Source energy refers to primary energy used to generate and deliver energy to the site. The source value of electricity is about 3-3.5 times the site value to account for generation, transmission, and distribution impacts. Electricity generated on site by PV systems uses the same source factor because each kWh generated by PV offsets the need for a kWh from the grid.

3) Net-zero Energy Cost: A customer's net energy use cost on an annual basis is less than or equal to zero. Because net metering customers are credited for the full retail value of the electricity generated on site, net-zero electricity and net-zero cost would be the same for customers on a standard residential electricity rate. Customers on a time-of-use utility rate may be able to be net zero energy cost, while consuming more electricity than they generate.

4) Net-zero Energy (Carbon) Emissions: The net zero emissions criteria accounts for the mix of electricity sources provided by the local utility. On-site renewable generation would only need to offset the emissions associated with the building's grid consumed energy. Hydroelectric and nuclear energy are considered emissions free.

Two alternative definitions have also been presented:

5) Net-zero Electric Energy: In all electric homes, this definition is the same as net-zero site energy, but where natural gas is used on site, the renewable energy system is sized to offset only the electrical energy use. While this is not a true zero energy condition, we are including it here because there is currently no means for net metering customers to offset and be reimbursed for their natural gas energy use with excess electricity generation.

6) Net-zero TDV (or "societal value"): The California Energy Commission (CEC) has defined a time-dependent valuation (TDV) methodology to reflect source energy, peak demand impacts, and other externalities, as a means to demonstrate Title-24 code compliance. Each hourly predicted gas and electrical energy use is multiplied by a TDV factor that represents the "societal cost" of energy for that hour. The CEC is considering using a TDV evaluation approach for definition of ZNE. Gas TDV values are fairly flat throughout the year, but summer peak electrical energy use has much higher TDV valuation than energy consumed during off-peak periods.

Each of these definitions has advantages and disadvantages. A summary of the key pros and cons are presented in Table 1.

Table 1: Comparison of Various ZNE Definitions

Definition	Advantage	Disadvantage
Site	Simple to understand, implement, and verify; best suited for all-electric	Ignores kWh generation, transmission, and distribution effects; Requires more PV than "source" approach for buildings with gas space/water heating (i.e. most of California)
Source	Better approach to fully account for primary energy associated with different "fuel" types	Applies "average" source conversion factor, undervaluing peak impacts; varies by utility and region
Energy Cost	Easy to measure and verify with utility bills; Under time of use (TOU) rates, will likely result in smaller renewable system than site method.	Not true ZNE; depending on rate structure, may be less stringent than other approaches; varies by utility and rate; natural gas use (cost) more challenging to offset since gas is relatively inexpensive compared to electricity.
Emissions	Accounts for GHG emissions related to energy supplied to building; credits low GHG electrical generation	Approach may not encourage efficiency in some cases; encourages large hydro and nuclear, which have other environmental impacts
Electric	Simple; allows for near-ZNE strategy, while avoiding natural gas complication	Not true ZNE approach
TDV ("societal")	Better reflects seasonal and peak kW impacts, as well as other externalities	California-specific; difficult for others outside the state to understand and implement

In addition to these categorizations of zero net energy, NREL developed a classification system for Net Zero Energy Buildings based on renewable energy sources and building uses. The classification system uses letters (A-D) to characterize energy use in order to encourage owners of ZNE buildings to use "all possible cost-effective energy efficiency strategies, and then use renewable sources and technologies that are located on the building and at the site" (Pless and Torcellini 2010). The classification scheme is detailed in Table 2.

Table 2: NREL Classification Scheme for Buildings Based on Energy Supply

Classification	Definition
NZEB: A	Buildings that generate and use energy through a combination of energy efficiency and renewable energy sources collected within the building footprint.
NZEB: B	Buildings that generate and use energy through a combination of energy efficiency, renewable energy generated within the footprint, and renewable energy generated within the site.
NZEB: C	Buildings that use NZEB:A and NZEB:B renewable energy strategies to the maximum extent possible. They also use off-site renewable sources that are brought on-site to produce energy.
NZEB: D	Buildings that use a combination of strategies from the other three classifications, and may also purchase energy from off-site renewable sources.

4.3 Relevant Research on ZNE Buildings

Over the past four decades, interest in building energy efficiency has shifted in response to local and international events and changing government policies. In the 1970's, experimental home designs utilized passive solar and increased envelope insulation were prompted by the oil embargo and spiking energy prices. By the 1990's, Greenhouse Gas concerns, tightening energy standards (predominantly in California), and advancements in building efficiency technologies led to renewed efforts to develop high performance buildings. In the early 1990's PG&E's Advanced Customer Technology Test (ACT^2) project[8] advanced the state of the art in developing methods for optimizing the selection of energy efficiency measures for residential and commercial buildings. At the beginning of the millennium the Department of Energy's Zero Energy Homes and Building America programs supported the development of near zero net energy (ZNE) production homes and communities. Decreasing costs of PV systems coupled with New Solar Home Program and California Solar Initiative incentives spurred the growth of the PV industry and residential and commercial installations. In addition to its research programs, the U.S. Department of Energy (DOE) continues to promote activities such as the Solar Decathlon to generate interest in the education sectors. The competition has also brought together teams of university students together since 2002 to develop, build, and operate innovative designs for solar homes. In the 2011 competition, seven out of nineteen teams achieved solar homes designs with measured zero-energy (or better) performance (U.S. Department of Energy 2012).

<u>KB Homes and the California 2020 Target</u>

As the state moves towards the 2020 ZNE residential target, builders are starting to pay increasing attention to the implications of the mandate. For instance, Jacob Atalla of KB Homes indicated that his company took the state's 2020 ZNE goal to heart and has started to explore ZNE design strategies, implementation issues, expected costs, and customer satisfaction in advance of the 2020 target. To date, KB Homes has built eight ZeroHouse2.0 ZNE homes throughout the U.S., including one in southern California. According to Mr. Atalla, all eight of these homes show a positive homeowner cash flow (monthly utility bill savings greater than added mortgage costs). These early projects allow KB to gain experience with ZNE implementation and also assess supplier capabilities, marketing issues, and cost implications.

Recent interest in ZNE projects has been driven by a number of factors, including the CPUC's Big Bold Energy Efficiency Strategies, AB 32, high energy costs, increasing buyer and building owner awareness of environmental issues, California energy efficiency standards, and financial incentives. The growing Passive House movement has also had an impact. In the past five years, a collection of commercial projects have achieved documented zero-energy or near zero-energy status with incremental costs for common buildings types ranging from 3.0-18.0% (New Buildings Institute 2012). These more recent, better documented, projects benefit from new and more efficient building technologies and practices, and falling PV prices. Advanced design techniques such as daylighting and passive cooling are being combined with lower cost photovoltaic (PV) installations and improved energy modeling tools to make ZNE buildings more achievable. Building owners,

<u>NREL Research Support Facility</u>

One of the flagship ZNE projects in the U.S. is the National Renewable Energy Laboratories (NREL) Research Support Facility (RSF). The 222,000 ft^2 RSF building, which was completed in 2010, utilized a unique design-build process with a specific building Energy Use Intensity (EUI) target incorporated into the contractual agreement. Based on the demonstrated success of the project, NREL is working on a "how to" guide for DOE and other Federal agencies for potential broader implementation of the procedures demonstrated. DOE, GSA, and the Army Corps of Engineers are also exploring this approach to see how it can be replicated.

[8] http://www.pge.com/mybusiness/edusafety/training/pec/inforesource/act2proj.shtml

designers and construction industry stakeholders are beginning to explore integrated design techniques, gain familiarity with advanced strategies, and develop contracting models that contractually specify strict energy targets for the building to demonstrate. The current collection of ZNE case studies includes buildings across many sectors: residential homes, non-profit headquarters, municipal buildings, schools and university buildings, and a few private commercial buildings.

Energy goals and design tradeoffs are integral to the planning processes for ZNE buildings. The building design process presents many opportunities for tradeoffs in building form, efficiency, comfort, and aesthetics. With limited budgets and a focus on cost-optimized solutions, these multiple goals must be balanced in order to achieve maximum energy performance, maintain comfort and safety, and incorporate an appropriate level of amenities. Some industry leaders tout the integrated design process as a critical tool for balancing tradeoffs. A life cycle cost perspective, which combines both first and replacement costs for materials, systems, equipment; maintenance impacts, and future avoided energy savings, is a critical component of the integrated design process in order to better convey to building owners the true expected costs to build, operate, and maintain the building. This paradigm shift may well represent a major challenge to the construction industry with its historical focus on first costs.

4.4 Benefits and Tradeoffs of ZNE Buildings

ZNE buildings offer many potential benefits for building owners and occupants. First, building owners generate long-term savings by reducing life cycle costs for energy consumption and maintenance. Second, building occupants benefit from healthier and more comfortable indoor environments through improved air quality and more stable internal temperatures. Third, improved indoor environmental conditions may increase occupant productivity, which can benefit companies and organizations that invest in ZNE buildings (Fisk 2000).

Efforts have been made to quantify these benefits, with some studies suggesting that for office buildings, the economic benefit of higher productivity may be many terms greater than the value of energy savings. Several studies have documented the added value of energy efficient, “green” buildings. A 2010 study of 10,000 subject and control buildings found that “green rated” buildings were found to command a 3% higher rental rates than comparable adjacent control buildings[9] (Eichholtz, Kok, and Quigley 2009). In the residential sector, Kok and Kahn (2012) studied a sample of over 1.6 million California real estate transactions from 2007 to 2012 including 4,300+ homes certified under Energy Star Version 2, GreenPoint Rated, or LEED for Homes. They found that energy efficient homes garnered a nine percent premium upon resale with greater market perceived incremental “value” in climate regions where energy use is higher[10]. Similarly, a study from Lawrence Berkeley National Laboratory found that for a dataset of California homes with PV that sold between 2000 and 2009, the incremental sales price for the PV-equipped homes was about $5.50 higher per installed Watt (DC) when compared to similar homes without PV. This incremental resale amount was equal to the additional costs of PV installation associated with the home (Hoen et al. 2011), suggesting that photovoltaic installations are highly valued by residential homebuyers. PV panels may be more valued than energy efficiency measures because they are more visible and may be viewed as a commodity, whereas energy efficiency measures are integrated into the design and often invisible to the homeowner (Dastrup et al. 2012).

While the green building industry seeks to better quantify and document these benefits, tradeoffs between energy efficiency, amenities, and size are essential considerations in ZNE buildings. Many industry professionals interviewed for this study noted that ZNE-capable commercial buildings can be completed at little or no incremental cost (excluding the cost of PV) compared to standard buildings in the current market, if energy performance is clearly defined and becomes a focal point for the design process. The design process,

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[9] When factoring in building occupancy levels, the green buildings were found to provide an effective 7% premium

[10] Energy efficient homes were those labeled as Energy Star, LEED for Homes-certified, and GreenPoint Rated

which ideally involves building owners, architects, engineers, construction managers, and potential occupants, is the most useful tool in asserting this prioritization and the associated tradeoffs.

With current practices and technologies, ZNE approaches are limited by physics. Many ZNE commercial buildings utilize daylighting to effectively distribute natural light, significantly reducing annual lighting energy use. Since commercial buildings in many climates are cooling dominated, daylighting also contributes to cooling system downsizing and lower cooling energy use due to reduced internal gains. Daylighting requirements limit the potential building width if the goal is to provide ample work lighting for all occupants. Similarly, the ratio of building height (number of stories) to footprint area is often constrained by the need to produce enough electricity through rooftop PV panels, posing a problem for many urban projects. Many ZNE buildings with planned rooftop PV installations are therefore not able to be taller than four stories. Doug Norwood, technical manager for the Sacramento Municipal Utility District's (SMUD) East Campus Project, noted how the project's ZNE design goals were constrained by county approval of building plans prior to their decision to pursue a ZNE design. The original six-story building design was approved before the full bid-build process was completed, meaning that bidding teams were working with a prior challenging constraint. Basic characteristics of size and space may continue to constrain location or physical aspects of ZNE or near-ZNE buildings.

For buildings to meet ZNE design goals once they are completed and occupied, extensive monitoring is often necessary, especially for pioneering projects where technologies and design synergies are being explored. By evaluating building performance during initial occupancy, building managers can assess the performance against established goals and identify additional commissioning needs. The processes and tools for evaluation, however, are often underfunded or overlooked all together. Several projects surveyed as part of this study have managed to implement rigorous energy use monitoring programs that provide insights into performance for comparison to initial design goals. For instance, Philippe Cohen, the director of the Leslie Shao-ming Sun Field Station in Stanford University's Jasper Ridge Biological Preserve, described how the building was designed to meet aggressive zero-energy goals that reduced operational costs and provide more money for program activities. The building was completed in 2002 at "per ft^2" costs equivalent to other Stanford educational buildings built in the same time period. A strong monitoring program for energy use was instituted at the time of commissioning and continues today. Recent data from the Field Station indicates that the building has achieved about 85% of the initial zero-energy goals. Building managers analyzed available data and found that greater than anticipated occupancy during evening hours, as well as increased loads from electric vehicles, were the likely causes for greater than-predicted electricity use. The building managers used this monitoring data to assess future goals and are planning to implement operational changes in the coming year. Thus, evaluation and monitoring can lead to future modifications, which is an effective loop for not only achieving but maintaining ZNE building performance.

<u>Leslie Shao-ming Field Station</u> (Stanford University, Jasper Ridge Biological Preserve)

The Leslie Shao-ming Field Station is located in a nature preserve. The motivation for seeking a ZNE-capable building, as described by director Philippe Cohen, was to reduce operational costs in order to maximize funding for programs. The building was completed under budget and with cost parity to other similar Stanford buildings. Several design approaches contributed to this achievement, including: developing a design that considered programming uses; a value-engineering approach that identified building features to be removed due to cost overruns; and use of locally-sourced materials. Total costs were $249/$ft^2$. The building has been consistently monitored for eight years, and is achieving near ZNE performance. The experience of the Administrative Director highlights the importance of continuity in the design and operation team, as well as the need for continued data collection to monitor building performance.

The question of funding energy efficiency or renewable energy measures can be challenging, especially for residential buildings. For example, if energy efficiency measures and PV installations for a home cost $50,000 more than comparable baseline construction, homeowners must identify a financing strategy for these costs.

In areas of the country with expensive real estate, including many coastal urban areas, these incremental costs do not significantly affect mortgage costs and homeowners may be willing to undertake initial financial burden to achieve long-term energy savings and improved comfort. In less-expensive areas, however, these additional measures would constitute a much larger percentage price increase and could therefore be adversely impacted by the appraisal process. These effects could deter both homeowners and lending organizations to invest in the property. The relative cost of ZNE measures in relation to the property value is an important consideration. Currently the SAVE Act[11] is currently on the floor of the U.S. Congress to help address the appraisal issue. The legislation would require that energy costs be included in the underwriting process for federally financed single-family mortgages.

4.5 Market Activity for ZNE Buildings: Past and Present

Passive solar heated buildings, which were an early precursor to the ZNE concept, have existed in current conception since the early 1940's (Parker 2009). Techniques for building highly-insulated homes increased in the 1970's as the Oil Crisis spurred interest in energy efficiency, off-grid living, and sustainability. Passive solar and highly-insulated building concepts developed a niche following, ultimately leading to the *PassivHaus* movement.[12] However, architectural and comfort concerns, especially summer overheating, as well as relatively flat natural gas and electricity prices, has limited the influence of passive design approaches. In the early 1990's, commercial introduction of photovoltaic systems allowed for demonstration of early ZNE (or ZNE-capable) research homes. Early successful projects included the Lakeland, Florida PVRES home, a modular home in Washington, D.C. (the Solar Patriot), a Livermore, California production home, and five Habitat for Humanity homes in Lenoir city, Tennessee (Parker 2009). These projects captured interest and increased visibility for ZNE approaches.

David Kaneda of Integral Group (a leading design firm specializing in high performance buildings) noted that over the course of the past decade, general market interest in ZNE buildings has grown progressively to include individual champions, architects and engineers, potential clients such as K-12 schools and non-profits, and most recently the first private-sector developers. The interest is driven by social and technological changes that emphasize the importance of, and opportunities for, very efficient buildings. In addition, more guidance is available regarding effective building practices, such as the Advanced Energy Design Guide (AEDG) series of publications (also known as the "50% Guides") available for office buildings K-12 schools, and hospitals (ASHRAE 2011a, 2011b, 2011c, 2012)[13]. The non-profit Architecture 2030 has called for carbon-neutral buildings by 2030, which is defined as buildings that use no fossil fuels or greenhouse-gas-emitting energy sources in operation. The organization advocates a phased approach, reducing building fossil fuel energy consumption by 10% every five years through 2030 (Architecture 2030 2011). Even with such resources and interest, ZNE projects need a champion who provides vision and pushes ZNE goals through the difficult interim decision processes that characterize design and construction. Important for the project developer is how the high performance home or building is valued by the marketplace. Some industry participants interviewed for the project noted that after completing the process of developing a ZNE building or development, they did not believe the associated costs and delays were justified by increased sales or marketing potential from the projects. Nolan Zail, project manager for the West Village ZNE community development in Davis, CA, conveyed that their perception of the student renters of the multi-family

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[11] http://www.imt.org/resources/detail/the-save-act-driving-job-creation-and-consumer-energy-savings

[12] http://www.passivehouse-international.org/index.php

[13] A collaborative effort between the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), the American Institute of Architects (AIA), the Illuminating Engineering Society of America (IES), the U.S. Green Building Council (USGBC), and DOE, the guides detail technical and design approaches to consume 50% less energy than conventional buildings.

apartments indicated awareness of the project's ZNE goal, but not that it was a compelling part of the rental decision.

In recent years, more examples of commercial ZNE (or near-ZNE) buildings have appeared in the U.S. market. The New Buildings Institute (2012) recently compiled a list of U.S. ZNE projects in the United States and found 21 buildings with either monitored or credibly-modeled ZNE status. These projects have completion dates from 2000 to 2010, and range in size from 1,530 ft^2 to 222,000 ft^2. NREL considers "highly energy efficient" buildings as those in the 25 to 30 $kBtu/ft^2$ range as a practical maximum for most ZNE applications. Of reported projects, NREL's new 222,000 ft^2 Research Support Facility, which was completed in 2010, is often seen as one of the most effective for instituting strict design targets to deliver ZNE at cost parity.[14]

Several interview participants noted that school buildings are prime candidates for achieving ZNE goals of less than 35 $kBtu/ft^2$-yr[15]. Schools typically have very predictable load schedules and construction is easily repeatable. The funding constraints for school building construction are often given per square foot as mandated by municipal or district expenditure codes. Several ZNE projects in various climates have been able to design school buildings at or below the state acceptable cost levels. In addition, the opportunity to use proven technologies can lessen the need for intricate modeling. Tony Hans of CMTA Engineers in Louisville, Kentucky notes that utilizing proven technologies and recognizing synergies is one of the key components in the delivery of new ZNE schools at costs equal to that of the state-mandated construction costs. For example, CMTA commonly specifies ground source heat pump systems for their high level of performance, reliability, and elimination of vandalism risk. In climates where the cooling load dictates the ground loop sizing, improved lighting systems, and reductions in computer and plug loads contribute to loop downsizing, which reduces costs. This can be further magnified by water heating with the system, which will reduce the summer heat rejection to the ground loop, further reducing loop costs.

Designing ZNE K-12 Schools

School buildings present a unique opportunity to improve market penetration of ZNE buildings, since they are often similar in design and occupancy schedule. Tony Hans of CMTA Engineers notes that this presents opportunities to utilize commercially-available strategies to achieve synergies in the design process. In an interview, Hans noted that CMTA commonly specifies ground source heat pump systems for their high level of performance, reliability, and elimination of vandalism risk. In climates where the cooling load dictates the ground loop sizing, improved lighting systems, and reductions in computer and plug loads contribute to loop downsizing, which reduces costs. This can be magnified by adding water heating functionality to the system, further reducing the summer heat rejection to the ground loop, and the resulting ground loop costs.

The evolution of the ZNE concept has led to community scale projects that integrate these approaches into an overall comprehensive project development philosophy, with both residential and commercial buildings. To date, a limited number of projects of this type are in the process of being completed, verified, and documented in detail. Recent examples in various stages of completion include the 1.5 million ft^2 University of California at Davis West Village development[16], the residential Kaipuni Village in Hawaii, and the Lafayette, Colorado 153-unit low income housing development. Construction on the West Village project began in late 2010 and, upon complete build out, will provide housing for over 3,000 people[17] and include

[14] Detailed information and published reports can be found at http://www.nrel.gov/sustainable_nrel/rsf.html

[15] The NBI 2012 report entitled "Getting to Zero 2012 Status Update: A First Look at the Costs and Features of Zero Energy Commercial Buildings" identifies 35 $kBtu/ft^2$-year as an approximate energy use upper limit for most ZNE-capable buildings.

[16] http://westvillage.ucdavis.edu/

[17] The project will include 662 student apartments and 343 single family homes for faculty and staff

42,500 ft^2 of commercial space. The student housing and mixed use portion of the project will be built out by 2013, although the single family construction will likely continue through 2018.

4.6 Design Approaches for Achieving Cost-Effective ZNE Goals

Building design is an essential component for any building process, but it is a critical component in achieving cost-effective ZNE goals. A variety of design strategies were detailed by industry leaders surveyed through the project. Key components of effective ZNE design strategies include:

- Promoting a focus on building architecture and design by contractually specifying an EUI target;
- Promoting design team collaborations throughout the project;
- Implementing climate-specific EEMs optimized for the application; and
- Implementing integrated design strategies which maximize energy and cost saving synergies.

Research through interviews and literature noted the importance of utilizing these strategies as part of an overall design approach.

4.6.1 Developing Energy Targets

Most interviewees noted the importance of setting clear and appropriate energy use targets for the building. These targets were often developed after rigorous pre-design modeling provided direction as to the expected building performance under a range of scenarios. Once established, the EUI targets served as a design goal through which building design and EEM selection could be prioritized. Many of the projects codified these goals as part of the subsequent RFP or bid process. Jim Dent of the Weifield Group, who was the electrical contractor for the NREL RSF project, noted that the process of including energy consumption targets in the proposal and contracting process "refocuses your thought process on energy", allowing the team to quickly focus on optimal design solutions that met the project energy performance and cost parameters. Normal design approaches involve iterations on solutions, cost effectiveness justifications involving all project participants, and value engineering efforts. Mr. Dent estimates that these inefficiencies can eat up several percent of their typical budget on a project such as the RSF.

ZNE Strategies: Energy Targets and Fully-Integrated Design

Successful ZNE projects often incorporate innovative strategies. For instance, in building its Research Support Facility, NREL developed clear energy consumption goals for the building and incorporated them as contractual requirements. The performance-driven design approach, although uncommon for most commercial projects, was highly effective in generating a design that could meet the project energy goal.

Highly integrated design strategies also helped to improve energy efficiency. Early in the design process, NREL and the design team brought a furniture design consultant into the design process. Their input allowed the office cubicles to be reduced from 100 ft^2 to 82 ft^2, while maintaining occupant satisfaction through improved daylighting and office configuration. (Shanti Pless personal communication, 2012)

4.6.2 Energy Efficiency vs. Renewable Generation

Reducing building load through efficiency measures is the first step in a ZNE design. Many commonly employed practices contribute to significant reductions in building energy use, including:

1. Architectural design to optimize the building envelope, glazing configuration, and daylighting availability,
2. Efficient building and system components,
3. Optimization of plug and computer loads, and

4. Diagnostic and quality assurance procedures to verify performance.

Assembling a core team of designers (mechanical and electrical), estimators, and the building owner and instituting procedures to make collaborative decisions throughout the design process is widely recognized as a successful tool to develop a project vision and focus on the defined project energy goal. Historically, high PV costs made an "efficiency first" approach the cost-effective strategy to achieve ZNE or near-ZNE status. Despite this, many early projects used oversized PV and solar thermal water heating systems as the primary mechanism to demonstrate ZNE status (Parker 2009). The advent of improved modeling tools in recent years has led to improved techniques for optimizing the balance point between EEMs and PV installations (Horowitz, Christensen, and Anderson 2008). Model projections, however, must still be reconciled with actual performance through monitoring and analysis.

Increasing PV system sizing may make increasingly more economic sense[18], as PV prices continue to fall. From 1998 to 2010, average installed costs (in real 2010 dollars) fell from $11.0/Watt to $6.8/Watt (Barbose et al. 2011), with homes participating in California new construction programs indicating slightly lower costs ($.70 lower, or $6.1/Watt). Data from the first six months of 2011 suggest an additional $.70/Watt drop in prices, with costs approaching the neighborhood of about $5/Watt. NREL projections for installed residential system costs indicate that by 2020 PV prices may fall another 60%, with three-quarter of the projected cost savings associated with reduced module prices, improved module efficiencies, and installation labor savings (Goodrich, James, and Woodhouse 2012).

To get a handle on residential PV costs on a typical California home, an analysis was completed for an all-electric[19] ZNE home in Sacramento to develop a ballpark estimate of the "per ft^2" costs for an occupant-owned PV system. Based on performance information generated in PG&E's companion ZNE project (Assessment of Technical Potential for Achieving ZNE Buildings in the Commercial and Residential Sectors), a 2,100 ft^2 ZNE home is projected to use 7,300 kWh per year (see Appendix C for details). With a representative Sacramento PV generation of 1,399 kWh/kWdc installed[20], a 5.2 kWdc system would satisfy the energy needs for the building. At a $4.50/Watt cost, this equates to a cost of about $8 - 10/ft^2 (of house floor area) for the all-electric ZNE. (Buildings with more common gas appliances and alternative ZNE definitions will have higher PV costs.)

KB Homes has built eight ZeroHouse 2.0 demonstration ZNE homes in various markets throughout the U.S. including Orlando, FL, Austin, TX, Washington, D.C., Denver, CO, and Lake Forest, CA. The ZeroHouse ZNE package includes fairly conventional efficiency upgrades, which are applicable to any floor plan[21], supplemented by a conservatively sized ~ 6.75 kW PV system for 2,000-2,600 ft^2 ZNE homes (and a 9 kW PV system for a 4,000 ft^2 model).

Even with falling PV costs, reducing loads through efficiency is still an important part of achieving ZNE. In the early to mid-90's, PG&E sponsored the Advanced Customer Technology Test (ACT^2), a rigorous engineering experiment which tested the limits of integrated design processes on a handful of residential and commercial buildings (PG&E 2012). The process of sequential analysis was developed in ACT^2 to assess the EEM loading order, recognizing that as each cost effective measure is added, the resulting savings of subsequent measures is likely diminished. At the time, the sequential analysis process was handled manually, but software development work at the National Renewable Energy Laboratory (NREL) led to the

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[18] Especially in residential situations where the homeowner has such a profound impact on energy usage

[19] An all-electric case was used to avoid added complications with converting gas use to site, source, or TDV energy.

