

research report

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Getting to Zero 2012 Status Update: A First Look at the Costs and Features of Zero Energy Commercial Buildings

With support from:



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Cover Photo: Richardsville Elementary School, Bowling Green, KY

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Executive Summary

In this first status report on Zero Energy Commercial Buildings, New Buildings Institute (NBI) gathered information to determine characteristics, costs, and features of Zero Energy Buildings (ZEBs) recently constructed in the United States. ZEBs (also called Net Zero or Zero Net Energy Buildings) have garnered attention over the last few years as a focus of some voluntary programs and public policy, most notably on the Pacific coast. Buildings constructed related to these efforts (the Living Building Challenge, for example) are just beginning to emerge.

For this report, we define ZEBs as buildings that use no more energy over the course of the year than they produce from on-site renewable sources. Information was gathered primarily from a variety of secondary sources, although personal conversations were conducted with some owners, designers and occupants. NBI located 21 ZEBs buildings in the United States, which had sufficient available documentation to enable some analysis.

In brief, NBI found that:

- ZEBs have been successfully built in most climate zones of the United States.
- The majority of ZEBs to date are small or very small buildings.
- All buildings to date use photovoltaic (PV) panels to provide their on-site renewable energy.
- Many of the earliest examples are academic buildings or environmental centers, in effect, demonstration buildings sometimes with low occupancy levels. More recent buildings include office buildings, K-8 schools and a credit union; buildings that represent large numbers of “average” or typical buildings. This trend is continuing, and ZEBs are becoming larger and more complex.
- ZEBs are constructed using readily available technology. An integrated design approach with careful attention to building siting and layout, envelope, mechanical systems, and electrical systems is critical to achieve the high levels of energy efficiency employed. Unique or experimental systems are infrequently used to reach net zero goals, but the emergence of new technologies will be a factor in the expansion to more building types.
- As the larger office buildings market moves towards ZEB, minimizing plug loads and other miscellaneous or “unregulated” loads is a priority.

Recent buildings include office buildings, K-8 schools and a credit union; buildings that represent large numbers of “average” or typical buildings. This trend is continuing, and Zero Energy Buildings are becoming larger and more complex.

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- Reported incremental costs are only available from a few ZEBs, and conclusions or trends are difficult to derive from the limited information available. However, the few reported ZEBs appear to show lower overall incremental costs than the modeled estimates, possibly due to trade-offs with other features in the design and construction process. These costs range from 0% to 10%.

Because of the limited information from the small data set of built ZEBs, NBI expanded the scope of the study in two ways. First, NBI reviewed data from a variety of additional low-energy buildings that we have studied for other purposes, and called these buildings Zero Energy-Capable (ZEC). These buildings demonstrated energy efficiency levels in the range of the documented ZEBs, but many did not include any (or sufficient) on-site renewable generation to cover their annual energy use. There are **39** such buildings (see building lists in Appendix A).

In addition, another **39** buildings were found that claimed to be possible ZEB or ZEC, but could not be verified and were not included in the study (see building lists in Appendix A).

Leslie Shao-Ming Sun Field Station;
Woodside, CA



While identification of new projects continues, we now have a list of 99 projects including verified ZEB and ZEC buildings, as well as unverified “emerging” projects.

Second, NBI included a review of several modeling studies of ZEBs and ZE-Capable buildings. Based on these more extended reviews, it appears

that the energy efficiency needed to achieve ZEB levels is readily available, at what are reasonable incremental costs for many owners. These studies showed incremental costs for common building types ranging from as low as 3% to a high of 18%, depending on building type, location cost factors, and climate (i.e. energy efficiency strategies needed in a given climate zone to achieve ZE-Capable levels of performance), not including an appropriately sized PV system.

Key overall conclusions of the study are that:

- ZEBs are uncommon, but increasing in numbers, building size and complexity.
- The efficiency levels needed for ZEBs are readily obtainable, with current technology and at reasonable incremental costs, for many common building types.

Three key recommendations emerge from this review of early ZEB examples.

Practical guidance is needed to help designers, developers, and owners identify areas of opportunity and available resources.

Data collection efforts should be enhanced as more ZEBs are constructed over the next few years. ZEBs are already entering a “second generation” of more typical building types. Ownership patterns and lessons learned from these examples could accelerate interest at both the market and policy levels towards ZEBs and ZE-Capable buildings.