[20] http://rredc.nrel.gov/solar/calculators/pvwatts/version1/US/California/Sacramento.html

[21] For southern California, outside of the use of solar thermal water heating, upgrade features include fairly conventional measures such as improved insulation, attic radiant barrier, high efficiency heat pumps, high performance windows, and HERS inspections for insulation quality, envelope leakage, and duct leakage.

development of the BEopt building simulation tool[22], which automatically develops packages of EEMs depending upon the efficiency targets of a project. This type of analysis is especially useful for evaluating ZNE designs. At some point in the design of a ZNE home, adding PV generation becomes cheaper than additional EEMs. The BEopt tool, widely used for documenting ZNE and high efficiency residential designs within DOE's Building America program, utilizes the DOE2.2 or EnergyPlus engine for simulating house performance. Such tools allow designers to balance energy efficiency and generation for overall cost-effectiveness, and accommodate changing prices for EEMs and PV. Detailed energy modeling is increasingly needed to recognize the changing price points, especially as ZNE activities move towards larger and more complex building types (Bazilian et al. 2012; Gao 2011).

4.6.3 Reducing Building Loads

Modeling and quantifying and building thermal loads is crucial for successful ZNE designs. For most building types, key elements can be evaluated with advanced building simulation models to identify and compare strategies, including orientation, configuration (i.e. aspect ratio, footprint), window area and location (daylighting), and climate. Often, significant energy savings can result from effective planning in the schematic design stage, with neutral or lower costs compared to conventional practice. Examples include elimination or downsizing of air conditioning systems leading to smaller air delivery systems, radiant delivery, displacement ventilation, heat recovery systems, and reductions in building perimeter (and associated wall area). This ability to shift construction dollars from HVAC equipment (via downsizing) to architectural or EEM costs is likely a bigger factor in commercial buildings where sizable capacity reductions can be implemented through efficiency improvements[23]. This type of integrated approach was clearly identified in PG&E's ACT[2] process, but a key factor in its success depends on design team integration and close coordination with the owner and the construction team. Many of the ZNE buildings surveyed identified daylighting and natural ventilation as cost-effective building strategies, with the latter especially well-suited for the moderate climate areas in California.

David Kaneda of the Integral Group noted that reduction of plug loads is an increasingly important issue for ZNE design in both residential and office buildings. In residential buildings, miscellaneous end uses utilize a large percentage of electricity usage, especially as efficiency measures have reduced total household consumption. In commercial buildings, the plug loads are often a smaller overall component, but significant savings opportunities still exist through motion-detected power switches, efficient data centers, and reduced standby energy. Technological solutions to reduce building miscellaneous electricity consumption are likely to become more cost effective as ZNE designs progress and gain a greater market presence.

Berkeley West Branch Library

The West Branch Library is one of four new Berkeley libraries that are in process of being built. Design activities began in 2008, with the passage of a public bond measure. From the outset, it was designed to be a ZNE building. The project director, Edward Dean, convinced the city that ZNE could be achieved at no additional cost. Pre-design modeling influenced the orientation and roof details to maximize PV generation. Daylighting, natural ventilation, and a solar pre-heating of incoming air were used to reduce building loads. The integrated design process with architects and engineers resulted in a bid request at $5.5 million, which was met by the winning bidder. This cost is equivalent to the other branches, of which one was a similar situation of a full tear-down and construction.

Edward Dean, the project director for the new Berkeley West Branch library, noted that in designing the library building, orienting and sizing the PV panels appropriately was critical to achieving ZNE

[22] http://beopt.nrel.gov/

[23] In the residential environment, the perception is that to accommodate the varied homeowner comfort needs (and avoid potential litigation), HVAC equipment downsizing is far more difficult to implement.

goals at projected construction costs equivalent to other simultaneous library construction projects in Berkeley. The modeling process was emphasized as a key step in the design workflow. In contrast, the South Branch of the Berkeley library, which was designed at the same time by a different team, considered ZNE goals only after building site and orientation were decided. This prevented optimal PV sizing and detracted from the building's overall performance capabilities.

4.6.4 Contracting Processes: Design-Build vs. Design-Bid-Build

The integration of design and construction processes is a critical area where ZNE projects are at the forefront of evolving industry practices. In traditional commercial building construction, a design-bid-build procedure is most commonly used. In that process, an owner hires an architect who hires professional designers to independently develop building sub-designs, often with limited interaction among the design professionals. The developed design is then bid out, with the winning construction company generally being the low bidder. This approach may lead to project cost overruns since imperfect design documents and a more compartmentalized design philosophy contribute to change orders through the construction process. Component substitutions may occur as the installing contractor replaces one product for another (often cheaper) product that may not deliver the same level of performance as intended. In addition, a focus on documenting cost-effectiveness of alternative options often leads to trimming energy efficiency measures at advanced stages in the design or construction process as costs tend to rise. Alternatively, design-build procedures seek a process where an integrated professional team works together throughout the project. Several industry leaders interviewed from both the design and construction sectors indicated that participants in the design-bid-build process are often more adversarial and protective of current roles. More collaborative approaches that bring together participants earlier in the process, with a core focus on the ZNE goal, can help to alleviate these traditional viewpoints, but resistance to change remains throughout the industry.

In the case of the NREL Research Support Facility, the design-build RFP specified very clear design objectives for competing bidders (Pless, Torcellini, and Shelton 2011). This included project objectives broken down into three groups: "mission critical", "highly desirable", and "if possible". In addition, by contractually specifying a building overall EUI, the candidate design-build teams were expected to complete simulation studies to demonstrate that the design would meet the 25 kBtu/ft^2-year design goal. This performance-driven design approach, although uncommon for most commercial projects, was highly effective in generating a design that could meet the project energy goal.[24] NREL also implemented a "voluntary incentive program" to set aside 2% of the construction budget to serve as a contingency/incentive fund. This was an effective way for the client to maintain some level of control during the construction process by setting performance requirements to achieve incentive payments. The repeatability of such an approach remains to be seen.

4.6.5 Utilizing Integrated Design

An integrated design process reflects a methodology for designing buildings that highlights collaboration and coordination among all the key design team participants in order to create a more holistic and effective design. In typical building construction, the building owner hires an architect to develop a building design with basic form, function, and cost constraints. The architect develops plans, estimates construction costs, and contracts with engineering and technical experts to design internal building systems. In many instances, the building design may not align with the technical requirements for building systems, which can later result in operational inefficiencies and cost overruns. The design is then bid out to construction firms, who assess the building design and accordingly develop a bid focused on low cost. Alternatively, integrated design changes this linear process by engaging technical and construction experts early (and throughout) the building design and construction process. Working with well-defined energy targets and project cost constraints, a good design team can quickly hone in on optimal integrated strategies that meet the defined performance and

[24] Due to the extensive work expected from the RFP respondents, each losing bidder was paid a stipend of $200,000.

cost parameters. The electrical contractor for NREL's RSF suggests that the targeted "optimal" solution approach can save several percent of a subcontractor's budget by eliminating iterative value engineering steps as EEMs are evaluated, incorporated, and then eliminated in the cost-cutting process (personal communication with Jim Dent, 2012). Such a coordinated design process is even more important when implementing innovative EEMs, which may be unfamiliar to some participants. For instance, if a mechanical engineer is designing a non-traditional system to meet ZNE goals, then a linear process may result in a design that may not optimally integrate with the building and require the architect to re-work later in the process.

4.7 Issues of Comparability

Several studies have sought to assess the cost-competitiveness of energy efficient buildings seek in the general marketplace. For ZNE buildings, this question is more complex than it may seem. Small data sets and the value of site-specific design, which is not always scalable, make cost-effectiveness difficult to assess in a more general, aggregate form. At this point in time, there are very few non-institutional commercial ZNE buildings that allow for such a comparison. Peter Morris of Davis Langdon notes that three possible comparators can be used to determine an answer to this question:

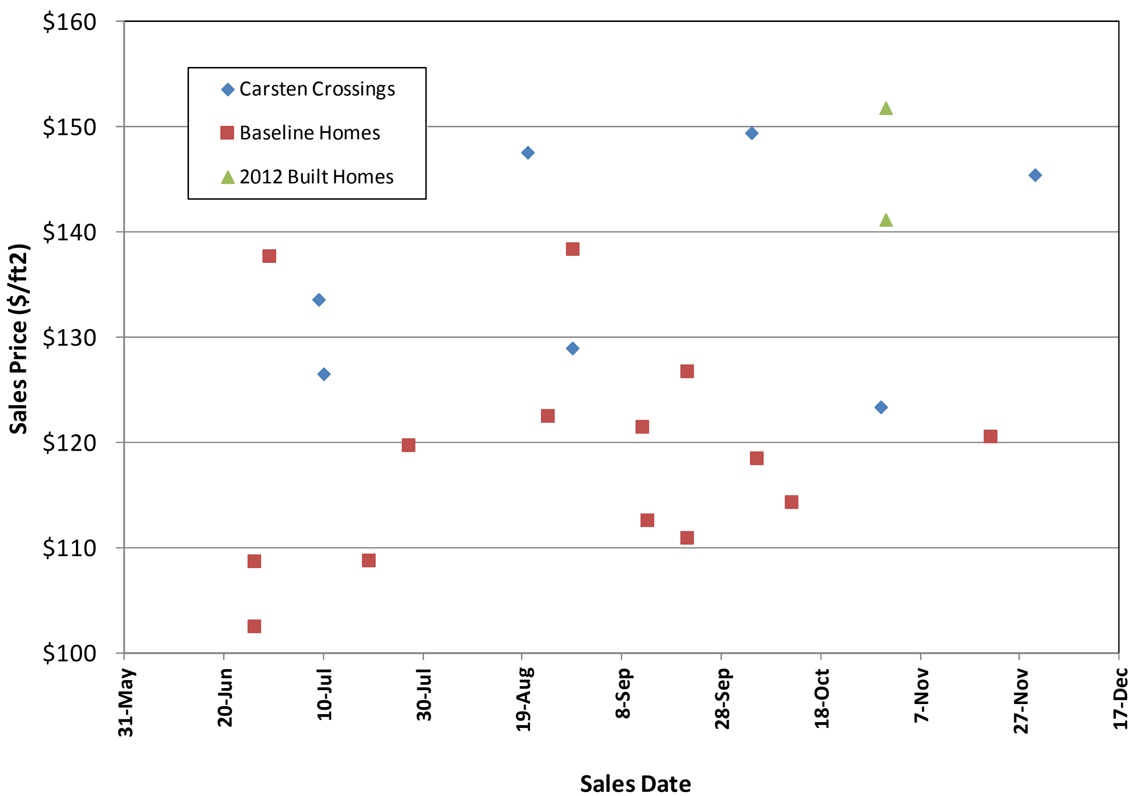
1) *Does a ZNE building cost more than a building chosen from a statistically-relevant local sample set?* For LEED-certified green buildings, no significant statistical difference was seen in building costs (Davis Langdon 2007). For ZNE buildings, a statistically-valid sample does not yet exist to identify a robust set of statistics regarding incremental costs. When comparing a particular ZNE building to a statistical sample set of other comparable, non-ZNE buildings, the comparison is difficult, but shows small or no incremental costs in many cases.
2) *Does a ZNE building cost more than a comparable building that is built to code but includes additional energy efficiency "add-ons"?* Through this scenario, incremental costs are likely to occur, as energy efficiency measures, PV installations, and other additions will generally incur additional costs over base code stipulations.
3) *Does a ZNE building cost more than a comparable building of similar size, climatic zone, and location?* This is perhaps the easiest and most relevant question to answer, and at this point the most relevant. It does require a level of specificity to understand all factors that would make things comparable, but these are often obtainable through data collection and interviews. Interviews and research completed in this study indicate that there is no consistent answer to this question, and some ZNE buildings are actually cheaper than comparable, non-ZNE buildings. The composition of any given building varies widely and the answer to this question depends on energy targets and specifics of building design.

A limited set of data is available from recent home sales at the Rocklin, California Carsten Crossings subdivision, a near-ZNE project developed from 2005 through 2007 (see case study in Appendix A). A total of 84 energy efficient and LEED-certified homes were built in the subdivision prior to the housing market crash. The homes were built to a performance level ~36% better than the 2005 Title 24 code and also included a 2.4 kW_{dc} PV system installed on every house. Through a source in the real estate community, the authors obtained MLS sales data from this neighborhood and surrounding baseline communities for the period extending from June through November 2012. A total of seven Carsten Crossings homes were sold during that period, as well as 14 baseline homes, and two brand new homes in a new subdivision. Figure 1 plots the sales price per ft^2 for all the homes sold. On average the baseline homes sold for \$121 per ft^2, the Carsten Crossings sold for \$136 per ft^2, and the two brand new homes[25] sold for \$147 per ft^2. The incremental sales price versus the baseline of about \$15 per per ft^2 matches up well with a \$5 per ft^2

[25] Energy features of these two homes include 15 SEER air conditioning, CFL lighting, EnergyStar appliances, spray foam insulation, Low-E3 windows, but no PV.

incremental resale vale for the PV (from the Lawrence Berkeley study[26]) and \$10 per ft^2 resale value for the energy efficiency and LEED certification indicated by Kok and Kahn (2012)[27]. Although this dataset is limited in size, it does offer general support to the concept of PV and energy efficiency being valued in the marketplace.

Figure 1: Comparison of Sales Price at Recent Efficient and Conventional Home Resales



5 Incremental Costs for ZNE Buildings

Incremental costs for constructing ZNE or ZNE-capable buildings have been steadily decreasing in the past decade. Many early ZNE projects sought simply to demonstrate that such projects were buildable and achievable. Visibility was often the primary goal for these early projects, with costs being less of a concern and often largely offset by incentives or research grants. Base case construction costs in many of these projects were not clearly defined, since economic comparison was not part of the project justification. Recent projects have started to have a greater focus on costs, as well as more thorough documentation of energy performance. This is a critically important step in developing the robust cast studies that will be needed to educate the broader market and begin the market transformation process.

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[26] The PV value of \$5/ft^2 is equal to 2.4 kW times \$5,500/kW divided by an average home size of 2,558 ft^2.

[27] The \$10 per ft^2 "energy efficiency" price increment equals \$25,600, or just slightly less than the Kok and Kahn observed premium of 9% (\$28,100) over the baseline price.

In 2012, NBI produced a study that compiled data on "well-documented" completed ZNE projects. Of 21 identified projects, most of which are small office buildings, NBI (2012) estimated that incremental costs (including PV) ranged from 3 to 18%. The study also reported that:

> *"Because of the limited number and atypical building types of the Zero Energy Buildings sample, the ability to extract meaningful conclusions from complete cases to date is limited. However, integrated design allowed projects to maximize energy savings among interacting systems, creating bundling measures that ultimately limited incremental costs of advanced technologies. Construction trade-offs did appear to limit total additional costs except for PV, with several reporting construction costs per square foot between 0% and 10% higher than current costs for traditional construction."*

Table 3 (residential) and 4 (commercial) provides a summary of key existing ZNE or ZNE-capable projects, including a summary of the project and the incremental costs. The data was compiled through both a review of literature and information collected through personal interviews with key project participants.

Table 3: Summary and Cost Data for Key Residential Projects

Residential Buildings					
Year Built	**Project Description/Location**	**House Floor Area ft^2**	**EEM Incremental Costs**	**PV Incremental Cost**	**Comments**
2004	Premier Homes subdivision, Sacramento, CA (95 home project); 50+% bill savings targeted, 2.2 kW PV, ZNE-capable	1,285 to 2,248	~\$7/ft^2 average including PV (not delineated separately). Average total costs of homes were \$18,836 greater than comparable homes	2.2 kW unit on each home.	ZNE-capable project with 54% less kWh use monitored during summer peak periods vs. similar nearby homes.
2010	CoreHaus, Portland, OR (PassiveHouse design)	1,407	\$5/ft^2 for EEMs	n/a	ZNE-capable; 75-90% projected savings, no PV)
2010	Sage Green, Beaverton, OR (18 single family homes, true ZNE)	1,484-1,535	\$72,650 incentives, including PV	7.5-7.8 kW	SIPS construction, triple pane glazing, heat recovery vent.
2005	Habitat for Humanity Building America home in Denver, CO (demonstrated ZNE)	1,280	21% higher than standard home (4 kW PV + solar thermal)		Sought near ZNE goal while balancing costs and design replicability. Used volunteer labor.
2002	Centex Livermore (demonstrated electric ZNE, 3.6 kW PV)	3,080	\$8.11/ft^2 gross cost for EEMs including solar thermal; costs include estimates for donated materials	\$8.70/ ft^2 Gross cost for PV; \$4.36/ft^2 net	
2002-2005	Habitat, Oak Ridge National Labs, Building America, and TVA: Five homes in Lenoir City, TN, 2.2 kW PV	1,060	\$19/ft^2 to \$27/ft^2 (total costs ranged from \$79,000 - \$88,000, with a base case of \$59,000)	\$14 - \$20/ft^2 (PV costs ranged from \$15-\$22,000 for the 4 yrs of building	Sought to show feasibility of advanced near ZNE targets in small homes.

2001	Washington, DC modular "Solar Patriot" (6 kW PV, near ZNE)	2,885	$8/ft^2	$16/ ft^2 ($46,000 total for PV and solar thermal)	Demonstrate potential for near ZNE in a mixed climate. The 6 kW PV was sized for reaching ZNE.
2003	Armory Park del Sol, Tucson, AZ (near ZNE, 4.2 kW PV, solar thermal)	1,722	$7/ft^2	~$20/ft^2 for PV and solar thermal	Designed for true ZNE in a hot climate. Actual energy production was 70% of 1st year consumption.
2006-2007	Carsten Crossings, Rocklin, CA (ZNE-capable, 2.4 kW PV).	2,168-2,755	$2.21/ft^2 for EEM's before incentives ($1.78/ft^2 after incentives)	$14,100 for 2.4 kW system	45% electric savings and 16% gas savings from utility bill analysis vs. control homes
2009	Boulder County Housing, Lafayette, CO (ZNE-capable, 2.2 kW PV, solar thermal, 3 models built)	153 homes planned, 1,000-1,800 ft^2	~$5/ft^2 for Paradigm Pilot (3 models)	$5-$9/ft^2 for PV & $2.50-$14/ft^2 for solar water heating in Paradigm Pilot and Josephine Commons project	Goal is ultra-low energy use for an affordable housing complex
2010-2017	UC Davis West Village ZNE Community, Davis CA (first community-scale ZNE project in US, ultimately housing 3,000 residents; To date, ~500 apt units complete, single family starts in 2013.	Range of floor areas	$3.87& $4.78/ft^2 for student apt and single family homes before incentives ($3.48 & $1.75/ ft^2 after incentives)	PV costs not available (owned by PPA for student apts)	Significant state and federal research funding supporting project. Showcase for public-private partnerships
2011	Super Energy Efficient Designed (SEED) House in Tucson, AZ (advanced envelope and HVAC system, 3.4 kW PV)	1,935	$16.76/ft^2 with no incentives offered for EEMs; Several advanced EEMs had high associated costs	$12.42 and $3.00/ft^2 (before & after incentives)	Through 9 months of monitoring, PV production offset 71% of total house electrical usage.
2012	Cottle House, custom Passive House in San Jose, CA (ZNE design with 5.5 kW PV)	3,170	$21.38/ft^2 before incentives, $18.30 after. Includes triple glazed windows and other high cost EEMs	$8.51/ft^2 before incentives, and $2.21/ft^2 after	Through four months of spring 2012 monitored occupancy, the house performed beyond ZNE level.

Table 4: Summary and Cost Data for Key Commercial Projects

Commercial Buildings					
Year Built	**Project Description/Location**	**Building Floor Area ft²**	**EEM Incremental Costs**	**PV Incremental Cost**	**Comments**
2013	Berkeley West Branch Library	9,400	No incremental cost compared to other current Berkeley library construction and upgrade projects. (Average cost is $585/ft²)	Estimated $26/ft²	Berkeley passed a public bond measure to build or upgrade four library branches. All built at equivalent costs, according to Project Director
2002	Stanford Leslie Shao-Ming Building (Stanford University; near ZNE	13,200	6.0% more and 5.7% less per ft² than two comparable Stanford buildings		
2007	IDeAs Z2 (San Jose, CA); measured ZNE	6,600 (major renovation)	$23/ft² (7%) incremental cost for EEMs.	$6.40/ft² (2%) cost premium for 28-kW PV system	Achieve zero energy use in a renovated building by minimizing loads and employing automatic shut-off sensors
2009	CMTA Engineering Firm Office Building (Louisville, KY)	20,000	Building constructed for $160/ft² with focus on zero incremental cost outside of 11 kW PV and CO_2 controls	$2.32/ ft² for undersized 11 kW system	ZNE-capable (PV generated ~15% of annual consumption for first year); Building EUI = 15.7 kBtu/ft²-yr.
2010	Richardsville Elementary (Bowling Green, KY); demonstrated ZNE (first ZNE school in the U.S.)	72,000	Total construction costs of $156/ft² total, but incremental costs for equivalent building not provided.	$39/ft² for 300 kW PV system	Designed to achieve very low energy use by improving on earlier high performance school designs. Project was less than KY budgeted costs for new school construction.
2010	NREL Research Support Facility, Golden, CO (office building)	360,000 ft² total, 222,000 ft² in Phase I	Total construction costs of $254/ft², but incremental costs not provided. Indicated to be comparable to other Denver-area buildings.	$34/ft² (PPA agreement)	Designed to use 50% less energy for large office building with data center. Met modeled energy target of 35 kBtu/ ft²-year after year 1 of occupancy

In many cases, ZNE projects received some level of free services, including government grants, volunteer work from industry experts or utility funding for design and modeling. For instance, in designing and constructing the Los Vecinos low income, multi-family housing projects, Global Green utilized funding from the California Energy Commission's Public Interest Energy Research (PIER) program (Bardacke and Wells

2010). Grant programs can support pre-construction modeling efforts, which can be very expensive but are important to the overall process of integrated design. In building the Green Idea House in Hermosa Beach, CA, the homeowner, Robert Fortunato, received energy modeling support from Southern California Edison, which improved the design and overall performance. Thus, while buildings may be able to be constructed at cost parity given tradeoffs, the design phase is still reliant on additional outside expertise, which may have additional associated costs. This is clearly part of the transition of ZNE from a research exercise to a mature market solution.

5.1 Incremental Costs for Residential Buildings

Residential ZNE costs reported in the literature were strongly driven by PV system costs, which have decreased significantly in last few years. Some older projects from last decade indicated incremental costs in the neighborhood of \$20-\$30 per ft², with roughly three-quarters of the costs associated with the PV (and occasionally, solar thermal) system. More recent data from the UC Davis West Village ZNE Community suggests incremental costs for the completed student apartments and planned single family homes of \$2-\$4 per ft² for the energy efficiency piece of the project, after available efficiency incentives.[28] The 2011 Solar Decathlon included twenty ZNE entries from U.S. colleges as well as foreign countries.[29] Each team developed their own design for a 1,000 ft² ZNE home that was monitored over a ten day period on the Washington, D.C. mall. Interestingly, the estimated construction costs for the structures ranged from \$230,000 to \$470,000, with no correlation between monitored net energy use and cost. This result highlights the learning process that is still underway, as alternative ZNE strategies are designed, demonstrated, evaluated, and reconfigured.

For residential construction, research and interviews suggest that an optimized package of more conventional EEMs is likely to cost between \$2 - \$8 per ft², after available incentives. This would reduce home "thermal" and lighting energy use by roughly 30-50%, depending upon EEMs and climate.[30] More advanced measures and technologies generally have higher costs since many of these technologies are emerging (i.e. expensive) and the delivery infrastructure is not mature. The California housing industry is beginning a very slow recovery from the market crash of 2008 and is operating in a highly cost competitive environment, which may not be aligned with the concept of construction quality, which emphasizes a high level of attention to detail in the thermal envelope (insulation inspection and draft-stopping for low infiltration) and HVAC installation (overall airflow, refrigerant charge, and air delivery). The statewide 2020 ZNE goal will require significant effort from the residential construction community in meeting these goals.

Seeking Alternatives to Expensive Design Approaches

Innovative technologies can often assist in achieving ZNE status, but sometimes at a high cost premium. For instance, in the Tucson, Arizona SEED house, innovative measures such as SIPS construction and radiant heating and cooling delivery from an air-to-water heat pump added nearly \$14/ft². Comparable performance may be achievable through the use of alternative products or construction strategies. Rigorous demonstrations and case studies are needed to document the cost and performance of these advanced strategies and inform the design and construction community.

In mild climates such as California, a central focus on demonstrating ZNE status hinges on household miscellaneous electricity use characteristics. Two recent ZNE projects documented a large variance in electricity consumption among a large group of monitored households (Backman et al, 2010; Bardacke and

[28] Modeling indicates that energy efficiency contributed 58% of the savings towards the ZNE goal at West Village.

[29] http://www.solardecathlon.gov/about.html

[30] Thermal energy use includes heating, cooling, and water heating

Wells, 2010). The variation in energy consumption between households in both cases is striking, and highlights the need to better identify and control the miscellaneous electrical use component.

While energy performance of ZNE homes is related to occupant behavior, the market value and retail popularity of ZNE homes is a prime concern for builders. For residential developments, developers must pay special attention to the carrying costs associated with holding and maintaining completed homes. One study looked at how sales in a high-performance Sacramento area subdivision (ZNE-capabile homes) compared to neighboring benchmark subdivisions (Dakin, Springer, and Kelly 2008). In this particular case, the builder absorbed the ~$20,000 incremental construction cost and used energy efficiency as a sales and marketing tool. During 2006 and 2007, sales of the high performance homes (84 total sales) in the Carsten Crossings neighborhood were at a rate 2.2 times greater than the neighboring projects. At the higher sales rate, the reduction in project carrying costs were calculated to be more than four times the increased construction costs. Whether this approach can gain traction in the future, when the construction market rebounds, remains to be seen.

At the community scale level, several projects have sought to achieve ZNE status at a scale broader than a handful of homes. To date, however, no completed developments have demonstrated full ZNE status. The most ambitious project, which is currently under construction, is the UC Davis West Village project. This project is a unique public-private partnership between the university and the developer (West Village Community Partners). This partnership provided an opportunity for the project to obtain grants only available to research institutions, including:

- U.S. Department of Energy's Community Renewable Energy Deployment program, to explore waste-to-renewable-energy alternatives ($2.5 million), with a $.5 million California Energy Commission (CEC) matching grant

- CPUC's California Solar Initiative, to study innovative technologies and innovative business models related to PV systems ($2.5 million), and

- CEC's PIER Renewable-Based Energy Secure Community program, to assist in the design and engineering of renewable energy systems ($1.94 million)

With these sources of funding, the project was able to explore in great detail many of the technical, market, and regulatory issues related to a project of this scope. Nolan Zail, former Senior Vice President of Carmel Partners (project developer), indicated that the support from the various research grants was instrumental in developing the technical basis for the development team to proceed with the understanding that the proposed strategies were workable and cost effective on a life cycle basis.

5.2 Incremental Costs in Commercial Buildings

Information from interviews and literature indicate that incremental costs for commercial buildings vary widely. In some instances, ZNE buildings could be shown to be less-expensive than specific guidelines, especially for municipalities, school districts, and universities that have cost per square foot construction budgets. Several ZNE commercial buildings, including the NREL Research Support Facility and Richardson Elementary School in Kentucky, were built at costs comparable to similar structures. Construction tradeoffs, especially in the case of commercial buildings, offer the possibility of reallocating costs from one key cost element to another. Figure 2 below (NREL, 2012) shows how electrical and HVAC costs associated with conventional construction practice can be shifted to potentially more costly architectural improvements that reduce building loads. The ability to achieve cost tradeoffs is much more pronounced in commercial buildings where the cost savings associated with equipment downsizing can be significant. For example, the

SMUD 59th Street ZNE project currently under construction is installing 180 tons of cooling, or 320 tons less than a typical base case building system design.[31] This is made evident in Figure 3 (NREL, 2012) where the overall building "per ft²" construction costs for the NREL Research Support Facility (RSF) are compared to a group of recently certified LEED commercial buildings located in the greater Denver, Colorado area. The graph shows a broad range in construction costs, with little relationship to LEED certification level. These data reinforce the notion that careful selection and contractual specification of a commercial building's EUI level, coupled with a defined construction budget, results in optimized performance.

Figure 2: Construction Cost Reallocations

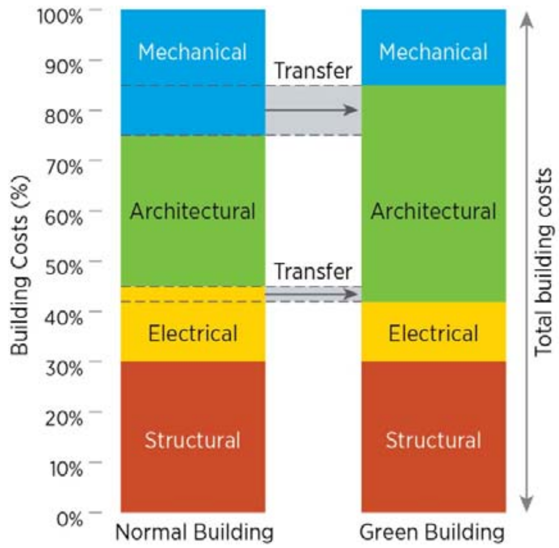

Figure by Stacy Buchanan, NREL

A key point of interest in better understanding ZNE construction cost impacts is how the local market responds to the features and amenities included in the ZNE building relative to standard practice in the area. According to Nils Kok, it is premature at this time to expect to quantify construction cost differences, since the early information on the handful of projects is limited and anecdotal at best. For example, the RSF building achieved slightly higher office space occupant densities through improved daylighting and ventilation strategies, and a shorter cubicle wall height which enhanced the occupant experience. These intangibles related to green office building "improved indoor experience" appear to be real, but are smaller than any incremental rents associated with the green offices (Eichholtz, Kok, and Quigley 2009). The small current sample size of buildings complicates the ability to define cost comparability.

To date, the emerging commercial ZNE activities have largely been focused on federal, state, and municipal buildings. The speculative commercial construction market has been slow to move from a "business as usual" that exclusively considers first costs rather than life cycle costs. One industry contact suggested that cutting-edge U.S. companies, such as Apple, Google, and Intel, will likely lead this transformation from public to private ZNE construction (personal communication with Porus Antia, 2012) at which time the broader commercial real estate will likely start to take notice (personal communication with Nils Kok, 2012).

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[31] In residences, the equipment size increments lead to less ability to downsize small increments. In addition, residential HVAC contractors are generally averse to taking on the potential liability with downsizing, since occupant comfort variability and integrity of the building envelope are large potential liabilities for the contractor.

Figure 3: Comparison of RSF Costs to Other Colorado High Performance Buildings

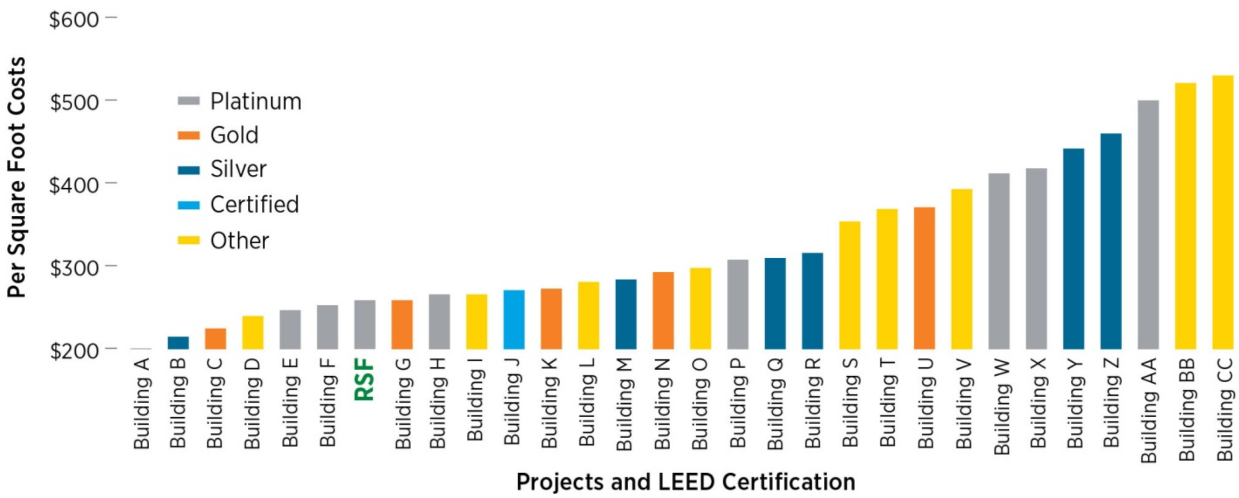

Figure by Stacy Buchanan, NREL

5.3 Cost Mitigation Strategies

The future rate of ZNE building construction in California depends upon a wide range of factors, including:

1) Legislative and regulatory changes to facilitate ZNE strategies, especially for community-scale projects;

2) Federal, state, and utility incentives and/or tax credits

3) Utility rates and rate structures that encourage efficiency; and

4) Reduction in EEM and PV component costs (through volume and contractor training/familiarity) to improve overall cost effectiveness.

5) The degree to which impending Title 24 Building Standards change the landscape

These factors interact in a dynamic landscape influenced by rapid changes in costs and differences in rates of technology advancement. For example, Jim Dent (electrical contractor for the NREL RSF building) indicates that the original RSF building lighting design looked hard at implementing Light-Emitting Diode (LED) lighting systems. At the time, cost for LED's was higher, and the efficacy was lower than competing fluorescent lighting. Since the RSF building was completed, that cost picture has changed dramatically and LED performance has leapfrogged past the 80 lumen/Watt level. Ability to recognize and accurately evaluate the changing landscape of technologies and costs is essential for a design team to effectively implement an integrated vision.

In both the residential and commercial realm, there is still much to learn about the packaging of efficiency measures and the performance of integrated design strategies in different applications and climates. Many of the early "one off" ZNE buildings have explored the use of cutting edge emerging technologies that have clear performance advantages over conventional technologies, but are very costly due as the technology is not yet mature. Performance synergies, for example combining added thermal mass and ventilation cooling, have not been fully analyzed to the point where designers can specifically quantify cost savings from improved wall system or HVAC system incremental costs without sacrificing energy performance. These are critical steps in the overall cost mitigation strategy, and appear to be of greater uncertainty on the residential side, where in most (mild) California climates, the occupant has huge control over building performance.

Critical to the cost mitigation discussion is a realization that the entire economic discussion needs to move from first cost to life cycle costs. Only with a life cycle perspective can one take advantage of future equipment replacement cost savings[32], extended replacement intervals (e.g. LED lighting), and projected future rate increases that generally improve economics. Transforming conventional economic wisdom to a life cycle perspective will require education and training for owners, developers, architects, and designers.

5.3.1 Commercial Strategies

Based on interviews and analysis, several cost mitigation strategies for designing and constructing ZNE commercial buildings have been identified and are listed below.

1) Develop building energy targets: As part of an integrated design process focused on high performance buildings, building owners and design team managers should develop appropriate EUI targets and integrate achievable and enforceable energy goals in the contracting process. This clear direction to the construction team focuses an integrated design strategy and fosters improved collaboration amongst team members. Many experts indicated this to be a critical component of achieving ZNE buildings. With ZNE building design still being in its infancy, this effort may require a detailed modeling study of alternatives. As the ZNE design community matures, improved design guides and practices will reduce the cost of this key ZNE component.

2) Design team integration throughout the design and construction process: An integrated design team collaborates from the beginning to the end of the project. An informed and engaged building owner plays a key role in setting the stage for the designers, estimators, and installers to deliver the final product. A design team focused on ZNE (or near ZNE) from Day 1 will conserve budget by focusing on the optimal cost-performance target, and avoid unnecessary costs associated with measure-by-measure economic justifications and design iterations.

3) Reduce building plug loads: Internal loads frequently lead to space cooling loads in California commercial buildings due to the generally mild heating season. Maximizing plug load efficiency by reducing standby energy, utilizing low power density workstations, and installing efficient appliances contributes to immediate energy savings, as well as secondary savings through reduced cooling loads (reflected in both energy and demand savings).

4) Maximize daylighting potential for appropriate building types: Daylighting is one of the preferred strategies for ZNE-capable buildings such as offices and schools. Incorporating daylighting into an appropriate building design can reduce building electricity consumption drastically. Jim Dent, the electrical contractor for the NREL RSF building, developed a lighting zoning plan with a high degree of local control to minimize the size of the lighting zone. The added cost of more zone controls was offset by operating savings from a higher resolution system allowing for more localized control. Mr. Dent estimates that the RSF electrical features cost an extra $300,000 (over a conventional $5 million bid) to achieve the realized performance level of 0.2 W/ft^2 system. Similar to the plug load reduction

[32] ZNE buildings will have a smaller mechanical plant due to load reduction impacts.

efforts, reduced lighting energy use also contributes to cooling energy and demand savings, as well as cooling equipment downsizing.

5) Maximize synergies which transform inefficiencies into efficiencies: Many commercial buildings offer untapped opportunities to reduce loads and therefore the size and costs of mechanical and electrical equipment. A few of the many examples include:

    a. Waste heat from data centers can be used to preheat outdoor ventilation air or contribute to more efficient heat pump water heater operation.

    b. Reduced building lighting, computer, and miscellaneous electrical loads contribute to reduced cooling loads, downsizing HVAC and air delivery systems.

    c. The cost and overall economics of geothermal heat pump systems in cooling dominated climates are especially sensitive to minimizing the peak summer load through reduced cooling loads. The incorporation of geothermal water heating serves to further reduce loop sizing, saving cost and improving efficiency.

   Good designers can explore and demonstrate these strategies, leading to recognition and wider adoption in the design community.

5.3.2 Residential Strategies

For residential buildings, research and interviews indicated the following strategies and barriers in achieving ZNE designs.

1) Identify optimal EEM packages for different California climate regions: As seen in the literature review and case studies, the recent ZNE residential examples have utilized a wide range of high efficiency conventional technologies, as well as more cutting edge EEMs which offer improved performance at a higher (current) cost. With PV prices falling, the optimal balance of EEMs and renewable technologies for a given building will continue to evolve. At the same time, some of the advanced technologies will continue to achieve greater market penetration, often resulting in reduced installation costs. Identifying preferred EEM packages and maximizing synergies is a key component in reducing ZNE costs.

2) Need for high efficiency low-capacity heating, cooling, and water heating equipment: The energy efficiency community is increasingly realizing the need for better product offerings for HVAC and water heating equipment in the lower capacity range. Interest among HVAC and water heater manufacturers is slowly beginning to recognize the need for developing smaller, more efficient products that are better suited for ZNE homes. As building loads decrease, utility costs rise, and residents become more cognizant of energy costs, the demand for small, high efficiency equipment will increase.

3) Improve education and training: Education and training programs for builders, installation contractors, realtors, and the purchasing public are all necessary to promote increased ZNE activity. California state policies are moving towards the 2020 ZNE goal, but market response is lagging. First cost considerations drive decisions by the construction industry and homebuyers. Life cycle and ancillary benefits (utility bill reduction, improved indoor air quality and comfort, reduced replacement costs) are widely undervalued by the market. At the same time, state agencies and standards organizations must promote education and training opportunities to ensure quality work. Contractor training on proper installation and commissioning practices is critical in achieving expected measure performance.

4) Identify systems and strategies that effectively address miscellaneous energy use: In mild climates such as California, technologies can provide greater flexibility to promote individual habits that facilitate energy savings. For instance, power strips with motion sensors can detect when houses are empty and reduce "vampire" loads. Providing the information to homeowners and actively controlling these loads are both critical components of reducing miscellaneous energy use.

5) Identify developer opportunities to maximize ZNE cost-effectiveness: A number of potential strategies can improve the cost picture for ZNE building. Developer fee structures can incentivize high performance homes.[33] Electric vehicle charging stations can augment energy savings if integrated effectively into overall building design. Other technologies such as off-peak cooling systems can significantly improve homeowner economics without compromising home energy efficiency, especially with appropriate Time of Use utility rate structures. Multi-family buildings provde opportunities to improve ZNE cost-effectiveness by exploiting diversity and higher shared loads (such as central water heating). Regulatory changes would be needed to facilitate some of these solutions while equitably sharing benefits between the end user, the utilities, and society as a whole.

6) Develop and promote California ZNE case studies: Many different ZNE design strategies exist for California residences. Well-documented studies are needed to highlight lessons learned and promote alternative strategies tailored to the state's many climatic zones. Providing clear, documented information to the various stakeholders in the construction community, will advance the ZNE effort.

6 Conclusions

Based on the findings of this study, we conclude that ZNE buildings can achieve cost-parity with comparable buildings, especially in commercial buildings where potential cost tradeoffs and energy synergies can be better exploited. A key component in demonstrating ZNE cost-comparability relies on viewing cost effectiveness from a life cycle basis that recognizes utility rate escalation impacts, improved equipment life characteristics (e.g. LED lighting), and reduced replacement costs through mechanical equipment downsizing. Research and interviews indicated numerous examples of commercial buildings that achieved very high energy performance or ZNE status at little or no additional cost. Residential buildings, which generally have a lower potential for "cost tradeoffs" common to high performance commercial buildings, are estimated to have incremental EEM costs on the order of \$2-\$8 per ft^2 for a package of conventional EEMs[34], with current PV costs on the order of \$4.50/ft^2. ZNE buildings require clear energy target specification, a life cycle economic perspective, and experienced personnel capable of working in an integrated fashion throughout the design, construction, and commissioning process. The traditional barriers that often complicate cooperation between architects, engineers, subcontractors, owners, and residents must dissolve during the design process to create livable and cost-effective ZNE buildings.

Cost-effective ZNE buildings require careful analysis of tradeoffs in energy efficiency measures, PV installations, and amenities as part of the design process. Commercial buildings often benefit from increased opportunities for harvesting synergies in efficiency measures and maximizing cost savings by downsizing equipment and optimizing functions. Residential building energy use, especially in the relatively moderate climates that define much of California, is much more influenced by nuances associated with occupant behavior and electronic equipment saturations, which complicates the "one size fits all" integrated ZNE design approach. Establishing achievable and climate-appropriate energy targets through early modeling

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[33] This could be based on the designed performance of the home, or retroactively be based on actual performance to incentivize homeowner behavioral changes to minimize energy use.

[34] Alternative (i.e. non-conventional) HVAC and envelope system options result in higher incremental costs at this time.

efforts establishes a performance baseline. These targets can be specified in the construction contracts as performance requirements, with incentives provided for builders that achieve targets. Design processes can identify the specific, appropriate mix of energy efficiency and PV installations to maximize performance. As PV installation costs fall and new business models such as solar leasing increase, PV installations are becoming increasingly competitive. How this will affect the ZNE design approach moving forward remains unclear at this time. To date, energy efficiency measures have been first in the loading order, prior to introducing PV.

Feedback from industry leaders interviewed in this project suggest that integrating design and construction activities through a coordinated framework will generally improve communication and eliminate inefficiencies that often add costs and reduce overall energy performance. Integrated design procedures focused on clear, contractually specified EUI targets help to efficiently optimize the mix of EEMs and generation technologies. Yet, building industry professionals that practice integrated design procedures currently constitute a niche market. Evolving codes and standards, and further emphasis and incentives for building professionals to participate in integrated design practices are necessary to increase pervasiveness of this key approach. Typical compartmentalized silos of architecture, engineering, and contractors often constitutes a significant barrier to achieving effective integrated design.

Further education and training is needed for both building professionals and consumers to advance ZNE building practices. Designers and installers must be trained in climate-appropriate approaches for achieving ZNE buildings. Builders and owners must use life cycle costs rather than first costs to evaluate design options and assess performance projections. As ZNE practices become more refined for various building types, designers will be better equipped to recognize performance synergies and cost reduction strategies unique to each building type. Multi-family buildings and community scale projects may be ideal candidates for central system designs, provided that current regulatory constraints are modified to encourage these alternative scenarios. Consumer education programs can work to improve economic decision-making on the part of homeowners for investments in energy efficiency and renewable energy, as well as common practices that reduce energy consumption through daily activities. Communication of the opportunity for and benefits of ZNE buildings will be critical in gaining public support for ZNE buildings that can drive development of a broader market.

Assessing incremental costs requires establishing a rubric for comparisons. Incremental costs are generally easier to estimate for residential buildings, since in most instances, adding EEMs does not constitute a major building re-design, but instead involves the addition of EEMs (\$2-\$8/ft^2 for conventional measures) and the incorporation of PV. A statistically-relevant sample of ZNE commercial buildings does not yet exist to compare costs with corresponding typical "base case" buildings. The literature shows that many traditional buildings may be constructed for less than a ZNE building, but the variety of building types means that more expensive non-ZNE buildings will also exist. Research and interviews indicate that incremental costs for ZNE commercial buildings range from 0-10% (NBI, 2012), with buildings increasingly achieving cost parity through effective design procedures and intelligent cost tradeoffs. Buildings that use more unconventional approaches such as experimental heating and cooling technologies often have higher costs, as the infrastructure in delivering many advanced technologies is not mature. Moreover, many experts are not able to assess the incremental costs, since key design components such as daylighting are integrated into the overall building structure, while other typical costs such as HVAC systems are eliminated. This also explains why many ZNE experts noted that any given building can be constructed to achieve ZNE at cost parity given appropriate tradeoffs, which may include perceived (but not real) degradation in amenities, such as the NREL RSF building's increased office occupancy densities.

New technologies, as well as cost and efficiency improvements in existing technologies (e.g. LED lighting systems) will continue to alter the ZNE cost picture. Continued reductions in the price of PV installations due to new designs and economies of scale in production would broaden the potential set of ZNE-capable building types. For residential buildings, smaller HVAC and water heating equipment appropriate for efficient

ZNE homes (currently not commonly available and therefore more expensive) would improve the cost picture. Continual improvements to the Title 24 baseline performance level will also continually "raise the bar" to which ZNE buildings will be referenced to. All of these factors will likely contribute to an emerging ZNE market in the near term as the successful demonstration and documentation of the early adopters provides a compelling story for the broader marketplace.

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Pless, Shanti, Paul Torcellini, and David Shelton. 2011. "Using an Energy Performance Based Design-Build Process to Procure a Large Scale Low-Energy Building." In National Renewable Energy Laboratory.

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Appendix A: Case Study Summaries

NREL Research Support Facility (RSF) Project

Photo credit: Dennis Schroeder, National Renewable Energy Laboratory (NREL/PIX 17820)

Project Summary Information

Building Type	Government-owned Office Building
Location	Golden, CO
Floor Area	First phase (two wings): 222,000 ft^2 Second phase (additional wing): 138,000 ft^2 Total area: 360,000 ft^2
Number of Stories	Three to four stories
Year Completed	RSF1 (First phase): 222,000 ft^2 completed in 2010 RSF2 (second phase): 138,000 ft^2 completed in 2011 Total: 360,000 ft^2, fully occupied since February 2012
Modeled Performance	ZNE
Monitored Performance	Annual Zero Energy consumption demonstrated
Energy Use Intensity	25 kBtu/ ft^2-yr for office space area, 35 kBtu/ ft^2-year accounting for full data center loads
Overall Project Cost	RSF1 (222,000 ft^2) $57.4 million for building (not including PV costs) $64 million including furnishings Total Costs for RSF1 and RSF2 (combined 360,000 ft^2) $91.4 million
Average Cost per ft^2	$254/ ft^2 without PV installation $288 including PV Power Purchase Agreement Comparable
PV System Sizing	Rooftop arrays: 857 kW Parking lot arrays: 1,680 kW
PV System Cost per ft^2	PV system funded through a Power Purchase Agreement (PPA)

Project Overview

The National Renewable Energy Laboratory (NREL) in Golden, CO, is dedicated to researching renewable energy and energy efficiency technologies and supporting their commercialization. As part of its mission, NREL sought to demonstrate that constructing a high-performance office building could be completed within a government prescribed project budget. NREL utilized integrated design methodologies and executed a fixed-price desing-build contract with embedded energy targets in order to achieve ZNE. A series of renewable energy and energy efficiency measures (EEMs) were integrated into the building design. Project costs were further controlled by arranging a Power Purchase Agreement (PPA) for the installation of solar panels. NREL has conducted significant monitoring and evaluation studies of the building since its completion in 2010 in an effort to both understand and improve performance, as well as to educate the building community.

Design Approach

The RSF design-build approach involved a multi-stage process for contractor selection. First, NREL solicited a Request for Qualifications and subsequently selected the three most qualified respondents to submit full proposals. The Request for Proposals specified stated performance goals (LEED certification, minimum safety qualifications), highly-desired performance goals (25 kBtu/ ft^2-yr, 50% of ASHRAE 90.1, completion dates, and desired amenities), and "if-possible" goals (Net Zero Energy approach, LEED Platinum, visual displays of energy efficiency measures, and others). Through this approach, NREL was able to build performance requirements and goals into the process in an incentive-based fashion, while still meeting federal contracting standards. In addition, NREL drew on design-build approaches from other organizations such as the Design-Build Institute of America (DBIA) in order to create a more collaborative relationship with the design-build team. The contract was divided into two stages: preliminary design and final design and construction.

As noted, the NREL contract had a specific, fact-based Energy Use Intensity built into the contract. A key element of the process was to have the "voluntary incentive program" (a DBIA best practice) built into the contract, including a set aside of 2% of the construction budget to serve as a contingency/incentive fund. The two percent set aside was a valuable mechanism for NREL to maintain a level of control during the construction process, which is not common in typical design-build relationships.

NREL ensured that the electrical and mechanical subcontractors were engaged early in the process to provide critical design input on the elements required to meet the targeted building performance. In addition to the key mechanical and electrical subcontractors, NREL also engaged a furniture consultant early in the process in order to advise the design-build team on implementation of a modularized approach to office space. The result was a layout with higher than typical densities (82 vs 100 ft^2/occupant), while maintaining a highly pleasing occupant environment. Identifying and maximizing these type of a synergies is a hallmark of early, large-scale, integrated ZNE design successes, such as the RSF building.

The unique energy efficiency features of the building included:

1) Narrow building configuration (60' width) enabling daylighting and natural ventilation;
2) Labyrinth thermal storage underneath the building, with concrete structures to provide thermal energy storage and passive heating;
3) Exterior wall transpired solar collectors, which pass outside ventilation air (preheated in the winter) into the internal building space;
4) Optimized daylighting, with high efficiency lighting (0.2 W/ft^2) and localized lighting control;
5) Triple-glazed, operable windows with "aggressive" shading controls;
6) Precast concrete insulated panels that improve thermal insulation for the exterior walls;
7) Radiant heating and cooling in the form of piping runs through all floors of the building;

NREL used a whole building energy analysis and simulation program to model the complex energy systems. The model was consistently updated to reflect current designs, which the NREL team identified as a key component of a successful design-build process (Hirsch et al. 2011). NREL designed the buildings data center to utilize natural cooling from outdoor air to cool the significant server heat generation. In addition, the building heating system uses excess heat from the data center for general purpose heating. NREL also modernized its servers, replacing old machines with newer, more efficient ones and making 70% of the server environment virtual (Sheppy et al. 2011).

Cost Considerations

NREL has published extensively on its design process, construction experiences, and post-occupancy monitoring at the RSF building. A key focus is on comparing overall building costs to other office building projects in the surrounding Denver, CO area. The figure below compares RSF costs to other recently completed Denver area high performance buildings. The figure highlights both the reasonable overall RSF costs, as well as the wide range in costs demonstrated by various neighboring projects. The latter point highlights the complexity in defining ZNE building comparability in these early stages.

In order to maintain cost competitiveness for the building, NREL utilized a PPA for the photovoltaic system components. If the building were to include the PV system as a purchased component, then the initial construction costs would have increased by $\$29/ft^2$, while long-term operational costs would have decreased (Pless, Torcellini, and Macey 2012). In addition, installing sufficient PV capacity to supply a large office building with a data center requires more rooftop space than is available on many buildings, especially in urban areas. For the RSF building, PV panels above parking lots helped NREL achieve these targets.