A better basis for benchmarking performance can come from the emerging experience. With more examples of successful zero energy-capable buildings, the benchmarking focus can shift to a forward-looking target of zero energy rather than comparison with existing building stock. Centrally reported results, with associated building and occupant characteristics, could start with a relatively small set of cases, making increasingly refined benchmarking possible as the comparison set grows in size and diversity.

Introduction

Zero Energy Buildings (ZEBs), those that use no more energy over the course of the year than they produce from on-site renewable sources, are increasingly specified in green building and public policy goals. With buildings accounting for nearly 40% of total domestic energy use¹, there is clear potential for significant reductions in pollution and increased energy independence from efficiency in this sector. The ZEB concept provides an effective end focus for a pathway that moves commercial buildings from current standard design practice to deep energy efficiency, and then to the final step of adding onsite renewables to supply the remaining energy needs. Documented cases of achieving zero energy, though still rare, are increasing, and more projects are in the planning stages. This paper summarizes the available literature on the incremental costs associated with technologies used to build ZEBs.², identifies leading buildings, and makes recommendations for advancing zero energy practice.

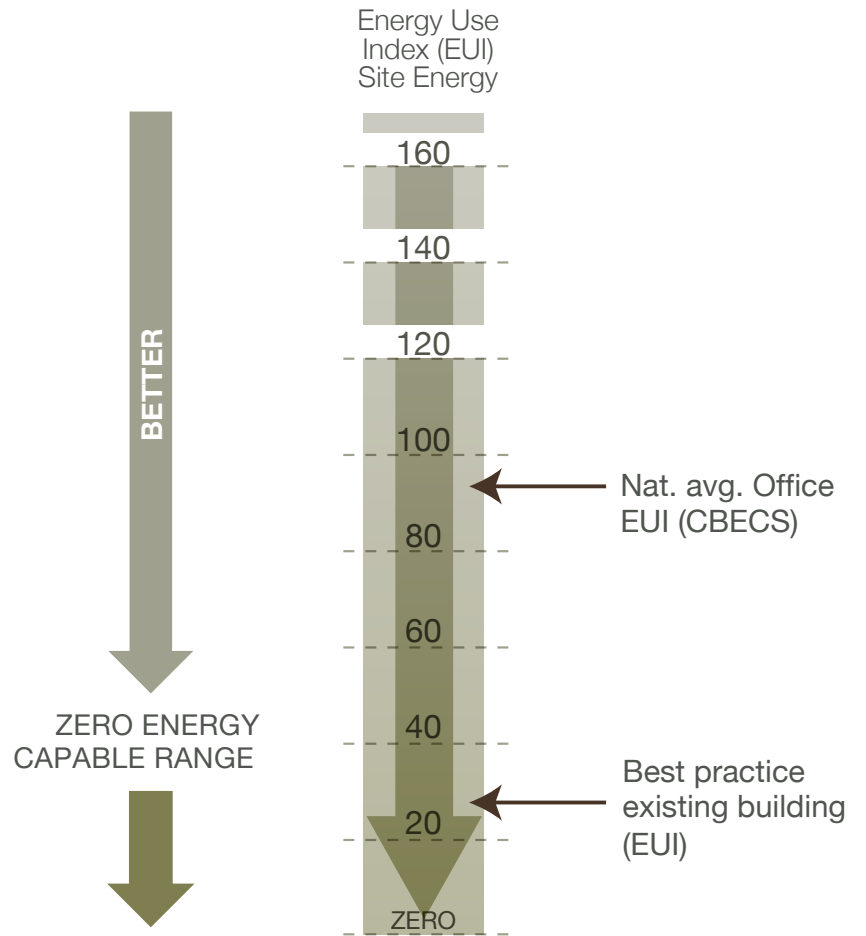
The 2003 national average energy use intensity (EUI) of all U.S. commercial buildings is 93 kBtu/square foot (sf). The least efficient buildings in this study had an EUI of 35 kBtu/sf, while the most efficient used less than 10% of the national average. While this might seem ambitious compared to the national level, examples are emerging that are achieving these superior energy efficiency levels. Communication of the lessons from those results, coupled with continued advances in high efficiency design, energy codes and standards, can help pave the way.

This paper focuses on cases in which the zero energy goal is achieved on a single site. While location, space constraints, and building activity type won't always accommodate this goal, the single site lessons also inform the pathway to achieving zero energy goals on a district or regional basis.

1 DOE Buildings Energy Data Book, March 2011. Commercial and residential total share of US primary energy.

2 Other publications have provided broad overviews of zero energy buildings. See for example, the 2011 white paper from *Building Design + Construction*, which covers definitions, strategies, and some case examples of zero energy construction efforts.

Figure 1: Adapted zEPI scale based on "Beyond Percent Savings," by Charles Ely, AEC



Energy Information Administration Commercial Building End-Use Consumption Survey (CBECS) 2003. Energy Star **Portfolio Manager** calculates an EUI for a building based on like building types, climate, size, occupancy and loads

In gathering this information, NBI cast a wide net to include both documented ZEBs and “zero energy-capable” (ZEC) buildings. The latter group includes buildings with documented energy use low enough to potentially reach net zero through the addition of onsite generation, even if they may not currently have taken that final step. Incremental costs are considered in two separate components: (1) efficiency measures used to reduce total energy use; and (2) the purchase of photovoltaic panels — currently the nearly universal choice for onsite generation. The limited available information on actual first costs is supplemented with cost estimates from published model-based studies.

The following four main sections cover:

- How Many Cases Are There: The size and source of the datasets used
- Design Strategies Utilized: Commonly mentioned efficiency features
- Reported First Costs: Extracted from existing case studies of current projects
- Design-Model Based Cost Estimates: Incremental costs derived from modeled data supplements the very limited reported first cost information available

How Many Cases Are There?

Current Zero Energy Buildings

The most cost-effective path to zero energy is to focus first on these efficiencies, reducing the amount of energy that must be produced from PV purchase and installation.

In Table 1, we identify 21 occupied commercial buildings with either measured net zero energy results (15 cases) or credible modeled³ expectations for such results (six cases).⁴ The cases without published measured results have been vetted by the U.S. Department of Energy's (DOE) Zero Energy Buildings Database or other reliable sources. In addition to the DOE database, these successful buildings were also drawn from NBI's Getting to 50 Buildings Database of high performing buildings, certified buildings under the Living Building Challenge, ASHRAE's *High Performing Buildings* magazine, NBI project work and other investigations. Table 4 in Appendix A lists 39 "emerging" ZEB projects under construction or very recently occupied, which had insufficient initial documentation and experience available for inclusion in this study.

With exception of two facilities completed in 2010 — Richardsville Elementary and the NREL facility — all ZEBs are less than 15,000 square feet, and half are less than 5,000 square feet. More large building examples will be helpful in expanding the ZNE impact. However, this relatively small building size is representative of the overall existing commercial building stock, as seen in the Commercial Building Energy Consumption Survey (CBECS).

Table 1 shows the annual purchased EUI, the number that must be near zero for a ZEB. We also show the total EUI, reflecting the building's annual energy use per square foot from all sources, including onsite renewables. This important number is a measure of how well building and occupant efficiencies have been achieved. **The most cost-effective path to zero energy is to focus first on these efficiencies, reducing the amount of energy that must be produced from PV purchase and installation.**

3 Sophisticated computer modeling of anticipated energy use is common in designing high performance buildings, as a tool for evaluating and choosing among alternative efficiency measures. Modeling reflects the building's performance goals and remains the only quantified estimate of performance until actual energy bills for at least one year of occupancy have been analyzed. The former, measured energy use gives the true indication the performance level achieved, and provides valuable feedback on successful strategies and areas of improvement.

4 Table includes all cases with less than 5 kBtu/sf of reported purchased annual energy. See for example, the 2011 white paper from *Building Design + Construction*, which covers definitions, strategies, and some case examples of zero energy construction efforts.