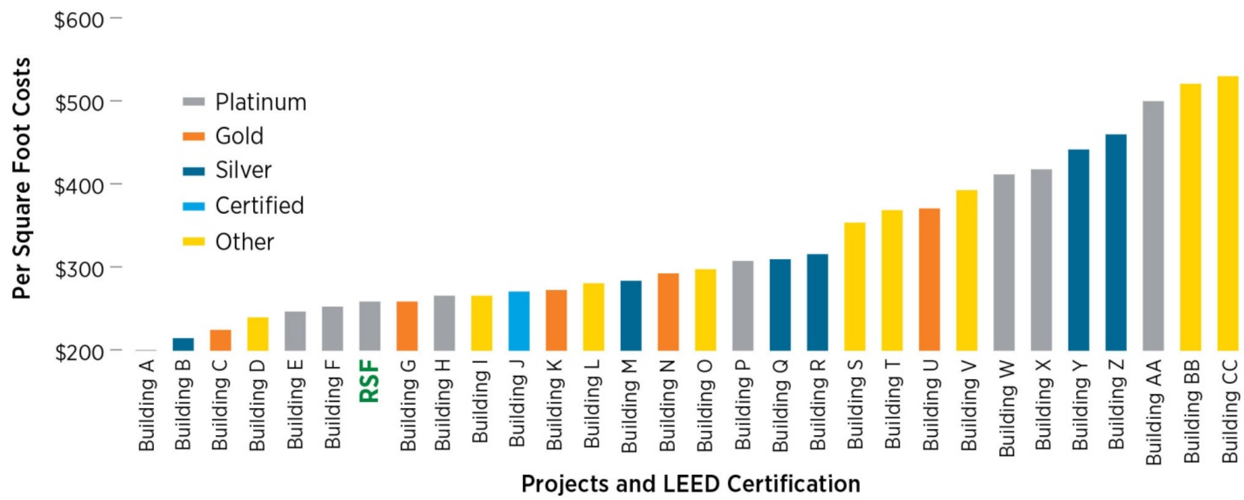

Figure by Stacy Buchanan, NREL

Lessons Learned

Through the project, NREL effectively demonstrated how to use a design-build process with strict energy targets to achieve a high performance ZNE building. This process required a high level of collaboration early in the process, including electrical and mechanical subcontractors, lighting consultants, interior decorators, and others. If this is not done, buildings designed for high-efficiency can actually incur significant cost overruns, as non-traditional approaches must be amended to allow for requirements related to HVAC, electrical, or other systems.

Weifield Group Contracting, the RSF electrical contractor, found that the contractual relationship, as well as the high level of design coordination, allowed the team to quickly focus on optimal design solutions that met the project energy performance targets and cost parameters. Normal design approaches involve iterations on solutions, detailed cost effectiveness justifications, and ongoing value engineering efforts. During the construction process, commonly incurred cost increases can result in value engineering that eliminates measures to remain within the project budget requirements. Jim Dent, the Weifield pre-construction manager for the project, estimates that these inefficiencies can eat up several percent of their typical budget on a project such as the RSF. Weifield's experience with the RSF process was highly favorable and they are now touting their experiences as a leading energy-efficiency firm prominently on their website.

The design-build approach implemented in this project is not the typical contracting approach used by the Federal government in building procurement. The success of this project has NREL now working on developing a "how-to guide" to instruct DOE and other federal partners on how to implement similar contracting procedures. There is also a DOE-funded project underway that is trying to replicate the RSF procurement process, with the Army Corps of Engineers and the General Services Administration also evaluating the contracting method. Succesful replication of the RSF procurement process is an important step in expanding the influence of this ambitious project into the commercial building construction industry.

Additional Resources

Hirsch, Adam, Shanti Pless, Rob Guglielmetti, and Paul Toricellini. 2011. “The Role of Modeling When Designing for Absolute Energy Use Intensity Requirements in a Design-Build Framework.” In Las Vegas, NV.

NREL. 2012. "The Design-Build Process for the Research Support Facility." http://www.nrel.gov/docs/fy12osti/51387.pdf

Pless, Shanti, Paul Torcellini, and Phil Macey. 2012. “Controlling Capital Costs in High Performance Office Buildings: 15 Best Practices for Overcoming Cost Barriers in Project Acquisition, Design, and Construction.” In Pacific Grove, CA.

Sheppy, Michael, Chad Lobato, Otto van Geet, Shanti Pless, Kevin Donovan, and Chuck Power. 2011. *Reducing Data Center Loads for a Large-Scale, Low-Energy Office Building: NREL’s Research Support Facility*. Golden, CO: National Renewable Energy Laboratory.

http://www.nrel.gov/sustainable_nrel/rsf.html

SMUD's East Campus Project

Photo courtesy of SMUD

Project Summary Information

Building Type	Office (main building), warehouse, shops, fleet garage
Location	Sacramento, CA
Floor Area	350,000 ft^2 (203,000 ft^2 main building)
Number of Stories	Six stories (main building); one and two story (other buildings)
Year Completed	Target: June 2013
Modeled Performance	~60% better than 2008 Title 24
Monitored Performance	n/a
Energy Use Intensity	34 site kBtu/ft^2-year (RFP target) with winning bid at 19 kBtu/ft^2-year (main office building) and 15.7 kBtu/ft^2-year (other buildings)
Overall Project Cost	$111,000,000 total project budget (~$75,000,000 for buildings)
Average Cost per ft^2	$214/$ft^2$ building construction budget (not including PV)
PV System Sizing	1.1 MWdc
PV System Cost per ft^2	$17/$ft^2$

Project Overview

The Sacramento Municipal Utility District's (SMUD) East Campus facility is currently under construction with a targeted June 2013 completion date. SMUD began project planning in 2008, with a goal of demonstrating its commitment to energy efficiency and sustainability in the development of the 350,000 ft^2 East Campus facility. The original project goals included LEED certification, but there was no clear definition of how aggressively the project would approach ZNE. In 2009, key SMUD planning staff began reaching out to industry experts for input regarding design strategies, including staff at the National Renewable Energy Laboratory (NREL). SMUD and NREL discussed how design strategies from NREL's Research Support Facility project (a ZNE office building located on NREL's Golden, CO campus) could be used in the East Campus project. Through collaboration with NREL staff, input from ASHRAE 50% design guides, and a detailed energy modeling effort, the SMUD design team developed a maximum building energy use intensity (EUI) requirement of 34 kBtu/ft^2-year as part of their Request for Proposals (RFP). SMUD felt that this EUI requirement pushed current energy efficient design practice forward by an estimated five years.

Of the twenty design-build teams invited to provide qualifications, ten were interviewed, and four were invited to bid on the project. The RFP specified that the PV costs required to achieve ZNE were to be included in the overall construction costs, which motivated proposers to maximize cost-effective energy efficiency rather than simply utilize higher-cost PV systems to achieve the energy targets. The winning team (Turner Construction and Stantec) proposed a design that achieved an EUI target of 19 kBtu/ft^2-year for the main office building, which far surpassed other proposals.

Design Approach

One factor constrained the level of design flexibility for the East Campus office building. SMUD had already received design approval by Sacramento County on a six-story building of a certain footprint prior to release of the design-build contract. This placed some constraints on the design team in fully maximizing daylighting possibilities, since the building footprint was specified.

Key design elements that were implemented in this all-electric building included LED lighting (to minimize installed lighting wattage), advanced lighting controls, energy recovery ventilation, radiant heating and cooling delivery via a cast-in-place concrete floor system, and geothermal heat pumps coupled with air source heat pumps. (The air source heat pumps are operated when conditions are more favorable than the ground loop.) The geothermal system also utilizes a cooling tower to take advantage of more favorable heat rejection conditions during dry summer periods, as well as to reduce the ground loop sizing. The integrated design approach for this Central Valley climate focused on minimizing cooling loads, and utilizing climate-appropriate cooling strategies to maximize efficiency and reduce costs.

Cost Considerations

By reducing cooling load requirements through efficiency measures, the original "base case" HVAC equipment sizing of 500 tons (for the 203,000 ft^2 main office building) was reduced to about 180 tons. By downsizing the building's mechanical equipment, which carries an installation cost of approximately $5,000/ton (personal communication with SMUD project Technical Manager Doug Norwood), the design generated roughly $1.6 million that could be used for other efficiency measures, including the cast-in-place floor system and LED lighting. This cost tradeoff highlights the integrated design process. Rather than spending for business as usual construction, project funds can be used to install energy efficiency measures that generate savings year after year.

The overall project budget of $111 million (including $6 million for PV), was only ten percent over SMUD's planned project expenditure of $100 million. According to Doug Norwood, the budget included significant site work representing nearly 30% of the cost. Removing the site and PV costs from the budget puts the construction budget ($214/$ft^2$) in line with SMUD's Customer Service Center, a comparably sized four-story building completed in 1996. The 174,000 ft^2 Customer Service Center, which was designed to exceed Title 24 by 36% at the time, was built for $38 million, or $218/$ft^2$.

Lessons Learned

For SMUD, this design-build project represented a deviation from the agency's normal design-bid-build contracting process. Doug Norwood commented that although the design-build process was not flawless, it did bring together the design team, key subcontractors, and estimators early in the process in order to make key project decisions. Without this early collaborative design approach, Mr. Norwood feels that the expected level of energy efficiency would not have been achieved.

Mr. Norwood expressed optimism that the construction industry is ready to support increased near term efforts in developing ZNE buildings. Although a business-as-usual viewpoint is viewed as being widespread in the construction industry, his personal experience suggests that contractors are willing to adopt more efficient and productive building techniques when shown sufficient rationale.

Additional Resources

https://www.smud.org/en/about-smud/news-media/smud-updates/2012-07-20-ECOC-half-way-mark.htm

Berkeley West Branch Library Project

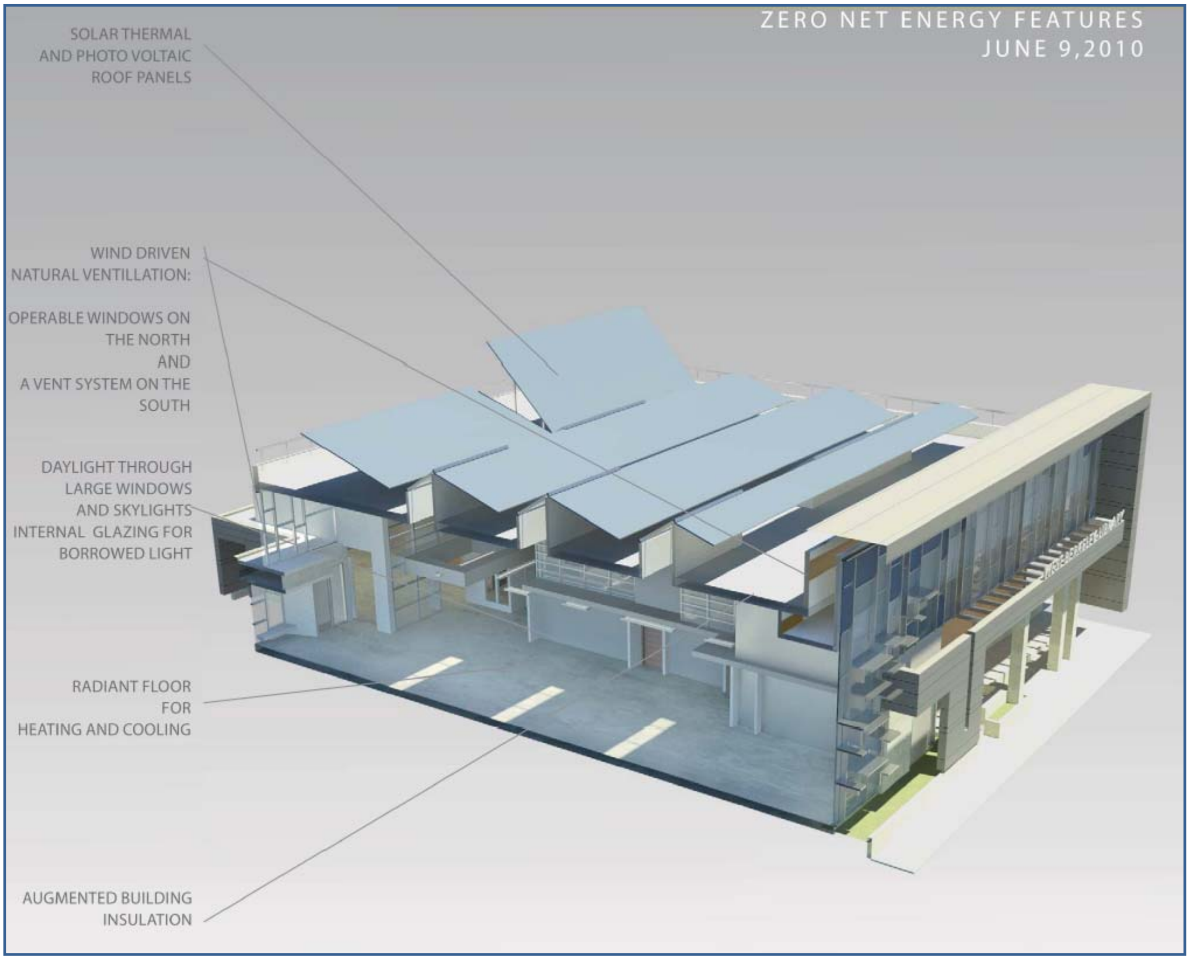

Photo courtesy of Harley Ellis Devereaux

Project Summary Information

Building Type	Municipal-owned Library Building
Location	Berkeley, CA
Floor Area	9,400 ft^2
Number of Stories	One story (with 2nd floor mechanical room)
Year Completed	Target: Summer 2013
Modeled Performance	Zero Energy
Monitored Performance	n/a
Energy Use Intensity	Approximately 20 site kBtu/ft^2-year (design target)
Overall Project Cost	$5,495,000
Average Cost per ft^2	$585/$ft^2$
PV System Sizing	41 kW
PV System Cost per ft^2	Estimated at $26/ ft^2 ($250,000 total cost)

Project Overview

In 2008, Berkeley residents approved a $26 million bond measure to fund upgrades to four city library branches. Of the four, two projects were rehabilitations of existing buildings and two were completely torn down and rebuilt. While each building incorporated some level of Energy Efficiency Measures (EEMs), the West Branch library was designed to be a Zero Net Energy facility. This was primarily motivated by the project director, Ed Dean, who convinced city personnel that the library could be built as a ZNE building at equivalent costs to the other three branches. The West Branch design went out for bidding in April 2012, with the design team estimating a cost of $5.5 million. The winning bid was submitted by West Bay Builders, Inc., at $5.495 million, meaning that projections indicate that the building will be constructed at relative cost parity to the other library upgrades.

Design Approach

The project benefited from experienced personnel who were passionate and knowledgeable regarding design of high-efficiency buildings. The project director had experience in integrated design methodologies that enhance energy performance while containing costs, and was able to effectively coordinate early design activities of architects and engineers. The project also benefited from being located in the San Francisco Bay Area, where interest and design professional expertise in collaborative design approaches is high. Finally, the design team received support towards the energy modeling process through PG&E's *Savings by Design* program.

The design process included a Concept Phase and Design Phase. The Concept Phase was used to determine the "preferred architectural design approach… as well as environmental goals such as zero net energy performance" (Harley Ellis Devereaux 2010). The team set a target goal of 18 kBtu/ft^2-yr for the energy use intensity (EUI) based on initial modeling of identified energy efficiency measures and climate. The team also developed a baseline building EUI of 36 kBtu/ft^2-yr. After setting an initial energy target, the design team worked on defining the energy features and mechanical systems for the building. The project utilized energy modeling to design building elements enhancing natural airflow design, daylighting, passive heating and cooling, and other measures. Space heating was provided by a solar thermal-assisted hydronic radiant floor heating system, with backup air source heat pump heating. Final schematic design modeling results indicate a projected EUI of 15.3 kBtu/ft^2-yr (Harley Ellis Devereaux 2010).

Cost Considerations

Construction costs for the West Berkeley Library Project was part of larger local bond issue passed by voters to upgrade four library branches in the city. As such, programs and budgets for each branch were similar and could not exceed allotted funds. The project director convinced the city that the building could be built as a ZNE building without additional costs. Behind the comparison between these buildings, however, real estate prices and specific characteristics of the San Francisco Bay Area labor market make the construction costs higher than many other buildings. The table below provides an overview of the costs, projected or actual, for each of the library branches.

Branch	Project Type	Square Footage	Completion Date	Construction Costs	Details
Claremont Branch	Renovation	8,110	May 2012	$3.3 million	Historic building renovation. Total project cost (including furnishings, books, and other equipment) was $4.2 million. Expansion brought building from 7,768 to 8,110 square feet
North Branch	Renovation	5,500	April 2012	$4.76 million	Historic building renovation. Total project cost (including furnishings, books, and other equipment) was $5.964 million.
South Branch	Rebuild	8,700	Spring/ Summer 2013 (projected)	$5.037 million (projected)	Building will seek LEED Gold certification, including PV installations, natural lighting, and ventilation. Not designed for ZNE from outset. Total project costs are $6.5 million.
West Branch	Rebuild	9,400	Summer 2013 (projected)	$5.495 million (projected)	See case study

As the West Branch Library project currently moves into the construction phase, the cost implications related to EEMs are difficult to assess. ZNE projects utilize an inherently different approach to design, incorporating non-traditional approaches while also trying to increase comfort and livability. Thus, while the total cost per square foot is quantifiable and comparable within a limited set of similar buildings, the incremental EEM costs are not readily quantifiable as the integrated design process weaves them into the overall structure of the building. When considered as "add-ons" to an existing building, EEMs will almost surely raise construction costs. In the case of the Berkeley West Branch library, various EEMs actually alleviate the need for traditional building systems. For instance, additional skylights to facilitate daylighting substituted for traditional lighting systems, thus creating both additional costs (more skylights and lighting controls) and savings (reduced lighting energy use). As the project director noted, "[w]e were given a project budget without any earmarks for 'energy efficiency measures' and were told to work with it. As we are trained (and skilled) to do, we made the project come in on budget."

Labor costs are also a significant issue for comparability, especially in areas like Berkeley and San where laws mandate the use of unionized local labor. This has prevented many local non-union contractors from bidding on projects. Instead, larger firms from outside of the region are often used as contractors or subcontractors. During the design process, the design team estimated the additional cost of this requirement for the project as an 11-30% premium. This cost would have to be accounted for in comparing the West Branch Library design and construction costs to a similar building in other localities.

Lessons Learned

The project demonstrated that ZNE building can be designed with projected costs equivalent to similar buildings, but building-to-building comparisons are often difficult depending upon the specifics of a given setting. For the Berkeley West Branch Library, the Concept Phase and Design Phase showed that setting early energy targets could influence the evolution of the project, while reassessment of the design is important in order to gauge how the schematic design performs compared to established performance targets. In this case, the modeled schematic actually performed better. In addition, analysis of PV orientation and sizing influenced the design approach as the project progressed.

This project emphasized how detailed modeling can be a key component towards designing ZNE buildings. In many cases, this design phase is an added expense that is not calculated into the costs of ZNE buildings because the design team is able to draw on outside funding sources or volunteer efforts to accomplish the task. Thus, as the ZNE design process evolves, methods must be developed to make the energy modeling phase more efficient and effective, using it as a costing tool to inform design rather than a specific engineering tool that fully describes buildings specifications.

Additional Resources

Harley Ellis Devereaux. 2010. *Berkeley West Branch Library: Zero Net Energy Design, Schematic Design Phase Report*. Berkeley, CA.

http://berkeleypubliclibrary.org/about_the_library/west_summary.php

Cottle Advanced Home Case Study

Photo courtesy of One Sky Homes

Project Summary Information

Location	San Jose, CA
Floor Area	3,170 ft^2
Number of Stories	2
Year Completed	2012
% beyond Title 24	Exceeds 2008 Title 24 budgets by 82% space heating, 87% water heating, and 63% space cooling
Modeled Performance	46% whole house source savings without PV; 90% savings with PV
Monitored Performance	During occupied period from March 2012 through June 2012, PV production exceeded electricity use by 65% (3,638 kWh vs 2,206) and source energy generation was 62% greater than use.
Cost for EEMs before incentives	$67,800
Cost for EEMs after incentives	$58,000
Incremental EEM Cost per ft^2	$21.38/$ft^2$ (before incentives), $18.30/$ft^2$ (after)
PV System Sizing	5.5 kWdc
PV Cost before incentives	$27,000
PV Incentives	$20,000
PV System Cost per ft^2	$8.51 (before incentives) and $2.21/$ft^2$ (after)
Incentives/Rebates as a % of total cost	31% ($29,800 out of $94,800)
Total Incremental Cost	$29.89/$ft^2$ (before incentives); $20.51/$ft^2$ (after incentives)

Project Overview

The Cottle project was designed and built to the Passive House standards, which, like a zero net energy approach, emphasizes minimization of heating and cooling loads. The design approach is more common in Germany and other European countries, but interest exists in California, especially in Northern California, where a majority of the certified Passive House consultants have been developing projects. As per the standards, primary energy use in the home shall not be more than 120 kWh/m^2 (11.1 kWh/ft^2). In the spring of 2012, the Cottle house was recognized by the California Energy Commission as the first certified Net Zero Energy new home in California. In this context, the Cottle project is of interest in an effort to determine what measures and strategies may be commercially viable in the California market.

Measures installed in the house include the following:

- 2x6 wall construction (24" o.c. advanced framing) with 1" rigid exterior insulation;
- R-50 ceiling insulation with CRCC Rated Cool Roof;
- Two types of triple pane high performance windows (U = 0.17-0.19, SHGC = 0.27-0.50)
- A heat recovery ventilator;
- High level of envelope sealing to achieve required leakage of < 0.6 air changes per hour (at a pressure differential of 50 Pascals);
- Sealed, conditioned crawlspace with R-21 perimeter wall insulation;
- High efficiency air-source heat pump (17 SEER, 13 EER, 9.5 HSPF) with an integrated night ventilation cooling system;
- 100% fluorescent lighting package;
- Solar water heating with condensing storage back-up water heater;
- 5.5 kWdc rooftop PV.

Design Approach

In conjunction with the developer, One Sky Homes, the Alliance for Residential Building Innovation (ARBI) Building America team completed energy evaluations and provided design support for the initial Passive House design. Working within the Passive House constraints, ARBI helped customize specifications for some measures, and also lobbied for the integration of ventilation cooling as an effective technique to minimize cooling loads in the mild San Jose climate.

The Passive House approach has evolved from a cold climate background, and therefore the focus has historically been on maximizing the performance of the building shell and minimizing infiltration. The mild San Jose climate presents unique challenges with this approach, making certain measures such as a sealed crawlspace, triple pane glazing, and an ultra-tight building envelope more challenging to justify economically. The integration of these measures does, however, offer an enhanced indoor environment with improved thermal comfort, greater sound separation from outdoors, and filtered outdoor air.

Cost Implications

The Cottle house is currently on the market at a price of $1.899 million. It is located in a high-end San Jose neighborhood with comparably priced homes nearby. The $65,000 net incremental cost for ZNE features ($58,000 EEMs and $7,000 PV) represents a 3.5% cost premium over the base house design. Key cost adders include the ultra-high performance windows ($12,500), the sealed crawlspace system ($19,000), the heat recovery ventilator ($9,600), and the solar thermal system ($7,000). In a high value market such as San Jose, these incremental costs are not significant, especially when countered by improved building "quality" as characterized by improved thermal comfort and sound attenuation, and incorporation of the electric vehicle charging capability available at the house. However, in other lower-cost real estate markets increased attention must be paid to EEM selection and cost effectiveness for ZNE projects. For example, lower cost (and performance) alternatives to the selected windows are available. Evaluating and documenting the performance of these measures in early ZNE projects is important. Using this information to validate savings estimations and inform further cost analysis models is the next step to identify strategies most appropriate for the range of California climates.

Finding the optimized balance of PV and EEMs can be challenging, especially in the current environment where PV costs have been steadily falling. The balance point also shifts with climate and space conditioning loads, as the "savings per dollar invested" is dependent upon the loads. At $7,000, the net cost of the Cottle PV system was $1.27/Watt. On a per kWh basis, the net PV cost is almost 10 times cheaper than the combined incremental cost of the efficiency measures in this project.

Performance Validation

The house was occupied by the builder (Allen Gilliland) and his wife from early March 2012 through the end of June 2012, prior to the official "opening" when the house went on the market. With funding support from both PG&E and DOE's Building America program, the home will be monitored through the end of 2012. For the period from March 22nd through the end of July, the PV system generated 3,638 kWh, or nearly 65% more than the electrical energy consumed (2,206 kWh). Monitored gas use has been minimal over that period of time (<4 therms) as the solar system has met virtually all of the water heating needs of the household.

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improved building “quality” as characterized by improved thermal comfort and sound attenuation, and incorporation of the electric vehicle charging capability available at the house[1]. However, in other lower-cost real estate markets increased attention must be paid to EEM selection and cost effectiveness for ZNE projects. For example, lower cost (and performance) alternatives to the selected windows are available. Evaluating and documenting the performance of these measures in early ZNE projects is important. Using this information to validate savings estimations and inform further cost analysis models is the next step to identify strategies most appropriate for the range of California climates.

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Lessons Learned

Allen Gilliland indicated in an interview that there are several key market barriers that need to be addressed to support the delivery of ZNE buildings. He feels that education of building designers, contractors, and the buying public is needed to fully convey the goals, implications, and inherent value of ZNE approaches. Currently only the pioneeering projects have been introduced to the market with little or no detailed documentation on performance and overall economics. The market needs corroborated case studies to develop a foundation for broader market transformation efforts. In addition, designers and contractors need to become more familiar with advanced techniques in order to gain experience in the design, installation, and bidding of such measures. Finally, from a real estate market perspective, valuing these buildings from a life cycle cost perspective is critical. Currently the

[1] With excess PV generation, an electric vehicle can be charged at a much more competitive “cost per mile” than a competing fueled vehicle.

market does not necessarily reflect long-term energy savings in the selling price of a house, but there are some indications that the real estate market is starting to recognize energy efficiency[2].

Additional Resources

http://siliconvalleyzeroenergyhome.com/

http://oneskyhomes.com/development/cottle-zero-energy-home

[2] http://www.appraisalinstitute.org/education/downloads/AI_82003_ReslGreenEnergyEffAddendum.pdf

Livermore Los Olivos Advanced Home Case Study

Photo courtesy of DEG

Project Summary Information

Location	Livermore, CA
Floor Area	3,080 ft^2
Number of Stories	1
Year Completed	2002 (has been monitored since construction)
% beyond Title 24	26% (1998 standards)
Modeled Performance	60% electrical savings and 47% gas savings projected
Monitored Performance	In most years house is net zero electric (2009: use was 0.5% > than PV generation) Gas use averages ~ 700 therms/year
Cost for EEMs before incentives	$25,000 (includes $8,830 for large shading trellis and estimated costs for donated components)
Cost of EEMs after incentives	$25,000
Incremental EEM Cost per ft^2	$8.11/$ft^2$ (before and after incentives)
PV System Sizing	3.6 kWdc
PV Cost before incentives	$26,820
PV Incentives	$13,390
PV System Cost per ft^2	$8.70 and $4.36/$ft^2$ (before and after incentives)
Incentives/Rebates as a % of total cost	26% ($13,390 out of $51,820)
Total Incremental Cost *	$16.81/$ft^2$ (before incentives); $12.47/$ft^2$ (after incentives)

* Note: Not true ZNE

Project Overview

The 3,080 ft^2 near-ZNE house built in Livermore, CA by Centex in 2002, was one of the early pioneering high efficiency production homes built in California (Parker 2009). The project was initially selected to demonstrate alternative cooling strategies under the California Energy Commission (PIER) supported Alternatives to Compressor Cooling (ACC) project, and subsequently as a pilot zero energy house under the DOE Zero Energy Homes program. Centex also had an interest in testing emerging green building standards under development by Alameda County Waste Management District. The Livermore house was built using a standard floor plan that was used repeatedly by Centex in their Los Olivos development in Livermore, but was modified to include ACC design features aimed at reducing compressor cooling energy use and peak cooling demand. Consistent with the ACC approach, the house design combined a high performance building enclosure, added thermal mass, and a prototype night ventilation cooling system. A 3.6 kWdc PV array and solar thermal water heating were added to fulfill the requirements of the Zero Energy Homes program. Other installed measures included radiant barrier, high performance windows, blown wet cellulose wall insulation, and exterior window shading.

Design Approach

Though it falls within California Climate Zone 12, Livermore represents a transitional climate between the hot Central Valley and the Bay Area marine climate. This type of transitional climate is problematic for electric utilities since peak cooling demands are similar to those experienced in the Central Valley, yet annual cooling energy use is generally low. Night ventilation cooling is ideal in this climate, since a well-insulated, tight building enclosure can store night cooling to coast through most days without the need for air conditioning, and the cooling load can be significantly reduced on peak days. The Title 24 compliance run indicated performance 26% better than standard, without any credit for ventilation cooling, since it was not a compliance option and could not be modeled.

Cost Considerations

Limiting construction cost was secondary to meeting the ACC and zero energy design objectives. To improve cost-effectiveness, several of the measures such as solar water heating and slab edge insulation should be revisited for future projects. The site fabricated trellis which provided exterior wall and patio shading, cost over $8,800, representing more than 1/6 of the total incremental cost. At that price, the trellis is clearly not cost effective, but similar shading can be incorporated into house architecture using roof overhangs and other features that have a much smaller impact on cost.

Another key market issue is contractor familiarity with the technology. The HVAC subcontractor charged nearly $4,000 in labor to install the two hydronic air handlers (which also provide night ventilation cooling). This was his first experience with the technology, and his bid reflected a high perceived level of risk. Given that the house could have utilized just one system, this cost could have been substantially reduced. The slab edge insulation, which also contributed to the cost, had a marginal energy savings value and was personally installed by the Centex project manager because the subcontractors were reluctant to do it.

Of the total project incremental cost of $51,820, EEMs added $25,000 to the overall cost, or about $8/ft^2. The PV cost of $26,820 was reduced by $13,390 through tax credits and incentives. The overall incremental project cost after incentives was $38,430, or about $12.50/ft^2. Given that the house was priced at around $800,000, the incremental costs added less than 5% to the overall price. In expensive real estate markets, ZNE (or near-ZNE) costs are easier to incorporate into the overall project cost.

Performance Validation

Monitoring results indicate that in virtually every year since the house was completed in 2002, the output of the 3.6 kW PV system was sufficient to balance annual household consumption. During the first year of monitoring, less than 15% of the 901 kWh consumed for cooling occurred during PG&E's Noon to 6 PM on-peak period, with total air conditioner compressor operation during the first summer totaling just nine hours. Low cooling demand and cooling energy use associated with the ACC design philosophy provides benefit to both the customer and the utility.

Lessons Learned

Demonstration projects, such as the Livermore ACC house, serve as a test bed for advanced strategies to both gauge performance and cost. This is an important step in the process of vetting new technologies. Except for solar water heating, the Livermore house (built in 2002) would probably just meet current Title 24 standards (R-13 wall insulation, high performance windows, and radiant barrier roof sheathing are all in current prescriptive standards).

Construction and monitoring of the Los Olivos house provided several lessons that can be applied to future ZNE homes:

- The combination of a good thermal envelope and ventilation cooling can successfully reduce air conditioner size and peak load and energy use in inland valley climates;
- Combined space and water heating systems using tankless water heaters are efficient and can provide equivalent comfort to furnaces;
- Careful selection of energy efficiency measures can avoid high cost measures that offer minimal return (such as slab edge insulation, in this case);
- Awareness by the homeowner of distinctive energy features can cause them to be advocates for energy efficiency (the owners had little interest in or knowledge of energy efficiency before they purchased the house and are now strong advocates);
- Builder and contractor familiarity with new technologies is critical in achieiving cost reductions.

Early adopters are sometimes victims of new technology. One of the three inverters installed in 2002 has malfunctioned and the owners are currently struggling to find someone who will service the AstroPower system. AstroPower was acquired by General Electric, who then discontinued manufacturing and support. This type of risk is not totally un expected when new technologies are introduced to the market.

Additional Resources

Parker, Danny S. 2009. "Very low energy homes in the United States: Perspectives on performance from measured data." *Energy and Buildings* 41(5): 512–520.

Springer, D., G. Loisos, L. Rainer. 2000. Non-Compressor Cooling Alternatives for Reducing Residential Peak Load. Proceedings, 2000 ACEEE Summer Study.

http://www.nrel.gov/docs/fy05osti/37320.pdf

http://discovermagazine.com/2003/apr/featunplug

Tucson Advanced Home Case Study

Photo courtesy of La Mirada Homes

Project Summary Information

Location	Tucson, AZ
Floor Area	1,935 ft^2
Number of Stories	1
Year Completed	2011
Modeled Performance	45% whole house source savings w/o PV; 73% savings with PV
Monitored Performance	From August 2011 to April 2012, PV generation offset 71% of household electrical consumption (all-electric home)
Cost for EEMs before incentives	$32,441
Cost for EEMs after incentives	$32,441
Incremental EEM Cost per ft^2	\$16.76/ft^2 (before and after incentives)
PV System Sizing	3.4 kWdc
PV Cost before incentives	$24,045
PV Incentives	$18,236
PV System Cost per ft^2	\$12.42 and \$3.00/ft^2 (before and after incentives)
Incentives/Rebates as a % of total cost	32% ($18,236 out of $56,486)
Total Incremental Cost *	\$29.18/ft^2 (before incentives); \$19.76/ft^2 (after incentives)

* Note: Not true ZNE

Project Overview

The "Super Energy Efficient Designed" (SEED) home, located in Tucson, Arizona, was developed with the goal of delivering an affordable, highly energy efficient home. The near-ZNE design, developed with support from DOE's Building America program, included two measures not commonly seen in residential construction: structurally insulated panel (SIP) walls and roof, and radiant floor delivery for space heating and cooling. This project provides an opportunity to evaluate the commercial viability of these aggressive energy efficiency measures (EEMs) in a hot-dry climate.

The Tucson climate (heating and cooling degree days of 1,578 and 3,017, respectively) is similar to that of the southern California region of Palmdale and Riverside, CA (1,569 and 1,446 heating degree days, respectively) in the heating season, and between Riverside and Palm Springs, CA (1,756 and 4,141 cooling degree days) in the cooling season. Climatically, one distinction is that Tucson does experience summer monsoon events, which contribute to higher summer humidity conditions than are common in California desert regions.

Design Approach

In conjunction with the developer, La Mirada Homes, the Alliance for Residential Building Innovation (ARBI) Building America consulting team evaluated potential energy efficiency measures using NREL's BEopt building energy simulation model[1]. Working with the builder, ARBI evaluated an air-to-water heat pump as the preferred approach to delivering radiant heating and cooling to the space. In addition to the 3.4 kW PV system installed on the house, the following EEMs were installed:

- SIPS (R-27 + R-5 exterior walls, R-41 roof) with tested low-leakage envelope (2.4 ACH50)
- High performance windows (U-Factor/SHGC = 0.29/0.21)
- Insulated slab foundation (R-7 slabedge, R-10 underslab), 5" thick exposed floor (thermal mass)
- R-6 insulated ducts in conditioned space (tested at <6% leakage)
- Compact fluorescent lamps for permanently wired lighting fixtures
- Energy recovery ventilator for fresh air ventilation
- Air to water heat pump (9 HSPF, 13 SEER, 11 EER)
- Hydronic delivery to slab with secondary forced air delivery via fan coil (for dehumidification)
- Active solar with electric resistance water heating backup

Combining hydronic space heating and cooling delivery with an exposed (and insulated) floor slab was a test of a high efficiency approach which can utilize the floor mass to shift heat pump operation to off-peak periods. Evaluations were also completed to assess solar space heating viability. The analysis concluded that the incremental savings in designing a combined space and water heating solar system was not sufficient to offset the added cost and complexity. The modeling effort indicated that incorporating the SIPs treatment and ducts in conditioned space each resulted in an approximate

[1] http://beopt.nrel.gov/

reduction of 25% in annual heating and cooling loads (combined ~ 45-50%) from the benchmark performance level. Cooling system sizing calculations indicated that a conventional 4-ton air conditioner could be reduced to 2-ton sizing due to the implemented load reduction measures.

Cost Considerations

The SEED house implemented several advanced efficiency strategies not commonly used in production housing, including SIPs wall and roof assemblies, and an air-to-water heat pump system with radiant delivery. At the SEED house, the SIPs incremental costs were projected at $16,094 ($8.31 per ft^2, before incentives), and the 2 ton air-to-water heat pump, radiant components, and air handler added $11,374 ($5.88 per ft^2, before incentives). These technologies are not considered mainstream, which results in higher costs due to an undeveloped delivery infrastructure, as well as higher bids from contractors unfamiliar with the technology.

Of the total project incremental cost of $56,486, EEMs added $32,441 to the overall cost, or nearly $17/ft^2. The PV cost of $24,045 was reduced by $18,236 through Federal and state tax credits, along with local utility incentives. The overall incremental project cost after incentives was $38,250, or about $20/ft^2. The developer offset much of that cost by reducing the level of amenities in the house including exposed flooring vs. carpeting (exposed floors are beneficial for radiant delivery), reduced flatwork cost, and less expensive countertops, cabinets, and lighting fixtures. The builder also reduced his profit margin on the home price in order to make the price of the home competitive in the Tucson market.

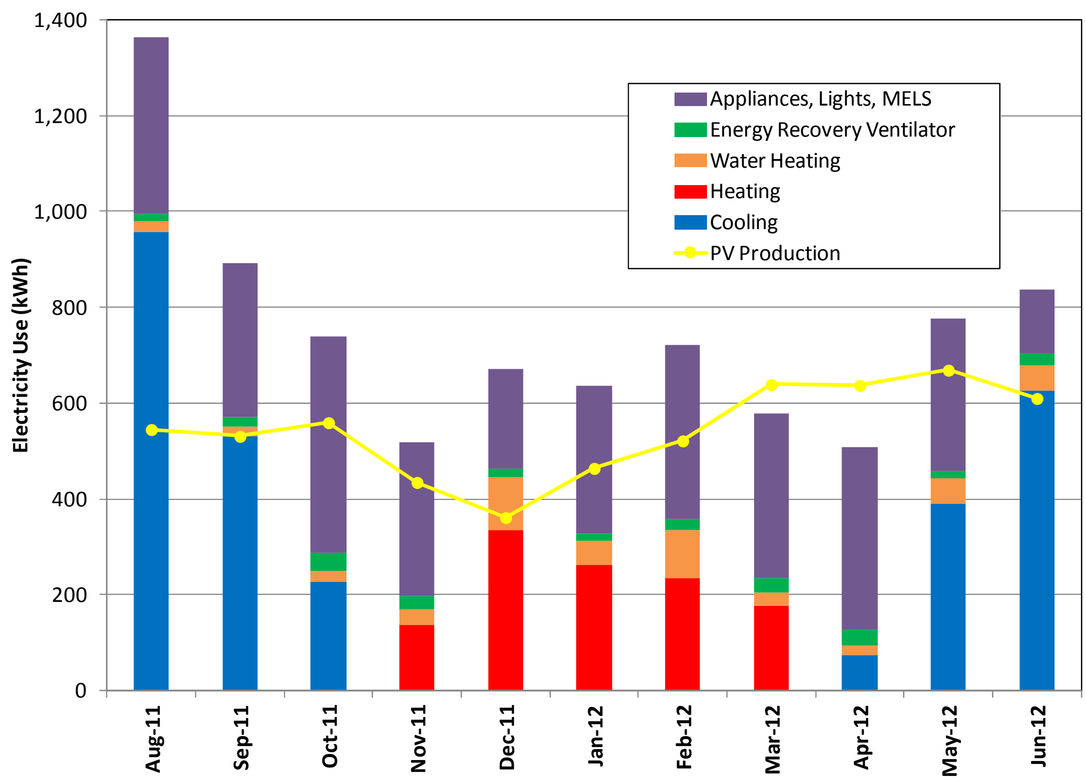
Savings projections estimate an annual utility cost savings of $1,162 per year. At the 5.5% interest rate assumed in the Building America report, this level of cost savings (ignoring utility rate escalation) would accommodate an additional $17,000 in amortized cost. (At more current 4% interest rates, the $17,000 would rise to $20,200.) Under a scenario where the more exotic measures in the SEED house would be considered more mainstream, it is conceivable that the $20,000 cost point could be achieved. Alternatively the EEM package for the SEED house could be further optimized to replace more costly components with lower cost alternatives. For example, a heat pump water heater could replace the solar water heating system at a much lower cost, or a traditional forced air system could be used to eliminate the radiant system cost, although some comfort and performance degradation might occur.

Performance Validation

The radiant slab cooling approach allows the compressor to remain entirely off-peak on virtually all days when outdoor temperatures remained below 100^{o}F. As well as providing significant energy savings, the house performance is also very attractive to the local electric utility in terms of on-peak avoidance.

Figure shows monthly monitored electricity use by end-use, including monthly PV system production, during the August 2011 to June 2012 occupied period. Electricity use in August is twice as high as most other months due to very high cooling loads. During the eleven month period, total electricity production from the 3.4 kW PV system offset 82% of total house electricity loads. Almost half of all electricity consumed during the eleven months is attributed to lighting, appliances, and miscellaneous electrical loads (MELs). Cooling use represents another 25% of monitored consumption. The radiant slab cooling approach allows the compressor to remain entirely off-peak on virtually all days when outdoor temperatures remained below 100°F. As well as providing significant energy savings, the house performance is also very attractive to the local electric utility in terms of on-peak avoidance.

Figure 1: Monitored SEED House Electricity Use and Generation



Lessons Learned

The costs of advanced measures such as SIPs construction and radiant delivery can be significant, primarily because many contractors are not sufficiently acquainted with implementing these technologies. Over $27,000 in added costs are associated with these two measures. Due to the prototype nature of this project, the HVAC system costs were higher than would be expected if installed by a contractor more familiar with this strategy. Although these features are central to the overall SEED efficiency (and thermal comfort), costs must come down for these measures to become mainstream. A key focus of the Building America program is to test and rigorously document advanced strategies in different climates and configurations to determine what works best. Identifying where alternative strategies may produce similar energy savings without compromising performance is also important. For example, double stud walls can achieve similar assembly R-value to SIP walls at a portion of the cost. However, in this case the tradeoffs include reduced quality assurance of assembly integrity and insulation quality. These tradeoffs can be addressed with proper contractor training and quality control.

As time-of-use pricing and demand response programs become more prevalent, and zero net energy homes are encouraged or mandated through regional and/or national energy policies, operational strategies such as off-peak cooling will likely play a more important role in home design. In dry climates such as California, high thermal mass designs can significantly dampen summer interior temperature swings and lower utility bills (under time-of-use rate structures) with little or no comfort implications.

The developer's strategy of trading high-end finish products with energy efficiency is interesting and demonstrates that high performance homes can achieve relatively low incremental costs if buyers are willing to accept certain trade-offs. However, it is not expected that this strategy will be easily replicated as marketing strategies surrounding high performance homes have typically focused on how a consumer's level of comfort can be increased without any quality or performance tradeoffs. Future work must focus on identifying which advanced technologies and strategies are viable and increasing their market penetration and acceptance thus lowering incremental costs.

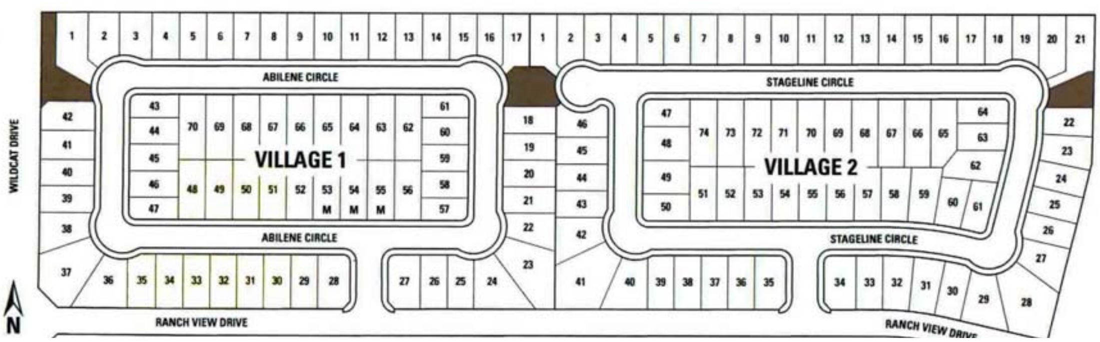
Additional Resources

http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ns/c15_super_ee.pdf

http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/seed_home_eval.pdf

Carsten Crossings Community Scale Project

Photo courtesy of DEG



Project Summary Information

Location	Rocklin, CA
Number of Residential Units	84 built (144 homes originally planned)
Range in House Floor Area	2,168 to 2,775 ft^2
Commercial Floor Area	n/a
Project Buildout	2005-2007
% below Title 24	36% better than 2005 Title 24
Monitored Performance	Utility bill evaluation of 61 homes vs. 95 reference homes (45% electric and 16% gas savings vs. reference homes)
Cost for EEM's before incentives	$5,275 for average home
Cost for EEM's after incentives	$4,250 for average home
Average Cost per ft^2	$2.21 and $1.78/$ft^2$ (before and after incentives)
PV System Sizing	2.4 kWdc (not designed for ZNE)
PV Cost after incentives	$14,100
PV System Cost per ft^2	$5.90
Total Incremental Cost *	$8.11/$ft^2$ (before incentives); $7.68/$ft^2$ (after incentives)

* Note: Not true ZNE

Project Overview

The Carsten Crossings neighborhood is located within the 1,200 acre Whitney Ranch development in Rocklin, California. It is one of the earliest examples of a subdivision-scale, near-ZNE project in the U.S. The project has been well-documented in terms of first costs, operating cost, and monitored performance[1]. The project, developed by The Grupe Company of Stockton, CA, will ultimately consist of 144 three-to-five bedroom homes. Early in the design process, Grupe requested design assistance from Davis Energy Group (DEG) and subsequently agreed to become a partner under the DOE-sponsored Building America Program. DEG helped Grupe select a package of energy efficiency measures (EEMs) and provided technical and marketing support through the construction process. The SunPower Corporation also provided support for the project through the CEC's Zero Energy New Homes program. Construction of the first homes began September 2005. Six plan types were offered, ranging from 2,168 ft^2 to 2,755 ft^2 homes. Prices for the homes ranged from $489,000 to $529,470 (Building America Program 2007). Following the 2008 collapse of the housing market, Grupe halted construction after having completed 84 homes.

Design Approach

Working closely with Grupe and SunPower, DEG evaluated potential EEMs using NREL's BEopt building energy simulation model. Grupe provided actual measure costs so that cost-optimal designs could be developed with a goal of achieving a positive cash flow for homeowners (annual utility bill savings exceed amortized cost of the measures for various configurations of EEMs. In addition to the 2.4 kW SunPower building integrated PV systems installed on every home, the following energy efficiency measures were installed:

- High performance (Low-E^2) vinyl frame windows (U-Factor = 0.35, SHGC = 0.32)
- Radiant barrier roof sheathing, and R-49 attic insulation with buried attic ducts
- HERS-rater inspected "quality" wall insulation (R-13), with R-4 rigid exterior wall insulation
- Compact fluorescent lamps for permanently wired lighting fixtures
- "SmartVent" night ventilation cooling system
- Continuous fresh air ventilation system
- 94 AFUE variable speed furnace
- 13 SEER AC (15 SEER air conditioners were added to later homes)
- Tankless gas water heater with PEX home run hot water distribution system

The combination of high performance walls, windows, and attics, combined with HERS inspections, contributed to a quality thermal envelope. On average the homes were found to be 36% more efficient than the 2005 Title 24 code in place at the time. The selected measures were fairly mainstream high efficiency choices at that time.

[1] http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_solar_casestudy_grupe.pdf

Cost Considerations

The total cost for the installed EEMs and PV systems averaged to be $18,350 per house. Efficiency measures before incentives averaged $5,275, or about $2.21/ft^2$ for a typical house plan. Utility efficiency incentives reduced the incremental cost to $1.78/ft^2$. PV represented the bulk of the incremental cost at $14,100 (after utility incentives) for the installed 2.4 kW system. After incentives and credits, net incremental costs ranged from $15,064 to $15,576, depending upon house size. At the time of original project reporting, the annual amortized cost to the owner at 7% interest (30-year fixed loan) totaled $1,229. (Using a conservative 2012 interest rate of 4%, the annual amortized costs would be $882.)

Due to the declining housing market in 2006 when the project was being built, Grupe felt that they had to sell homes at the neighboring market rate and not charge a preimum for the EEMs and solar features. This gave Grupe a unique opportunity to differentiate their homes from the competition. Grupe felt that the energy features would give them a sales advantage over their competition, and they could recover the additional construction costs through quicker home sales. They also hoped for additional benefits including increased publicity and improved customer satisfaction.

A 2008 ACEEE paper (Dakin, Springer, and Kelly 2008) evaluated the sales data and clearly validates the builder's decision. With Grupe's carrying costs for keeping a subdivision operation underway, they would need to sell 2.0 homes a month to break even. During a period that spanned 2006 and 2007, they sold an average of 4.0 homes a month. In comparison, the neighboring eight active subdivisions averaged sales of 1.8 homes per month. Over the course of the full 144 unit planned build-out, this would reduce carrying costs by nearly $13 million, or roughly five times Grupe's investment in EEMs and PV.

Performance Validation

As part of Building America program evaluation activities, DEG was required to collect neighborhood-wide utility bill data for homes of similar size and vintage in adjacent Rocklin neighborhoods (the "reference" communities) in order to compare utility bills over a broad sample of homes. PG&E provided utility bill data for two nearby communities: Community #1 was built between 2003 and 2004 and included houses ranging from 1,899 to 4,059 ft^2; and Community #2 was built in 2006 and included houses ranging from 1,801 to 3,096 ft^2. PG&E utility meter data from July 2007 to June 2008 was used in the evaluation. A total of 61 Carsten Crossings and 95 reference community homes were used in the evaluation, with homes eliminated that did not have a complete years' worth of electricity use, had swimming pools, or where energy usage was identified as a statistical outlier.

Figures 1 and 2 graphically present the annual metered electricity and gas energy consumption for each of the 156 homes in the study reported in a 2010 ACEEE paper (Backman et al, 2010). Annual electric savings averaged 45% relative to the reference community (5,245 vs. 9,483 kWh/year), with several of the households being net generators over the course of the year. On the gas side, annual savings averaged 16% (391 vs. 465 therms/year). Higher observed percentage savings for electricity reflect the combination of both efficiency and PV generation, while gas savings are solely attributable to efficiency improvements. Annual utility bill savings averaged 53% ($1,181 savings[2] vs. $2,247 reference community average bill), which was significantly more than the amortized incremental cost.

Figure 1: Annual Metered Household Electric Use

(Each bar represents one house)

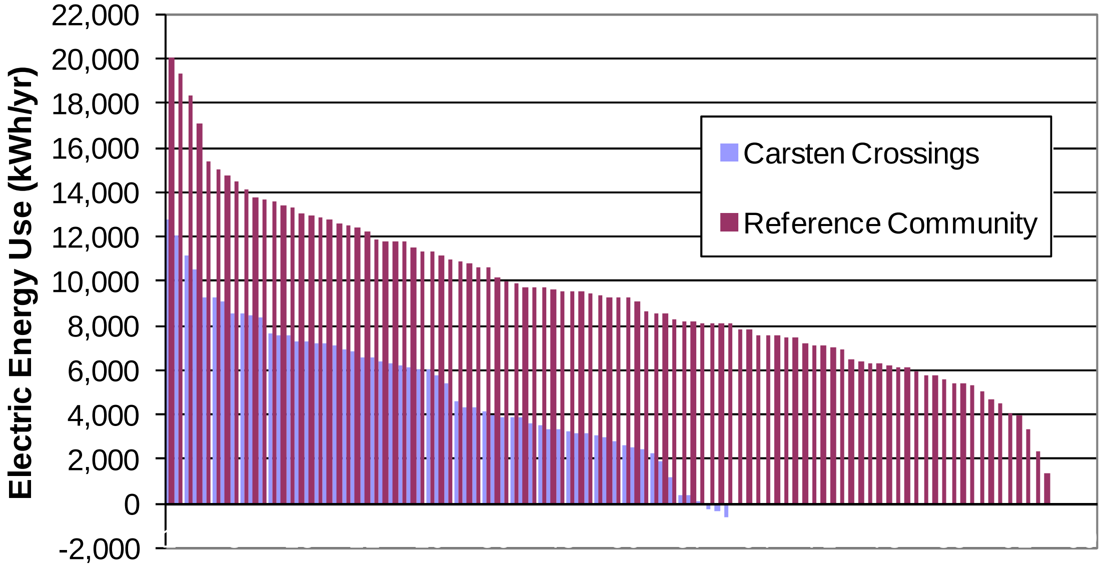
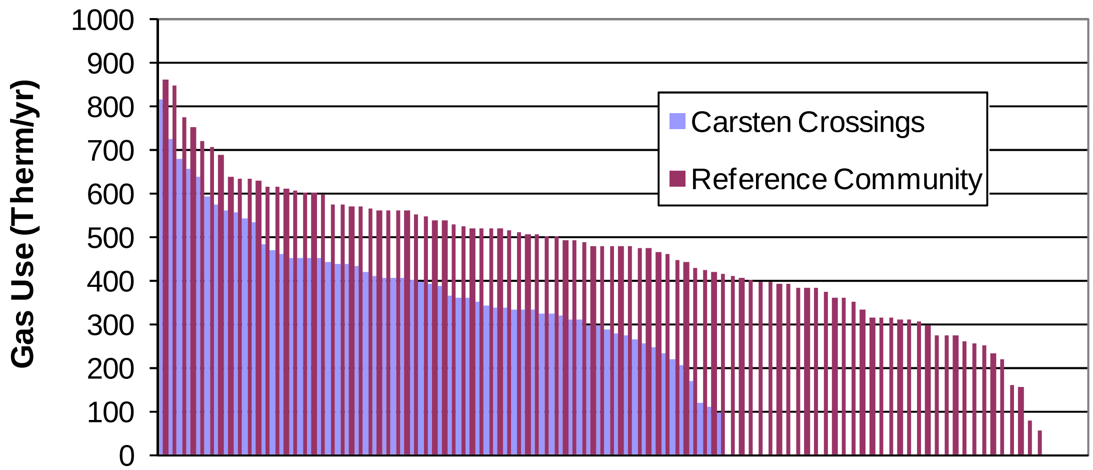


Figure 2: Annual Metered Household Natural Gas Use

(Each bar represents one house)



[2] Homeowner cost savings are greater than the energy savings due to PG&E's tiered rate structure.

Lessons Learned

A collaborative design process involving the builder team and consultants helped to facilitate the demonstrated performance of this community. Detailed modeling completed during the design phase identified the potential for favorable homeowner economics. The modeling process gave the builder a level of confidence that the economic picture for homeowners was compelling and would contribute to increased buyer demand. The greater market interest was realized and documented through a home sales rate nearly 2.5 times faster than eight neighboring active subdivisions. The carrying cost savings realized by the builder due to faster sales, was more than five times greater than the incremental construction costs. With the housing downturn, this approach has not been replicated, although the potential for success appears high.

In addition to realizing economic benefits, Grupe also experienced customer service benefits with fewer post-occupancy callbacks. Quality assurance measures such as insulation inspections and HVAC commissioning contributed to improved comfort and system performance. Grupe's experience in this project helped to transform their business model and refocus their efforts to a more efficiency-oriented, sustainable approach.[3]

Additional Resources

Backman, C., Dakin, B., and D. Springer. 2010. "A Case Study in Reconciling Modeling Projections with Actual Usage." ACEEE Summer Study. In Pacific Grove, CA.

Dakin, B., Springer, D., and B. Kelly. 2008. "The Effectiveness of Zero Energy Home Strategies in the Marketplace." ACEEE Summer Study. In Pacific Grove, CA.

[3] http://www.greenbygrupe.com/

West Village ZNE Community Case Study

Photo courtesy of UC Davis

Project Summary Information

Location	Davis, CA (University of California at Davis campus)	
Building Type	**Multi-Family**	**Single Family**
Number of Units	504 student apartments occupied as of Sept 2012; 156 slated for '13 completion	343 homes planned (Construction starting early 2013)
Range in Floor Area	785 to 1,453 ft^2 apartments	1,637 to 2,258 ft^2
Commercial Floor Area	42,500 ft^2 of Retail/office space in mixed use buildings; completed 2012	
Project Build out	2010-13 for apartments & mixed use	2013-2017 for single family
% below Title 24	~40% better for student apartments and ~20% better for mixed use	~54% better than 2008 Title 24 for typical single family home
Monitored Performance	Apartment monthly data available January 2012	n/a
Energy Efficiency Measure (EEM) Cost before incentives	\$5,166 (\$3.87/ft^2) for typical student apartment (1,334 ft^2)	\$8,500 (\$4.78/ft^2) for average home (1,780 ft^2)
EEM Cost after incentives	\$4,641 for student apartment	\$3,100 for average home
Average EEM Cost per ft^2 after incentives	\$3.48/ft^2	\$1.75 /ft^2
PV System Sizing	2.55 - 4.73 kWdc systems on student apartments (developer owned)	~ 6.5 kWdc systems (PV owned by homeowner)
PV Cost	Not available	

Project Overview

UC Davis West Village is the largest planned Zero Net Energy (ZNE) community in the United States[1]. Initial concept planning on the development dates back to 2003. The project, located adjacent to the main University of California, Davis campus, is designed to demonstrate that a ZNE community is practical and achievable on a large scale. The $280 million dollar project, developed by private developer West Village Community Partners[2] on University owned land, will ultimately include over 1.5 million ft^2 of conditioned floor space. The project is comprised of approximately equal parts student apartments and price-controlled faculty and staff single family homes, as well as 42,500 ft^2 of mixed use space, and a 56,000 ft^2 community college building. Most of the student apartments are completed as of September 2012, with the remaining units slated to open in 2013. Construction of single family homes will begin in 2013. The project includes extensive energy efficiency efforts to reduce building loads, and a total of 5.2 MW of PV located both on rooftops and ground-mounted over parking areas. Additional efforts are underway to integrate alternative renewable resources, potentially including an agricultural waste-fueled biogas digester powering a microturbine.

Design of the buildings and mechanical systems was supported with a variety of research funding, including the Department of Energy's (DOE) Community Renewable Energy Deployment program and Building America program, as well as California Energy Commission funding through the California Solar Initiative and PIER's Renewable-Based Energy Secure Community program. The research funding played a critical role in evaluating alternatives. Nolan Zail, project manager for the development team, indicated that the overall ZNE project design would likely not have gone forward without outside technical support.

Design Approach

From the very early conceptual stages, UC Davis was interested in promoting sustainability and energy efficiency at West Village, as well as offering affordable housing for University faculty and staff. Initial modeling efforts completed in 2003 and 2007 were performed to provide a high level review of potential energy efficiency measures (EEMs) for the planned single family homes. However, it wasn't until after UC Davis had signed a contract with West Village Community Partners (WVCP) that the ZNE goal was introduced. Though the developer was not contractually obligated to achieve this ambitious goal, they were open to incorporating EEMs that could be justified as cost-effective. With support from the California Energy Commission, Davis Energy Group was hired by Chevron to complete detailed modeling to determine if overall community ZNE goals were achievable. DEG also worked with Chevron and WVCP to develop EEM packages that were acceptable to WVCP and their design team. This evaluation included a life cycle cost analysis to provide WVCP assurance that the project was viable in the case that the complex business model fell through. The detailed modeling effort involved use of

[1] http://www.ucdaviswestvillage.com/community

[2] West Village Community Partners is a joint venture led by Carmel Partners of San Francisco with their partner, Urban Villages of Denver.

advanced simulation models (BEopt, eQuest, EnergyPro) and an iterative approach to evaluate measures for cost effectiveness (EEM package with simple paybacks of about 8 years) and feasibility of installation or construction. WVCP's construction timeline focused on getting the mixed use buildings and the first phase of student apartments (192 units) completed for the 2011-12 academic year. Selected EEMs for the student apartments include:

- 2x6 wall construction with R-21 batts and R-2 rigid exterior insulation;
- R-49 ceiling insulation with attic radiant barrier and Cool Roof roofing ;
- High performance windows (U-Factor/SHGC = 0.32/0.23);
- Third party Home Energy Rater inspections: Envelope leakage, duct leakage testing (<6%), quality insulation inspections & quality HVAC installation inspections;
- Added thermal mass on upper floors, with ceiling fans for low energy cooling
- 100% fluorescent lamps for permanently wired lighting fixtures with vacancy controls
- Energy Star dishwasher, refrigerator, & clothes washer
- Central air-to-water heat pump water heater; each serving 12 apartments (2.7 Energy Factor)
- High efficiency air source heat pump (8.5 HSPF, 15 SEER, 12.5 EER)

While the EEM packages focused on practical, cost-effective measures, additional measures were incorporated into the building design in order to get total estimated community energy use to a level where the zero net energy community goals could be met based on the available renewables. These additional EEMs included hard-wired high efficacy lighting fixtures and vacancy sensors in all rooms, plug load control capabilities, and solar water heating. Solar water heating was dropped from the final package when PV was moved to the roof and the plug load control devices have not yet been successfully implemented.

Proposed single family measures are generally consistent with the multi-family with the exception of space and water heating. The current plan for the single family homes is to utilize natural gas condensing tankless water heaters in a forced-air combined hydronic configuration.

The original renewables design strategy was for the community to have centralized PV with a micro-grid owned and operated by the university. Due to regulatory issues and cost restraints, the utility trenches are owned and maintained by PG&E and the PV systems are installed as individual systems per apartment. NSHP program requirements at the time the first Phase was developed required that each apartment have a dedicated meter and PV system behind the meter. WVCP is the utility account owner and pays for the utilities for all apartments.

Cost Considerations

To date, accurate costs exist only for the multi-family units, since the single family homes are in the final design process[3]. The multi-family list of measures includes conventional off-the-shelf efficiency measures with the exception of the central heat pump water heater. The modeled energy savings for the EEM package were calculated to develop a 58% reduction in site energy at a cost of just under $\$4/ft^2$ (before incentives). Incentives through the California Multi-Family New Home (CMFNH) Program reduce the incremental costs to $\$3.50\ ft^2$

The developer owns and operates the student apartment units with all energy use costs covered in the rental rates. While rents are on the high end, accounting for utility costs, the rents are competitive with other higher end student rental properties in town. Incremental costs for the EEMs and for the PV are being recouped over time in the apartment rents.

The complexities of the West Village project make it challenging for the developer to recover capital costs. To provide affordable housing to campus faculty and staff, UC Davis is limiting the home sales prices for the single family homes. The model is for the homes to cost no more to the builder or the homeowner than a home purchased in town. UC Davis has agreed to reimburse WVCP for incremental efficiency and PV costs. This cost is to be recovered from homeowners in some form, possibly through land use or homeowner association fees. In return, homeowners would own a ZNE home at no additional cost than a standard house built to existing code. However, the overall monthly operational cost (utility + any fees to UC Davis) would also be the same as the house across the street, but presumably escalate at a lower rate than general utility rates. This is a persuasive model, but not necessarily replicable. The unique characteristics of this project, such as the university-owned land and upfront payment to the developer for incremental capital costs of the ZNE design, make it a unique public-private partnership.

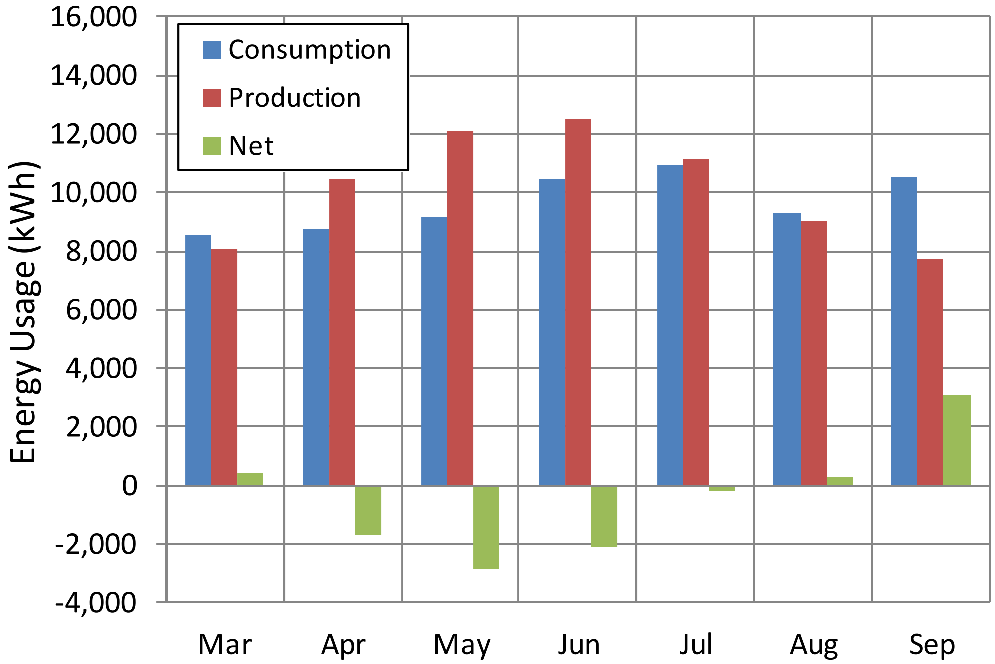
Performance Validation

Phase 1 buildings were completed and occupied in September 2011 but the PV systems did not start to come online until November 2011. SunPower, the PV installation contractor, developed a web portal to access both gross electrical energy consumed and PV generated from each of the apartments. The SunPower meters did not go online until early 2012. Preliminary review of utility bill and SunPower data for the student apartments shows that on average the student apartment buildings are close to achieving zero net energy. Figure 1 shows average monthly building electricity consumption, PV production and net building usage data from March through September 2012, which represents the period when the Phase 1 PV was fully operation and all billing and generation data were available. This initial data shows that, on average, the buildings are net zero for the period of March through

[3] Preliminary cost estimates for the single family efficiency measures suggest EEM incremental costs of about $\$4.78/ft^2$ for the average floor plan. Preliminary estimate of incentives through the California Advanced Home Program indicate incentives of ~$5,400, reducing the incremental costs to $\$1.75/ft^2$.

September 2012, although the low PV production months during the winter are not yet accounted for. The expectation is that the project's overall energy picture will improve as issues get resolved with some of the underperforming heat pump water heaters and project-wide tenant education messaging can be developed and better targeted to the West Village community.

Figure 1: Average Monthly Student Apartment Building Energy Flow



Lessons Learned

Nolan Zail, former Senior Vice President of Carmel Partners (and now an independent project consultant), provided several interesting insights on the ambitious West Village product. Many of his comments relate to the complexities of developing the project, which involves resolving regulatory, tax, and legal issues in a situation where the university owns the land, a non-taxable subsidiary owns much of the PV, apartment rents include base electrical consumption[4], and a myriad of other issues. Mr. Zail stated that navigating rules and regulations in order to optimize the capital cost recovery for the project was an extremely complex process. Regulatory and market barriers prevented the university and WVCP to pursue a West Village micro-grid and forced them to install individual PV systems per apartment in the first phase of the project. Regulatory changes since that time has allowed for virtual net metering within each building, which simplifies the PV installation and allows the benefit of excess PV generation from an individual apartment to be shared by the whole apartment building.

[4] The mechanism for billing tenants for excessive electric use is complicated and not ideal.

A significant challenge that exists with community scale ZNE projects is in the implementation and installation of on-site renewables. While annual energy use may be estimated using average consumption assumptions, actual consumption tends to vary significantly unit by unit, depending on occupant behavior and number of occupants. Current regulatory rules preclude centralized generation, whereby differences in energy use by unit can be averaged over all of the buildings in the community. Sizing PV systems to individual apartments is impractical for ZNE due to occupant variability. Virtual net metering is necessary to more accurately size PV systems for community projects and allow for the community to take advantage of excess PV generation from a low consumption apartment to offset an apartment with higher consumption.

Through the first year of student occupancy vacancy rates at West Village were very low as the amenities and location directly off campus provided a high degree of desirability. Mr. Zail indicated that the students were aware of the unique energy efficiency and sustainability focus of the project, but he personally felt that "the energy and sustainability piece was a small part of the puzzle" in the overall marketing to students. At this point he feels it is unclear what role the ZNE and sustainability aspects of the project factor into the renters' decision. The single family development may yield a different assessment of the ZNE benefit, although it is premature at this time.

Although he remains enthusiastic about the project and the future evolution of community-scale ZNE projects, Mr. Zail expressed concern about the complexities of creating such a project and the challenges of developing a compelling business model. From Carmel Partners' viewpoint, participating in such a landmark project certainly has given them the credentials to pursue similar projects in the future, but it is unclear at this time whether they would enter into a free-market ZNE project in the future. Mr. Zail stated that WVCP would prefer to be in the housing business and leave the energy production to utilities or others. Regulatory simplification for projects such as this would certainly enhance future community scale projects.

Additional Resources

http://www1.eere.energy.gov/office_eere/de_commre_davis.html

http://www1.eere.energy.gov/office_eere/pdfs/webinar_ucdavid_west_village.pdf

http://aceee.org/files/proceedings/2010/data/papers/2276.pdf

Price S., Chait, M., Dakin, B., and A. German. 2012, "Low Cost ZNE! Implementation of a Zero Net Energy Community at UC Davis' West Village," Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings. In Pacific Grove, CA.

Appendix B: Literature Review Summaries

Residential #1: Building America Best Practices Case Study (4 pages): Premier Homes-Premier Gardens, Sacramento, CA

The report details a case study of Premier Gardens in Roseville, CA, which is a near zero energy community built by Premier Homes in the last decade. The neighborhood was designed to cut energy bills by 50% and incorporate solar energy as a standard feature. More specifically, the homes included a 2.2 kW PV system, a tankless hot water heater with R-4 insulated pipe, high efficiency heating and cooling systems, tight air sealing, fluorescent lighting, and R-38 insulation. The homes achieved Building America goals of 60% reduction in drawn power and reduced natural gas consumption. The additional costs per home were $10,000-15,000, of which the local utility, SMUD, subsidized $7,000 towards construction.

Building Description Building Type: Residential Homes Location: Roseville, CA Square Footage: 1,285-2,248 Number of Floors: 1
Qualitative Assessment of ZNE Package Approach A 2 kW PV system, a tankless hot water heater with R-4 insulated pipe, high efficiency heating and cooling systems, tight air sealing, fluorescent lighting, and R-38 insulation
Quantitative Approach to ZNE (or near ZNE) Goal as Indicated by Monitoring Sought to meet Building America standard for near ZNE home by achieving 60% reduction in energy use.
Incremental Cost per Square Foot (itemized as per efficiency and PV/generation when possible) No provided. Total additional costs were $10,000-15,000 per home.
Avoided Cost due to ZNE Integrated Design Strategies Unknown
Degree of Confidence in Cost Estimates Medium
Incentives and Rebates as a Percentage of Pre-incentive Total Incremental Costs Local utility SMUD contributed $7,000 to offset additional costs for each home
Financing and Partnership Strategies Builder and utility financed.
Motivation in Building ZNE Project Not specified

Residential #2: EnergyTrust of Oregon (brochure): Clearing the Path to Net Zero

The overview describes two Portland-area homes, built by two different builders, which utilize different approaches to minimize energy use and seek to achieve zero energy performance. The *CoreHaus*, built by PDX Living, used air sealing and solar gain heating to reduce energy costs by 75-90%. The *Sage Green* houses built by Green One Construction sought to achieve zero energy performance through a variety of treatments, including innovative wall construction, solar panels, heat recovery systems, and efficient heating and cooling. Information was not provided regarding specifics of actual energy consumption or savings for either project.

Building Description

Building Type: Residential Homes
Location: Portland, OR
Square Footage: 1,400-1,600
Number of Floors: 2

Qualitative Assessment of ZNE Package Approach

CoreHaus: air sealing, solar gain heating

SageGreen: innovative wall assemblies, high-efficiency windows, air sealing, heat recovery ventilator, air-source heating, cooling, solar panels

Quantitative Approach to ZNE (or near ZNE) Goal as Indicated by Monitoring

CoreHaus: zero energy not achieved, sought to reduce energy by 75-90%; SageGreen: not specified

Incremental Cost per Square Foot (itemized as per efficiency and PV/generation when possible)

CoreHaus: incremental costs not provided, total additional costs without considering subsidies were $18,000

SageGreen: incremental costs not provided

Avoided Cost due to ZNE Integrated Design Strategies Unknown

Degree of Confidence in Cost Estimates Medium

Incentives and Rebates as a Percentage of Pre-incentive Total Incremental Costs

CoreHaus: Received $11,000 in Oregon energy tax credits, but the costs detailed above do not include this credit.

Sage Green: $72,000 per house

Financing and Partnership Strategies

CoreHaus: Privately financed and purchased

Sage Green: not specified

Motivation in Building ZNE Project

CoreHaus: demonstration project by building to show market viability

Sage Green: demonstration project by building to show market viability

Residential #3: NREL (Norton, Christensen, Hancock, Barker, and Reeves). The NREL Habitat for Humanity Zero Energy Home: A Cold Climate Case Study for Affordable Zero Energy Homes (2008)

In the study, the authors analyze the design and performance of a 1,280 ft^2 Zero Energy House (ZEH) built by Habitat for Humanity in Danver. The house utilizes envelope efficiency, energy-efficient appliances and lighting, and passive and active solar features to achieve zero energy performance. In considering construction of a Habitat for Humanity house, the design required several unique characteristics related to zero energy construction, including repeatability, use of volunteer labor, no special operation requirements, full-value cost calculations, and simple design. They provide detailed descriptions of the envelope treatments, heating systems, and PV system, as well as performance statistics and PV generation for the first year of operation (Feb 2006 to March 2007).

The research describes costs by breaking them down into separate categories. Construction costs are localized for the metro Denver area, including site, material, and labor costs. Overall, the ZEH cost 8% more per square foot than the standard practice home, and the cost categories affected by the ZEH design were 42% higher for the ZEH than the standard home. The authors note that the costs for land, water, and sewer were higher for the practice home, skewing overall cost figures. The authors provide a detailed breakdown of construction cost data for the ZEH and referenced homes, which is shown in the table below as presented in the publication.

Of note, the authors indicate that a zero energy home is not necessarily devoid of utility bills. For this house, the builders had worked out an agreement with the power company whereby the house would use natural gas for space heating, backup water heating, and clothes drying, with excess energy accumulated at the end of the calendar year compensated based on electricity use. This type of arrangement speaks to the complications involved in defining zero-energy buildings and the interaction with off-site generation capabilities.

Table 2. Construction Cost Data for the ZEH and Reference House

	ZEH	Standard Practice Home	Incremental Costs
Square feet	1,284	1,222	
Number of bedrooms	3	3	
May Be Affected by ZEH Design ($)			
Excavation, foundation	10,630	10,543	87
Joists, decking, framing	9,497	6,029	3,468
Concrete flatwork	5,017	4,248	769
Windows, exterior doors	3,099	1,561	1,538
Trusses, roof, sheathing	3,496	6,137	–2,641
Shingles, gutters	1,723	1,697	26
Siding	4,423	4,696	–273
Mechanical	2,600	5,805	–3,205
Electrical	19,744	4,567	15,177
Plumbing	14,002	6,340	7,662
Insulation	2,893	1,197	1,696
Drywall	3,174	2,473	701
Painting, staining	1,498	1,548	–50
Appliances	903	1,792	–889
Subtotals	**79,525**	**56,160**	**23,365**
Not Affected by ZEH Design ($)			
Vinyl floors	1,784	1,025	759
Interior trim	537	2,177	–1,640
Carpet	1,440	1,209	231
Cabinets	1,384	1,384	0
Land	18,797	39,729	–20,932
Permits	4,529	1,565	2,964
Temporary utilities	636	1,361	–725
Landscaping	5,509	3,480	2,029
Property taxes	33	313	–280
Property development	6,101	4,978	1,123
Soils, surveys	1,219	2,005	–786
Water, sewer	24,603	13,013	11,590
Punch list	80	355	–275
Subtotals	**69,826**	**75,067**	**–5,241**
Grand totals	**149,351**	**131,227**	**18,124**
Cost per square foot	**116**	**107**	**8%**

Building Description Building Type: Residential Homes Location: Denver, CO Square Footage: 1,280 Number of Floors: 1
Qualitative Assessment of ZNE Package Approach envelope efficiency, energy-efficient appliances and lighting, and passive and active solar features
Quantitative Approach to ZNE (or near ZNE) Goal as Indicated by Monitoring Predicted net zero source energy consumption over the course of a year using typical weather and occupant behavior data.
Incremental Cost per Square Foot (itemized as per efficiency and PV/generation when possible) 8%, but not entirely accurate, as land, water, and sewer costs for comparison home were substantially higher than the NZE home. If determined through six pertinent categories, it would be 21% incremental cost over standard package.
Avoided Cost due to ZNE Integrated Design Strategies unknown
Degree of Confidence in Cost Estimates High
Incentives and Rebates as a Percentage of Pre-incentive Total Incremental Costs Not included in analysis
Financing and Partnership Strategies Habitat for Humanity funding and volunteer labor
Motivation in Building ZNE Project Denver-area Habitat for Humanity was motivated to do these projects to explore new models for housing construction.

Residential #4: NREL (Carlisle, Van Geet, and Pless). Definition of a "Zero Net Energy" Community (2009)

The authors provide a definition for a Zero-Energy Community (ZEC) as one that "has greatly reduced energy needs through efficiency gains such that the balance of energy for vehicles, thermal, and electrical energy within the community is met by renewable energy." Building on past NREL work that described definitions for a Zero-Energy Building (ZEB), the authors expanded the scope from buildings to communities. The research uses the Toricellini (2006) definitions for net-zero energy, including: 1) net-zero site energy, 2) net-zero source energy, 3) net-zero energy costs, and 4) net-zero energy emissions. In the end, however, the authors use the term "net zero" in an on-site energy consumption sense, because it has a "more narrow focus than some of the other terms and one can measure and determine if the goal has been achieved."

Communities are classified for net-zero energy use based on a hierarchical methodology (A, B, C, and D) that involves criteria for cost-effectiveness, renewable energy production, and demand-reduction approaches. Further, the beneficial use of brownfields and green spaces in planning is recognized. Communities that meet ZEC energy use requirements entirely through use of renewable energy are placed at the top of the hierarchy. Other communities are rated as "excellent" if they combine varying levels of on-site or off-site renewable energy generation along with energy efficiency strategies and green space in order to achieve net-zero energy consumption. As mentioned, the hierarchy especially emphasizes the positive use of brownfields, which are contaminated sites where redevelopment is more complicated due to health, safety, and environmental concerns. Successful incorporation of brownfields contributes significantly to the overall rating criteria.

The report notes that the goals of a net-zero energy community will need to be "time-phased with intermediate goals" in order to maximize flexibility and minimize economic and social impacts. They argue for development of successful milestones, tailored for a community, that gradually reduce energy use through renewable generation, energy efficiency, and other approaches.

Building Description

Building Type: Not provided
Location:
Square Footage:
Number of Floors:

Qualitative Assessment of ZNE Package Approach

A Zero-Energy Community (ZEC) as one that "has greatly reduced energy needs through efficiency gains such that the balance of energy for vehicles, thermal, and electrical energy within the community is met by renewable energy."

Quantitative Approach to ZNE (or near ZNE) Goal as Indicated by Monitoring

The authors use the term "net zero" for on-site energy consumption.

Incremental Cost per Square Foot (itemized as per efficiency and PV/generation when possible)

n/a

Avoided Cost due to ZNE Integrated Design Strategies

n/a

Degree of Confidence in Cost Estimates

n/a

Incentives and Rebates as a Percentage of Pre-incentive Total Incremental Costs

n/a

Financing and Partnership Strategies

n/a

Motivation in Building ZNE Project

Further the definition of zero net energy to encompass communities.

Residential #5: Parker, D. Very Low Energy Homes in the United States: Perspectives on Performance from Measured Data (2009).

Parker describes a history of the design, performance, and costs associated with low-energy and Zero-Energy Homes (ZEH) in the U.S. through a series of case studies. The review provides a useful background of historic and recent developments for Low-Energy and Zero-Energy homes in the U.S., including features of the earlier generations of homes. MIT was active in early efforts to develop low-energy homes in the 1950's and 1960's. With the onset of the energy crisis in the 1970's, the U.S. saw an explosion of activity regarding low energy homes, especially concentrating on passive solar design and insulation.

The case studies of zero energy homes begin with a home designed by the Florida Solar Energy Center in the late 1980's. By this time, advances in photovoltaic technologies reduced the price of active solar energy production for residential properties. Two experimental "PVRES" buildings were constructed in Lakeland, FL in 1998, which were successful in achieving nearly zero-energy use and peak coincident demand. Based on this demonstration, the U.S. Department of Energy took on the Zero Energy Homes effort, funding a ZEH called the "Solar Patriot." In 2002, a zero-energy home was designed and constructed by Davis Energy Group and Centex Corporation in Livermore, CA, using relatively high levels of insulation and a night cooling system to reduce energy use. Added costs for this home were $26,000, with another $40,000 for the PV and solar water heating systems.

At the same time, Oak Ridge National Laboratories constructed 5 advanced, near-zero energy homes along with Habitat for Humanity, employing innovative heat recovery, ground source heat pumps, heavy structural insulation, high performance windows, and a grey water waste heat recovery system. The added costs for the home were $48,000. In 2003, a ZEH home was built in Tuscon, AZ by John Wesley Miller, featuring an all-electric, well-insulated home with a reflective roof and high efficiency cooling system. The cost of the PV system was $46,100. Parker notes that one of the more impressive ZEH homes is a Habitat for Humanity home in Wheat Ridge, CO, designed by the National Renewable Energy Laboratory (NREL). The PV home produced more electricity than consumed during trials, for an additional cost of $42,500, including the PV system. ZEH development work moved to a larger scale with the construction of Premier Gardens in Sacramento, CA, where 95 entry-level homes were built with moderate levels of energy efficiency design. Energy consumption was significantly reduced at an average incremental cost of $18,836. Parker concludes by describing the German *Passivehaus* design, which seeks to reduce first cost and operational costs through improvement of building envelope, compact design to minimize exterior surface area, and air tight construction. The first *Passivehaus* built in the U.S. was in Urbana, IL in 2002-2003. The electricity production was significantly greater than consumption, and the estimate incremental cost was $18,000 ($162/m^2), with an estimated addition of $32,000 for a PV system.

Parker provides a summary analysis with graphs and tables showing energy performance vs. added initial costs. The range of additional costs for a PV system was $20,000-40,000 (potentially lower now), while the incremental costs for energy efficiency measures varied significantly, but within "the marketable realm."

Building Description

Building Type: Numerous residential homes throughout U.S.

Qualitative Assessment of ZNE Package Approach

The definitions of zero net energy varied based on the various houses described in the document. Homes qualified as zero net energy or near zero net energy through different characterizations.

Quantitative Approach to ZNE (or near ZNE) Goal as Indicated by Monitoring

In most cases, the total site energy consumption of the home was compared to total site energy production of PV panels

Incremental Cost per Square Foot (itemized as per efficiency and PV/generation when possible)

Costs were provided as total incremental costs.

- Washington, D.C. modular home (2001): $22/sq ft., including a $39,000 in a PV system and $7,000 in a solar water heating system
- Livermore, CA (2002): additional $9/sq ft. incremental cost, and $40,000 for the PV and solar thermal system
- Lenoir City, TN (2002-05): incremental costs per square foot not provided, but total incremental cost of $48,000-54,000 depending on year built.
- Wheat Ridge, CO: $33/sq ft. incremental cost, including $32,000 for the PV system
- Smith-Klingenbert Passivhaus: $15/sq ft. incremental cost.

Avoided Cost due to ZNE Integrated Design Strategies

Not provided

Degree of Confidence in Cost Estimates

High

Incentives and Rebates as a Percentage of Pre-incentive Total Incremental Costs

Varies, with many projects qualifying for rebates, but not specified if included in incremental costs

Financing and Partnership Strategies

Varies

Motivation in Building ZNE Project

Multiple projects were described, most of which were early demonstration houses for particular design strategies. In most cases, the homes were collaborative efforts of several companies, government entities, and academic institutions.

Residential #6: Marszal et al. Zero Energy Building: A Review of Definitions and Calculation Methodologies (2010)

The authors review existing Zero Energy Building (ZEB) definitions and methodologies, while trying to define a set of important criteria that should go into development of a definition for ZEBs. While many national building codes are integrating ZEB design into their standards, a commonly accepted definition of a ZEB home does not yet exist. To create such a definition, the authors outline the following key questions to address:

1) *Metric of Balance*- Several metrics can be used, including final or delivered energy use, carbon dioxide equivalent emissions, energy costs, or other standards. The base unit of analysis must be defined and agreed-upon.
2) *Period of Balance*- The period of time over which the energy calculations for the building are performed is important and often varies. The annual energy balance is often used.
3) *Type of Energy Use*- Energy use in a building can vary, so as to include or exclude occupant behavior, actual weather conditions, and methods for heating, cooling, dehumidification, ventilation, humidification, hot water heating, and lighting. Zero Energy Buildings could be considered by developing common metrics to compare between buildings based on the above characteristics, or simply based on overall energy use.
4) *Type of Balance*- The authors note that this is most relevant for grid-connected ZEBs, because there are exchanges of energy between the building and the grid. Thus, definitions could vary based on energy delivery to the grid vs. actual energy consumption.
5) *Renewable Energy Supply*- The distinction between on-site and off-site renewable energy production is important.
6) *Connection with Energy Infrastructure*- ZEB definitions to date have distinguished between off-grid or on-grid zero energy buildings.
7) *Requirements*- Research on ZEBs to date has described the requirements for design, including energy efficiency requirements, indoor climate requirements, and building-grid interaction requirements.

The authors use 12 different approaches for calculating ZEB home performance, with different methods employing different treatments of the above questions to calculate overall energy balance. A model home from Denmark is analyzed to test the variations in methodologies. The authors find that the various methodologies are "quite consistent," with small differences in calculations for delivered energy, primary energy, and costs. The authors present the above questions as a rubric for determining a common definition of ZEBs without delineating a specific definition themselves.

Building Description

Building Type: Multifamily apartment building with 60 units
Location: Aalborg, Denmark
Square Footage: 7,000
Number of Floors: not provided

Qualitative Assessment of ZNE Package Approach

12 different approaches are characterized for calculating ZNE, with the model home used to test the various approaches.

Quantitative Approach to ZNE (or near ZNE) Goal as Indicated by Monitoring

The 12 approaches use various metrics, periods, definitions of energy use, and on- vs. off-site electricity generation. Table 1 provides a breakdown for the various methods.

Incremental Cost per Square Foot (itemized as per efficiency and PV/generation when possible)

Not provided

Avoided Cost due to ZNE Integrated Design Strategies

Not provided

Degree of Confidence in Cost Estimates

Not provided

Incentives and Rebates as a Percentage of Pre-incentive Total Incremental Costs

Not provided

Financing and Partnership Strategies

Not provided

Motivation in Building ZNE Project

The researchers did not build the ZNE project, but use it to explore building performance across various definitions for calculating ZNE.

Residential #7: NAHB Research Center. Final Report for the M.E.G. Home: Maryland's First ZNE Home (2007)

The report describes a near-Zero-Energy Home (ZEH) constructed between 2004 and 2006 by the NAHB Research Center, the Maryland Energy Administration, the Department of Energy's Building America program, and Bob Ward Companies. The home is located near Washington, D.C. The collaborators selected a 2500-square-foot stock-model home and applied "off-the-shelf" methods such as:

- an improved foundation,
- optimum value engineering framing,
- exterior rigid foam insulation,
- high-performance windows,
- air and duct sealing,
- blown fiberglass insulation,
- high-efficiency heating and cooling systems,
- duct improvements,
- a domestic hot water system,
- efficient lighting, and a
- PV solar electric system.

As a stock home, changes in design were made to accommodate PV panels. The overall goal was to implement efficient design and construction that minimized cost increases. The evaluation of benefits and costs from construction is shown below.

Monthly Home Ownership Cost Comparison Example		
	Standard Home	Ultra High Efficient Home
Home Financed Price	$451,900.00	$487,615.00
Monthly Mortgage Payment*	$2,856.32	$3,082.06
Mortgage Interest Deduction*	-$611.95	-$660.31
Monthly Utility Costs	$433.23	$237.95
Total Monthly Cost	$2,677.60	$2,659.70
Total Monthly Savings	-	$17.90
Return on Investment (ROI)		8.2%

After a year of testing as a demonstration house, the report authors concluded that, "[t]he cost/benefit analysis for the home indicates that the value of the energy savings can exceed the investment. Because this benefit lasts for the lifetime of the home, the dollar savings will increase as utility costs increase."

Building Description

Building Type: residential home
Location: Maryland
Square Footage: 2,500
Number of Floors: 2

Qualitative Assessment of ZNE Package Approach

The home was designed to save over half of the energy of a typical house in the same climate. The primary goal was to demonstrate a decrease in the energy use in a "typical" production home in Maryland using technologies and construction methods that could realistically and affordably be translated to the marketplace by builders in new production and custom housing. The home utilized a variety of efficiency treatments, along with a PV system.

Quantitative Approach to ZNE (or near ZNE) Goal as Indicated by Monitoring

Total site electricity consumption was compared with electricity production from the PV panels

Incremental Cost per Square Foot (itemized as per efficiency and PV/generation when possible)

Not provided

Avoided Cost due to ZNE Integrated Design Strategies

Not provided

Degree of Confidence in Cost Estimates

Not provided

Incentives and Rebates as a Percentage of Pre-incentive Total Incremental Costs

Not provided

Financing and Partnership Strategies

Private financing in coordination with the Maryland Energy Administration, the NAHB Research Center, and the DOE Building America program.

Motivation in Building ZNE Project

The company was motivated to demonstrate the cost effectiveness of energy efficient construction.

Residential #8: NAHB Research Center. Final Report: Zero Energy Home- Armory Park Del Sol (2004)

The report summarizes the design, construction, and monitoring of a Zero Energy Home (ZEH) in Armory Park del sol in Tuscon, AZ. The project was a 1,718-square-foot home that combined renewable energy systems and energy efficiency features to achieve a "net-zero annual energy consumption design." The house was built by a team of public and private designers and consultants from industry, government, and the NAHB Research Center. Being situated in a desert climate, the home was designed to maximize reductions in cooling costs, including insulation and windows. With regard to remaining energy use, it has a solar water heater and 1-kW PV system, as well as efficient lighting and appliance loads in order to reduce the energy consumption.

Simulations were run before construction to simulate energy use and costs. In the base case, the home used 12,377 kWh/yr. After modeling 5 energy efficient features (wall and ceiling insulation, high-efficiency air conditioner, ENERGY STAR appliances, and efficient lighting), it used 6,831 kWh/yr[2]. The PV system and energy efficient features ultimately used were selected from 32 simulation runs that minimized overall costs, including costs for the PV installation, energy efficiency measures, and energy use. In model runs, the anticipated incremental cost for the selected energy package was $38,344, a 14% increase over typical sales prices for the area. This cost did not include financial incentives for renewable energy systems. The table on the next page shows a breakdown of life cycle costs and savings for different elements.

During the first six months of use as a model, energy production was about 70 percent of total energy use.

Table 6
Summary of Life Cycle Cost of Energy Features Added to Standard Design Individually

System	Description	Life Cycle Cost, 30 Years	Life Cycle Cost Savings (Premium) over Standard
Wall System	8" Block with Solid Grout	$35,053	($2,343)
	R-13 Light Frame	$26,670	$6,040
	Armory Park Standard	$32,710	$0
	Armory Park 3" Insl.	$33,378	($668)
	Armory Park ¾" Insl.	$33,876	($1,166)
	Durisol W25	$34,571	($1,861)
	Durisol W30	$34,826	($2,116)
Ceiling Insulation	R-30 Fiberglass	$12,232	$0
	R-38 Fiberglass	$12,218	$15
	R-42 Cellulose	$12,182	$50
Windows	Aluminum, Double, Clear	$14,241	$0
	Andersen Narroline	$14,387	($147)
	Milgard	$12,697	$1,544
HVAC	Heat Pump SEER 10, HSPF 6.8	$12,865	$0
	Heat Pump SEER 12, HSPF 7.8	$12,658	$207
	Heat Pump SEER 17, HSPF 9.1	$12,169	$696
Radiant Barrier	No Barrier	$11,397	$0
	With Radiant Barrier	$10,756	$641
Ductwork	In Attic	$12,656	$0
	In Conditioned Space	$11,040	$1,616
Washer	Standard	$2,120	$0
	Premium Efficiency	$2,291	($171)
Dryer	Standard	$2,482	$0
	Premium Efficiency	$2,286	$196
Refrigerator	Standard	$1,303	$0
	Premium Efficiency	$1,275	$28
Dishwasher	Standard	$1,485	$0
	Premium Efficiency	$1,373	$111
Water Heater	Electric Tank	$5,996	$0
	Electric Tank with Active Solar	$7,508	($1,512)
	Tankless with Active Solar	$7,136	($1,140)

Building Description
Building Description Building Type: Residential Home Location: Tuscon, AZ Square Footage: 1,718 Number of Floors: 1
Qualitative Assessment of ZNE Package Approach The home combined renewable energy systems and energy efficiency features to achieve a "net-zero annual energy consumption design." It includes a 4.2 kW PV electric system and energy efficiency features tailored to a desert climate.
Quantitative Approach to ZNE (or near ZNE) Goal as Indicated by Monitoring Total site electricity consumption was compared with electricity production from the PV panels
Incremental Cost per Square Foot (itemized as per efficiency and PV/generation when possible) $22/sq ft.
Avoided Cost due to ZNE Integrated Design Strategies Not provided
Degree of Confidence in Cost Estimates Medium
Incentives and Rebates as a Percentage of Pre-incentive Total Incremental Costs The incremental cost did not include financial incentives for renewable energy systems, which would have totaled between $6,000 and $8,400 depending on the type of rebate program. A state tax incentive of $1,000 was also not included.
Financing and Partnership Strategies The home was a collaborative effort between a private building, the NAHB Research Center, and NREL. Financing for design development came from the NAHB Research Center.
Motivation in Building ZNE Project The company was motivated to demonstrate the cost effectiveness of energy efficient construction.

Residential #9: CTG Energetics. Los Vecinos Monitoring Report: An Affordable Multi-Family ZENHs Project (2011)

This CEC PIER report describes monitoring and utility bill analysis from 42 unit Zero Energy multi-family project in Chula Vista, CA. The project was completed in 2009 and monitoring occurred from July through December 2009. Monitoring was high level with apartment-level electrical monitoring and gas and electric use from utility billing data. Installed energy efficiency measures are summarized in the table below.

R-49 Attic Insulation
Attic Radiant Barrier
R-19 Wall Insulation
Quality Insulation Inspection
Glazing: 0.39 U/ 0.36 SHGC
Tankless Combined Hydronic Water Heating
No Air Conditioning (ceiling fans installed)
Tight Ducts (6%)
CFL and pin-based Lamps
EnergyStar Appliances
94 kW Photovoltaic System

The cost goal for the project was that the costs would not exceed $5,000 per unit. Actual costs were not reported in this document, but will be available in a subsequent report. Over the six month monitoring period, the average apartment was determined to generate 7% more electricity than was consumed and apartment gas use was 40% lower than a baseline project used for comparative purposes. One interesting comparison in the project was evaluating monthly utlity costs. Due to minimum bill charges, electric bills did not reflect the fact that the PV system generated more than was consumed. On average, apartment electric bills were 62% lower than the baseline project bills.

Building Description Building Type: 42 unit multi-family building Location: Chula Vista, CA Square Footage: ~ 35,300 ft^2 Number of Floors: 3
Qualitative Assessment of ZNE Package Approach No discussion on design process presented, only a table of the implemented efficiency measures.
Quantitative Approach to ZNE (or near ZNE) Goal as Indicated by Monitoring Project goal of 25% beyond 2005 T24 (43% TDV savings were modeled). Based on July - December monitoring, average unit PV production was 7% greater than consumption; 40% natural gas savings vs comparison "conventional" units.
Incremental Cost per Square Foot (itemized as per efficiency and PV/generation when possible) Project target of $5000 per apartment incremental cost; actual costs not presented.
Avoided Cost due to ZNE Integrated Design Strategies n/a
Degree of Confidence in Cost Estimates n/a
Incentives and Rebates as a Percentage of Pre-incentive Total Incremental Costs n/a
Financing and Partnership Strategies n/a
Motivation in Building ZNE Project CEC PIER zero energy home research project.

Community Scale #1: Davis Energy Group (Dakin, Springer, and Kelly). Case Study: The Effectiveness of Zero Energy Home Strategies in the Marketplace (ACEEE, 2008)

This study documents the impact in the marketplace of selling high performance homes versus competing conventional subdivisions. The particular project being represented was the Carsten Crossings project in Rocklin, CA, with sales during 2006 and 2007 (immediately prior to the housing market collapse). Table 1 summarizes the actual average measure incremental costs for the full 144 home community (84 homes were sold during the course of this study) with projected utility bill savings estimated at 50-70% lower than conventional Title 24 homes. House size ranged from 2,168 to 2,755 ft^2.

Table 1: Summary of Incremental Costs

System Measure	***Incremental Cost***
Ceiling Insulation (R-38 to R-49)	$ 350
Attic Radiant Barrier	$ 740
Air Conditioning (13 SEER to 15 SEER/12 EER)	$ 500
Furnace (80 AFUE to 94 AFUE w/ ECM blower)	$ 770
SmartVent Night Ventilation Cooling	$ 772
Tankless Water Heater	$ 1,018
Fluorescent Lighting Package	$ 625
HERS Tests and Inspections (Insulation, TXV, SEER, Blower Door, System Airflow)	$ 500
2.5 kW PV System (net cost after rebates)	$14,100
Utility Efficiency Rebates	$ 1,025
Total Incremental Cost per House	**$18,350**
Total Incremental Cost for Community ($18,350 x 144 homes)	**$2,642,000**

With builder carrying costs of $311,000 per month (for the full subdivision), the added $2.6 million construction costs would need to be offset by an 8.5 month reduction in carrying costs. At a sales rate 2.2 times higher than competing subdivisions, the actual reduction in sales time was calculated at 3.5 years, resulting in a sizable savings to the builder.

Building Description

Building Type: Single family development (144 homes)
Location: Rocklin, CA
Square Footage: 2, 168 to 2,755 ft^2
Number of Floors: 1 and 2 story

Qualitative Assessment of ZNE Package Approach

Detailed modeling to develop package of measures; air conditioner downsizing was achieved based on evaluating loads with package of implemented EEMs. With BEopt whole house modeling, projected electric savings of 40% and gas savings of 18% were estimated.

Quantitative Approach to ZNE (or near ZNE) Goal as Indicated by Monitoring

Utility bill comparison of 75 "ZNE" and 100 "baseline" homes showed an average annual kWh reduction of 48% and annual gas savings of 40.5%. Utility bill savings averaged 60%, due to the tiered PG&E rate structure.

Incremental Cost per Square Foot (itemized as per efficiency and PV/generation when possible)

The installed EEMs cost an additional $1.72 per ft^2 of average house floor area. Net PV costs were $5640 per installed kW, or $5.73 per ft^2.

Avoided Cost due to ZNE Integrated Design Strategies

n/a

Degree of Confidence in Cost Estimates

High

Incentives and Rebates as a Percentage of Pre-incentive Total Incremental Costs

Utility efficiency rebates offset about 20% of the efficiency measure incremental costs.

Financing and Partnership Strategies

Huge reduction in carrying costs due to faster sales vs. competing area subdivisions.

Motivation in Building ZNE Project

Builder was in interested in using PV as a means to attract buyers. DEG sold builder on the benefits of incorporating efficiency as part of the package.

Community Scale #2: Davis Energy Group (Dakin, Hoeschele, Backman). Zero Energy Communities: UC Davis' West Village Community (2010)

This study documents the design process and cost and performance projections used in the development of the first large-scale ZNE community in the United States: the University of California's West Village community. The 200+ acre project located adjacent to the main UC Davis campus will ultimately provide housing for an estimated 4,350 people: 343 new homes for faculty and staff, and apartment housing for 3,000 students. (Currently the student housing is ~ 1/3 completed). The project's 1.5 million ft^2 of floor area will achieve project ZNE status through a combination energy efficiency and renewable generation (largely PV, with potential some bio-gas resource). Results from the deetailed modeling effort indicate that 57% of the site energy savings are projected to be due to the selected energy efficiency measures, with the remaining 43% being offset by renewable generation.

Table 1 summarizes overall economics in terms of costs, incentives, tax credits, and payback, and Table 2 summarizes the installed EEMs.

Table 1: Summary of Costs and Paybacks for Energy Efficiency Measures (EEMs)

		Single Family[1]	Multifamily Building No Solar WH	Multifamily Building w/ Solar WH
Incremental first cost for EEM's (w/o incentives)		$12,269	$61,992	$94,558
Projected incentives:	PG&E Utility Incentives	$1,900	$6,300	$6,300
	Solar Thermal Incentives	$2,130		$15,930
	Fed Tax Efficiency Tax	$2,000		
Net cost after incentives		$6,239	$55,692	$72,328
Annual operating cost savings (PG&E rates)		$505	$6,546	$7,661
Simple payback (with incentives)		12.4 years	8.5 years	9.4 years
Adjusted Internal Rate of Return (with incentives)		6.6%	8.2%	7.6%

1. Single family evaluation includes solar water heating

Table 2: Selected Building Energy Efficiency Measures

	Single Family	Multi-Family
BUILDING ENVELOPE:		
Walls (Exterior)	2x6 16” o.c. R-21 batt w/ 1” exterior foam. Quality Insulation Inspection.	2x6 16” o.c. R-21 batt w/ ½” exterior foam. Quality Insulation Inspection.
Roof (Attic)	R-49 blown insulation; Radiant barrier roof sheathing	R-49 blown insulation; Radiant barrier roof sheathing
Roofing Products (roof slope > 2:12)	Aged solar reflectance ≥ 0.2; thermal emittance ≥ 0.75 (Cool Roofing products)	Aged solar reflectance ≥ 0.2; thermal emittance ≥ 0.75 (Cool Roofing products)
Glazing U-Factor/ SHGC	Average U ≤ 0.33 / SHGC ≤ 0.21	Average U ≤ 0.33 / SHGC ≤ 0.21
Distributed Thermal Mass	5/8” drywall throughout	Addit. 1/2" gypcrete on Floors 2 and 3
HVAC:		
Cooling	15 SEER / 12.5 EER Heat Pump	15 SEER / 12.5 EER Heat Pump
Heating	8.5 HSPF Heat Pump	8.5 HSPF Heat Pump
Ducts	R-6.0 ducts in conditioned space	R-6.0 ducts in conditioned space
Fresh Air Mechanical Ventilation	NightBreeze for summer night ventilation cooling & fresh air mechanical ventilation	Per ASHRAE 62.2, mandatory Jan. 2010
Ceiling Fans	In bedrooms	
WATER HEATING:		
Type	Heat Pump Water Heater in garage or exterior closet.	Central HPWH in each bldg
Mfg / Efficiency	Energy Factor ≥ 2.0	ETech / 3.3 COP
Solar Water Heating	Active solar water heating system. 1- 4x8 collector per home.	Active solar water heating option
3RD PARTY TESTING / VERIFICATION:		
Duct Tightness / Duct Location	Ducts Conditioned Space; Tested < 6% Leakage	Ducts Conditioned Space; Tested < 6% Leakage
Envelope Integrity / Tightness	Blower Door Testing @ CFM50: ≤ 1.5 SLA; 3rd Party Quality Insulation Inspection	Blower Door Testing @ CFM50: ≤ 3.0 SLA; 3rd Party Quality Insulation Inspection
Cooling System	ACCA Manual J & D; Fan Power and EER Verification; Cooling Coil Air Flow	ACCA Manual J & D; Fan Power and EER Verification; Cooling Coil Air Flow
LIGHTING / APPLIANCES:		
High Efficacy Lighting	All hard-wired lighting fluorescent or LED. Assume 80% hardwired lighting. Lighting controls / Vacancy sensors.	All hard-wired lighting fluorescent or LED. Assume 80% hardwired lighting. Lighting controls / Vacancy sensors.
Energy Star Appliances	Dishwasher; Homeowner incentives to encourage purchase of other EStar apps	Dishwasher, Refrigerator, Washer
Miscellaneous Load Control	One switch wiring, energy usage displays	One switch wiring, energy usage displays

Building Description

Building Type: Multi-family, Single family (343 homes), and 42,500 ft^2 commercial
Location: Davis, CA (UC Davis campus)
Square Footage: 1.5 million ft^2
Number of Floors: 1-4 stories

Qualitative Assessment of ZNE Package Approach

Integrated design approach; EEM packaging and optimization working with measure costs provided by developer.

Quantitative Approach to ZNE (or near ZNE) Goal as Indicated by Monitoring

100% ZNE as per modeling (actual use data for partial project starting to come in)

Incremental Cost per Square Foot (itemized as per efficiency and PV/generation when possible)

EEM cost (before incentives) of $62,000 per building (~ $3.90/$ft^2$). PV costs not part of this study.

Avoided Cost due to ZNE Integrated Design Strategies

Uncertain. AC downsizing not implemented by HVAC contractor.

Degree of Confidence in Cost Estimates

High

Incentives and Rebates as a Percentage of Pre-incentive Total Incremental Costs

Utility efficiency rebates offset about 10% of the efficiency measure incremental costs.

Financing and Partnership Strategies

Project leveraged DOE, CEC, and California Solar Initiative funding to support project design and evaluation activities.

Motivation in Building ZNE Project

The University of California and UC Davis were highly motivated to develop this as a ZNE or near-ZNE project. Planning began around 2004.

Community Scale #3: NREL (Dean Van Geet, Simkus, Eastment). Design and Evaluation of a Net Zero Energy Low-Income Residential Housing Development in Lafayette, Colorado (2009).

The report details the design of a zero-energy low-income housing community near Denver, CO, called Josephine Commons Project. The project was initiated by the Boulder County Housing Authority (BCHA) and the city of Denver. The primary goal was to set the performance objective of maximizing energy savings with the combined mortgage plus energy bill cost at parity with a code-built home for a similar project using the optimization tool BEopt.

Table 1 shows the installed measures for the three plans.

Table 1: BCHA Housing Efficiency Measures

	Paradigm Pilot Duplex	Paradigm Pilot Ranch House	Josephine Commons
Mechanical ventilation	ERV	ERV	ERV
Furnace	96% eff. Condensing	None	None
Air conditioner	None	GSHP	GSHP
Ground source heat pump	None	4.0 COP heating	4.0 COP heating
		18.2 EER cooling	18.2 EER cooling
Water heater	Gas tankless	0.94 EF Electric	0.94 EF Electric
		w/ desuperheater	w/ desuperheater
Refrigerator	ENERGY STAR	ENERGY STAR	ENERGY STAR
Cooking range	Electric	Electric	Electric induction
Dishwasher	ENERGY STAR Electric	ENERGY STAR Electric	ENERGY STAR Electric
Clothes washer	ENERGY STAR Electric	ENERGY STAR Electric	ENERGY STAR Electric
Clothes dryer	Electric	Electric	Electric
Hardwired lighting	100% CFL	100% CFL	100% CFL
Plug-in lighting	100% CFL	100% CFL	100% CFL
Renewable energy	2.2 kW PV system	2.2 kW PV system	6.0 kW PV system
	evacuated tube solar hot water		

The modeling indicated a source-energy savings of 37% over the proposed BCHA baseline design and a reduction in the incremental mortgage and utility costs by approximately $166/yr. The total incremental installed cost to implement the energy efficiency upgrades was estimated as $10,680. Installation costs were reduced by using manufactured housing, which was transported in sections and assembled on site.

Home performance was compared to model predictions for home energy use, with measured data lower than expected. For different home designs, measured savings were $500-800 lower than model predictions.

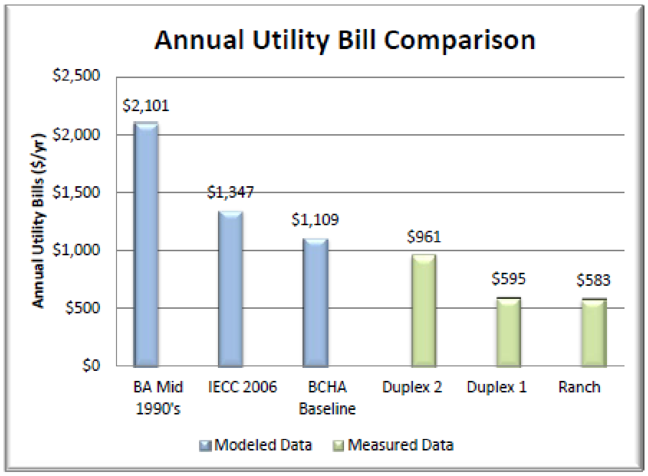


Figure 39. Annual utility bill comparison

Building Description

Building Type: Residential housing (3 units, a single-family home and two different 2-story duplexes)
Location: Lafayette, CO
Square Footage: varies
Number of Floors: 1-2

Qualitative Assessment of ZNE Package Approach

The primary goal was to set the performance objective of maximizing energy savings with the combined mortgage plus energy bill cost at parity with a code-built home for a similar project. The project used a variety of EEMs and electricity generation approaches to reduce energy use.

Quantitative Approach to ZNE (or near ZNE) Goal as Indicated by Monitoring

Measurement and monitoring of sub-metered data.

Incremental Cost per Square Foot (itemized as per efficiency and PV/generation when possible)

Total incremental cost for energy efficiency upgrades was estimated to be $10,680. Total construction cost was $90-125/sq ft, which was set to meet local affordability thresholds.

Avoided Cost due to ZNE Integrated Design Strategies

Energy modeling used to optimize design, but avoided costs were not indicated in relation to base case. Comparison was done between measured and modeled performance (see graph above).

Degree of Confidence in Cost Estimates

Medium

Incentives and Rebates as a Percentage of Pre-incentive Total Incremental Costs

Not specified

Financing and Partnership Strategies

Not specified.

Motivation in Building ZNE Project

Boulder County Housing Authority wanted to show how a public housing project that required redevelopment of abandoned land could be approached more efficiently and serve as a model for reduced energy use in the community.

Commercial #1: Commercial Buildings Consortium. Analysis of Cost and Non-Cost Barriers and Policy Solutions for Commercial Buildings (2011)

The report summarizes the findings of seven workings groups in the Commercial Buildings Consortium (CBC), as well as two reports focusing on technologies, regarding barriers and recommendations for uptake of zero-energy home design. The topics covered by the working groups included:

- Codes and Standards
- Integrated Design and Building Delivery
- Benchmarking and Performance Assurance
- Voluntary Programs
- Finance and Valuation
- Owners and Tenants
- Workforce Development

In general, the working groups recommended focusing most heavily on reducing energy consumption rather than increasing renewable energy production to meet zero energy goals. Additionally, a long-term metric is needed to measure performance of zero-energy buildings and policies. More specifically, each working group provided a detailed assessment and recommendations.

Regarding the findings of the financial working group, the report noted that typical finance vehicles for energy improvements are short-term (2-3 years), while savings are recouped over the long-term (15-25 years). More financing vehicles are needed that reflect the realities of the "first-cost" hurdle. The report did not discuss any specific findings related to financial costs or savings for zero-energy buildings.

Building Description Building Type: No specific examples provided Location: n/a Square Footage: n/a Number of Floors: n/a
Qualitative Assessment of ZNE Package Approach n/a
Quantitative Approach to ZNE (or near ZNE) Goal as Indicated by Monitoring n/a
Incremental Cost per Square Foot (itemized as per efficiency and PV/generation when possible) n/a
Avoided Cost due to ZNE Integrated Design Strategies n/a
Degree of Confidence in Cost Estimates n/a
Incentives and Rebates as a Percentage of Pre-incentive Total Incremental Costs n/a
Financing and Partnership Strategies n/a
Motivation in Building ZNE Project n/a

Commercial #2: New Buildings Institute (NBI). Getting to Zero 2012 Status Update: A First Look at the Costs and Features of Zero Energy Commercial Buildings (2012).

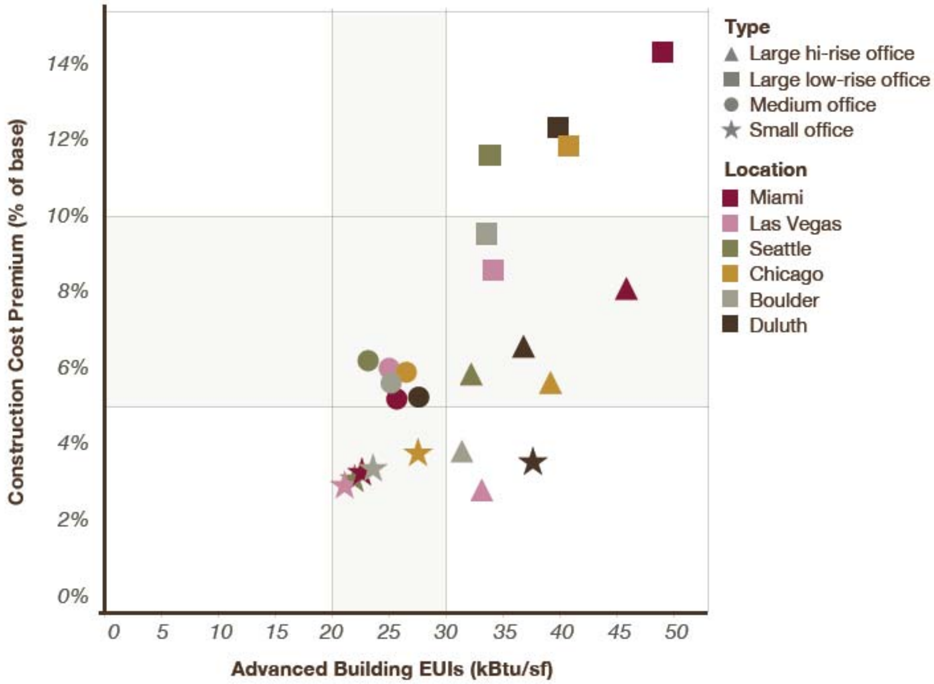
The report followed on an earlier study by NBI to analyze 21 buildings in varying climate zones around the country in order to measure performance and costs of Zero-Energy Buildings (ZEBs). The report found that most ZEB construction sites are small buildings that use PV panels. Currently, ZEBs are a mix of academic and environmental demonstration projects, as well as schools and a few businesses. As larger office buildings are considered for ZEB, minimizing plug and other "unregulated" loads will be important in achieving ZEB goals.

The report noted the difficulty in quantifying the actual costs of green buildings, as prior has "found it impractical to quantify incremental costs, but instead [use] the total construction cost per square foot of buildings." Often, prior research considered all LEED-certified projects rather than ZEBs alone. It does provide the additional construction costs associated with several of the study buildings, including:

1. **Leslie Shao-Ming Building (Woodside, CA)**, which cost 3.6% and 10% more per square foot to construct than two comparable buildings. If considering "soft costs," however, such as design fees and development chargers, the total cost per square foot for the building was 6.6% and 11% less than other comparable buildings.
2. **Aldo Leopold Legacy Center (Baraboo, WI)** only reported the cost of the PV system in relation to total project cost (6.1%).
3. **IDeAs Z2 (San Jose, CA)**, which reported about a 7% ($23/sq-ft) premium for renovation costs associated with energy efficiency upgrades. Additionally, a 2% ($6.40/sq-ft) cost premium resulted from installation of a 28-kW PV system.
4. **Hudson Valley Clean Energy Headquarters (Rhineback, NY)**, which reported incremental costs equating to an additional $680/month in higher mortgage payments. The owners are said to be avoiding $841/month in energy bills, resulting in a savings of $139/month.
5. **Richardsville Elementary (Green, KY)**, which was completed for $195/sq-ft, an amount below the state-allocated budget for general new school construction. Incremental costs were not reported.
6. **IAMU Office and Training Headquarters (Ankeny, IA)**, which noted no additional total construction costs over a conventional building. The report indicated that the project cost analysis "carefully noted both incremental cost items and offsetting areas of resulting savings."
7. **EcoFlats Building (Portland, OR)**, which targets net zero energy use for target rents in a low-to-moderate income neighborhood.

In almost all of the examples, the costs of the PV system were a sizeable portion of the total incremental first costs. For buildings associated with *Living Buildings* movement, which combines zero net energy with on-site rainwater and wastewater treatment, the David and Lucille Packard Foundation funded an effort to assess the cost of such a building.

Finally, the report noted the findings of a study by the Pacific Northwest National Lab and NREL, which looked at costs to reduce energy use 50% below current ASHRAE standards. The incremental costs were found to be below 5% for a 20,000 sq-ft building, 5-7% for a 50,000 sq-ft building, and 3-8% for large office buildings. Results are shown in the graph below.



Construction Cost Premium (% of base)
14%
12%
10%
8%
6%
4%
2%
0%
0
5
10
15
20
25
30
35
40
45
50
Advanced Building EUIs (kBtu/sf)
Type
Large hi-rise office
Large low-rise office
Medium office
Small office
Location
Miami
Las Vegas
Seattle
Chicago
Boulder
Duluth

Commercial #3: NREL (FEMP brochure). Reducing Data Center Loads for a Large-Scale, Net Zero Office Building

The short report describes the design and construction of an energy-efficient data center in support of a new research facility on the NREL campus. The new data center achieved energy savings of 1.45 million kWh, resulting in $82,000, though the time period for these savings was not specified. The data center used building best practices, innovative design, and energy efficient appliances to reduce the overall energy load.

The center was designed to achieve 50% less annual energy use than the legacy data center, while still meeting or exceeding performance requirements for operation and maintenance. To achieve these goals, the design used efficient fans, servers, and uninterrupted power supply devices, employing virtual servers, high-efficiency lighting, and climate-specific cooling to reduce energy use. In addition, it implemented a robust metering system that tracked energy use and reuse. Finally, it optimized air flow and designed the space to minimize local hot spots so as to allow for dissipated cooling.

Building Description
Building Type: Commercial Data Center Location: Golden, CO Square Footage: 220,000 (entire research center) Number of Floors: 1
Qualitative Assessment of ZNE Package Approach
Energy efficient appliances, climate-specific cooling systems, building design that accounted for the unique characteristics of a data center.
Quantitative Approach to ZNE (or near ZNE) Goal as Indicated by Monitoring
Not specified, though it noted a 60% reduction in overall load compared to former data operations center.
Incremental Cost per Square Foot (itemized as per efficiency and PV/generation when possible)
Not provided.
Avoided Cost due to ZNE Integrated Design Strategies
$82,000 cost savings (time period not specified)
Degree of Confidence in Cost Estimates
Medium
Incentives and Rebates as a Percentage of Pre-incentive Total Incremental Costs
Not specified
Financing and Partnership Strategies
Not specified
Motivation in Building ZNE Project
NREL has been a leader in designing and constructing high performance buildings, especially on its campus. It sought to demonstrate how to operate a high performance data center that significantly reduced energy consumption and associated costs.

Commercial #4: NREL (Langner, Deru, Zhivov, Liesen, Herron). Extremely Low-Energy Design for Army Buildings: Tactical Equipment Maintenance Facility (2012, ASHRAE pre-print)

The report describes an analysis by the U.S. Army Corps of Engineers (USACE), the USACE Construction Energy Research Laboratory (CERL), and NREL, which sought to achieve a 2015 energy performance goal on military bases through energy savings in various military buildings. Housing (barracks), administrative buildings, a company operations facility, a technical equipment maintenance facility (TEMF), and a dining facility were analyzed together with the goal of achieving 60% energy savings as specified by a 2007 law.

The team conducted modeling for a technical equipment maintenance facility (TEMF) using *EnergyPlus*. It improved building performance by adjusting the envelope, lighting, daylighting, HVAC efficiency, garage/repair bay conditions, and flooring in order to reduce energy load. The report provides extensive details for specific load reductions in each area as specified by the optimization model. The buildings were modeled for cities in representative climatic zones throughout the country.

Building Description
Building Type: Army Operations Centers Location: Various Square Footage: Varies Number of Floors: 1
Qualitative Assessment of ZNE Package Approach
Used modeling to determine the effects of improvements to envelope, lighting, daylighting, HVAC efficiency, garage/repair bay conditions, and flooring on overall energy use
Quantitative Approach to ZNE (or near ZNE) Goal as Indicated by Monitoring
Not specified, though the report noted 51-76% modeled energy savings versus base performance.
Incremental Cost per Square Foot (itemized as per efficiency and PV/generation when possible)
Not provided.
Avoided Cost due to ZNE Integrated Design Strategies
Not provided
Degree of Confidence in Cost Estimates
Low
Incentives and Rebates as a Percentage of Pre-incentive Total Incremental Costs
Not applicable
Financing and Partnership Strategies
Not specified
Motivation in Building ZNE Project
The Department of Defense is mandated through the 2007 Energy Independence and Security Act (EISA) to achieve improved energy performance on its facilities by 2015. The modeling study sought to clarify potential strategies to achieve those energy savings.

Commercial #5: NREL (Pless, Torcellini, Shelton). Using an Energy Performance Based Design-Build Process to Procure a Large Scale Low-Energy Building (2011, ASHRAE pre-print)

This paper documents the design-build process and how it was effectively utilized for both selecting a contractor and evaluating alternative designs for the 220,000 ft^2 NREL office building constructed in Golden, CO in 2010. The design-build RFP contained a contractual requirement for the project to achieve a site energy budget of 25 kBtu/ft^2-year, including the data center. Ten qualified teams were selected from a national RFQ process, with three teams shortlisted to participate in the RFP which included a management plan, conceptual design, and performance modeling to support the site energy budget goal. Key NREL design objectives are outlined below:

1. Mission Critical
    - a. Attain Safe Work Performance and Safe Design Practices
    - b. LEED Platinum Designation
    - c. Energy Star Appliances, unless other system outperforms

2. Highly Desirable
    - a. 800 Staff Capacity (later adjusted to 822)
    - b. 25 kBtu/ft^2 including NREL's datacenter
    - c. Architectural Integrity
    - d. Honor "Future" staff needs
    - e. Measurable 50% plus energy savings versus ASHRAE 90.1-2004
    - f. Support culture and amenities
    - g. Expandable building
    - h. Ergonomics
    - i. Flexible workspace
    - j. Support future technologies
    - k. Documentation to produce a 'How to' manual
    - l. "PR" campaign implemented in real time for benefit of DOE/NREL and DB
    - m. Allow secure collaboration with outsiders
    - n. Building information modeling
    - o. Substantial completion by June 2010

3. If Possible
    - a. Net-zero design approach
    - b. Most energy efficient building in the world
    - c. LEED Platinum Plus
    - d. Exceed 50% savings over ASHRAE baseline
    - e. Visual displays of current energy efficiency
    - f. Support public tours
    - g. Achieve national and global recognition and awards
    - h. Support personnel turnover

Building Description Building Type: Office building, data center Location: Golden, CO Square Footage: 222,000 Number of Floors: 4
Highly integrated design approach; waste heat capture; daylighting; thermal mass
Quantitative Approach to ZNE (or near ZNE) Goal as Indicated by Monitoring Design budget of 25 kBtu/ft^2-year (increased to 35 for increased occupancy). PV to offset usage.
Incremental Cost per Square Foot (itemized as per efficiency and PV/generation when possible) Total building costs below average of other high performance buildings (LEED) located in the greater Denver area.
Avoided Cost due to ZNE Integrated Design Strategies Not quantified in this paper.
Degree of Confidence in Cost Estimates High.
Incentives and Rebates as a Percentage of Pre-incentive Total Incremental Costs Not specified.
Financing and Partnership Strategies Not specified
Motivation in Building ZNE Project Support NREL and DOE's broad goals; October 2009 Obama Executive Order with 2020 goal of path to ZNE federal buildings.

Commercial #6: NREL (EERE brochure), Rebuilding it Better: Greensburg, Kansas (2012)

In 2007, a massive tornado destroyed over 90% of Greensburg, KS, and community leaders have supported a rebuilding effort focusing on energy efficiency and sustainability. NREL worked with the community to design and construct new buildings that incorporate energy efficiency features in order to demonstrate the viability of community-level design for reductions in energy use.

The report provided totals for annual site energy use across several commercial buildings, comparing the totals to other comparable buildings outside of Greensburg. Many of the reconstructed buildings achieved LEED-certification status at some level. Statistics for size and consumption are provided in the table below.

Name	Building Type	Floor Area (ft^2)	Total Energy Consumption ($kBtu/ft^2/year$)	Utility Energy Consumption ($kBtu/ft^2/year$)	Percent On-site Renewable Energy	Percent Energy Savings[1]
5.4.7. Arts Center	Interpretive center	1,670	24.2	13.6	44%	70%
Best Western Plus Watchman Inn & Suites	Lodging	27,000	72.9	35.4	51%	75%
BTI - Greensburg John Deere Dealership (includes BTI-Greensburg Wind Energy Building)	Retail	41,000	65.5	44.6	32%	55%
Centera Bank	Financial and communications	4,100	49.5	49.5	0	46%
City of Greensburg SunChips Business Incubator	Commercial office; retail	9,580	28.1	24.7	12%	71%
Greensburg City Hall	Public order and safety	4,700	46.6	41.4	11%	65%
Greensburg City Public Works	Service facility	11,200	36.6	35.9	2%	58%
Greensburg State Bank	Financial and communications	4,000	52.7	52.7	0%	36%
Kiowa County Courthouse (includes Kiowa County Sherriff's Office)	Public order and safety	26,820	47.2	47.2	0%	54%
Kiowa County Memorial Hospital	Healthcare	48,500	141.0	128.8	9%	59%
The Peoples Bank	Financial and communications	2,100	43.9	43.9	0%	51%
S.D. Robinett Building	Retail	4,500	34.9	34.9	0%	58%
USD 422 Greensburg K-12 School	K-12 education	132,000	30.6	24.7	23%	71%

1. Utility energy consumption compared to a typical building.

Building Description
Building Type: Various Location: Greensburg, KS Square Footage: Varies Number of Floors: Varies
Qualitative Assessment of ZNE Package Approach Pursue LEED certification and reduced energy use through common implementations such as orientation, wall construction and insulation, daylighting features, efficient windows, and energy-efficient appliances.
Quantitative Approach to ZNE (or near ZNE) Goal as Indicated by Monitoring Not specified. Multiple different projects achieved various levels of LEED certification, so no one strategy was appropriate.
Incremental Cost per Square Foot (itemized as per efficiency and PV/generation when possible) Not provided.
Avoided Cost due to ZNE Integrated Design Strategies Total operating cost savings over 13 Greensburg buildings totaled at $200,000 per year.
Degree of Confidence in Cost Estimates Medium
Incentives and Rebates as a Percentage of Pre-incentive Total Incremental Costs Not specified
Financing and Partnership Strategies Not specified
Motivation in Building ZNE Project The devastation and necessary rebuilding of the town allowed city managers to rethink the infrastructure in the town. NREL was willing to participate in helping the town rebuild in a more sustainable manner.

Commercial #7: NREL, Controlling Capital Costs in High Performance Office Buildings: 15 Best Practices for Overcoming Cost Barriers in Project Acquisition, Design, and Construction (2012 draft paper)

This draft report is one in a series of documents that describe various aspects of the recently-constructed NREL Research Support Facility, a energy efficient 220,000 sq ft. building on NREL's campus, to explore best practices for minimizing capital costs. The best practices are broken down into various participants, as follows:

Owner Best Practices

- Best Practice #1: Select a project delivery method that balances performance, best value, and cost savings.
- Best Practice #2: Incorporate measureable energy use performance requirements into a performance-based design-build procurement process.
- Best Practice #3: Clearly prioritize project objectives at the beginning of the design process.
- Best Practice #4: Competitively procure an experienced design-build team using a best value, firm-fixed price process.
- Best Practice #5: Include best-in-class energy efficiency requirements in equipment procurement specifications.

Design Best Practices

- Best Practice #6: Leverage nonenergy benefits to efficiency strategies.
- Best Practice #7: Consider life cycle cost benefits of efficiency investments.
- Best Practice #8: Integrate simple and passive efficiency strategies with the architecture and envelope.
- Best Practice #9: Allow for cost tradeoffs across disciplines.
- Best Practice #10: Optimize window area for daylighting and views.
- Best Practice #11: Maximize use of modular and repeatable high-efficiency design strategies.
- Best Practice #12: Leverage alternative financing to incorporate strategies that do not fit your business model.

Construction Best Practices

- Best Practice #13: Maximize use of off-site modular construction and building component assembly.
- Best Practice #14: Include a continuous value engineering process as part of the integrated design effort.
- Best Practice #15: Integrate experienced key subcontractors early in the design process.

Building Description Building Type: NREL Research Support Facility Location: Golden, CO Square Footage: 220,000 Number of Floors: 3-4
Qualitative Assessment of ZNE Package Approach Use energy modeling and integrated design to determine effective mix of energy efficiency treatments, including solar radiation for heating and light, PV electricity generation, insulation, and power saving measures related to appliance and computer loads.
Quantitative Approach to ZNE (or near ZNE) Goal as Indicated by Monitoring Assessed building performance according to four methods of defining zero net energy.
Incremental Cost per Square Foot (itemized as per efficiency and PV/generation when possible) Total construction costs were $259/sq ft. An outright purchase of the building, without tax breaks or subsidies, would have increased the cost by $34/sq ft.
Avoided Cost due to ZNE Integrated Design Strategies Total cost savings over 13 Greensburg buildings totaled at $200,000 per year.
Degree of Confidence in Cost Estimates High
Incentives and Rebates as a Percentage of Pre-incentive Total Incremental Costs Approximately 12%
Financing and Partnership Strategies Tax breaks and subsidies, including American Recovery and Reinvestment Act (ARRA) funding.
Motivation in Building ZNE Project NREL wanted to continue to showcase advanced design and building methods on its campus, including a highly-efficient office building that manages electricity through a broad approach that considers typical costs of heat and loads from computer servers.

Appendix C: Calculation of PV Costs for Typical All-Electric Home

This summary documents the development of cost estimates for a PV system sized to meet typical ZNE consumption levels for a moderately sized new home (~2,100 - 2,400 ft^2) located in Sacramento, CA. PV "per ft^2 of house floor area" costs will vary based on climate and the level of energy efficiency implemented in the house design. For this simplified study, we will bracket the PV sizing based on both the Lake Forest, CA KB Homes ZeroHouse 2.0[1], as well as an estimate of consumption for a slightly more aggressive EEM design as documented in PG&E's current companion ZNE project entitled "Assessment of Technical Feasibility for Achieving ZNE Buildings in the Commercial and Residential Sectors". In that project, detailed modeling on a 2,100 ft^2 prototype floor plan resulted in an EEM package design that featured a combined hydronic heating system (providing both space heating and domestic hot water) using a condensing gas tankless water heater. In addition, clothes drying and cooking were assumed to be gas. Resulting annual energy usage is summarized below:

Electric Use:	3,974 kWh/year (cooling, lighting, miscellaneous electric loads)
Gas Use:	233 therms/year (total use)
	131 therms/year space heating
	102 therms/year (water heating, cooking, clothes dryer)

The 102 therms was broken down into water heating (49 therms), clothes dryer (22 therms), and cooking (31 therms). The latter two end uses are estimated as provided for PG&E households in the 2009 RASS data.

To represent the gas use in an all-electric ZNE home (this simplifies any issues related to ZNE definitions with converting gas use to electric), space heating was converted to an air-source heat pump (at an annual average 2.0 COP) water heating was converted to a heat pump water heater (at an annual average 1.8 COP), and gas cooking and drying were switched to electric appliances (as per RASS average PG&E usage). The estimated annual consumption for the all-electric home is then estimated as:

Base electric usage:	3,974 kWh/year (cooling, lighting, miscellaneous electric loads)
Space heating:	1,750 kWh/year
Water heating:	1,004 kWh/year
Cooking, dryer:	899 kWh/year
Total	7,627 kWh/year

According to NREL's PVWatts on-line calculator[2], a 1 kWdc south-facing PV system in Sacramento will generate 1,399 kWh/year. To satisfy the 7,627 kWh energy demand, a 5.5 kWdc system would be required.

Currently PV production home installed costs are roughly $4.50 per Watt. To compute approximate costs of the PV component, we used the calculated PV sizing, the assumed $4.50 per Watt cost, and the 30% Federal

[1] http://investor.kbhome.com/releasedetail.cfm?releaseid=634000

[2] http://rredc.nrel.gov/solar/calculators/pvwatts/version1/US/California/Sacramento.html

tax credit. California CSI credits are not factored into this evaluation. With these assumptions the range in expected "per ft^2" costs for the 2,100 ft^2 prototype, as as follows:

5.50 kW x $4,500/kW x 70% = $17,325 / 2,100 ft^2 = **<u>$8.25/ ft^2</u>**

6.75 kW x $4,500/kW x 70% = $21,262 / 2,100 ft^2 = **<u>$10.13/ ft^2</u>**

The $8.25 - $10.13/$ft^2$ cost range provides a reasonable assessment of the cost of PV to be compared with observed EEM costs.