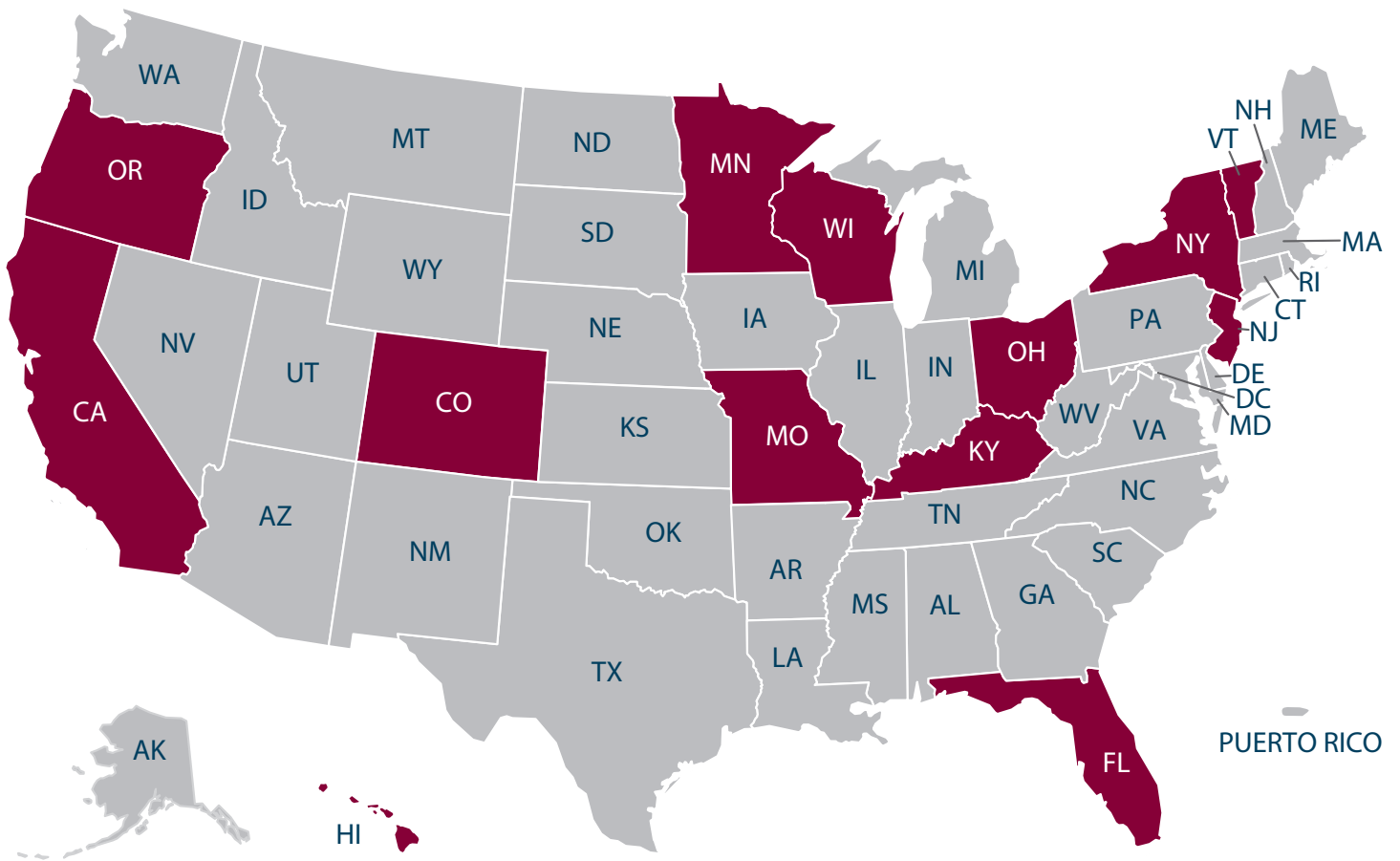
Table 1: Zero energy buildings considered in this study

	Building	Type	Location	Square Feet	Purchased EUI⁽¹⁾	Total EUI⁽²⁾	Data Source
2000	Oberlin College Lewis Center	Higher ed	Oberlin, OH	13,600	0	32.2	Meas.
2001	Environmental Tech. Center Sonoma State	Higher ed	Rohnert Park, CA	2,200	0	2.3	Meas.
2002	Challengers Tennis Club	Recreation	Los Angeles, CA	3,500	0	9.1	Mod.
	Leslie Shao-Ming Sun Field Station	Higher ed	Woodside, CA	13,200	3.8 ⁽³⁾	9.5 ⁽³⁾	Meas.
2003	Audubon Center at Debs Park	Interp center	Los Angeles, CA	5,000	0	17.1	Mod.
	Science House	Interp Center	St Paul, MN	1,530	0	17.6	Meas.
2005	Hawaii Gateway Energy Center	Office; Interp center	Kailua-Kona, HI	3,600	0	27.7	Meas.
2007	Aldo Leopold Legacy Center	Office; Interp center	Baraboo, WI	11,900	0	15.6	Mod.
	IDeAs Z2	Office	San Jose, CA	6,600	0	24.6	Mod.
2008	Camden Friends Meeting House	Assembly	Camden, DE	3,000	0	na	Meas.
	Environmental Nature Center	Assembly	Newport, CA	8,535	0	17.6	Meas.
	Hudson Valley Clean Energy HQ	Warehouse; Office	Rhinebeck, NY	4,100	0	13	Meas.
2009	Chrisney Library	Library	Chrisney, IN	2,400	0	15.3	Meas.
	Living Learning Center (at Tyson Research Center)	Higher ed	Eureka, MO	2,968	0	24.5	Meas.
	Omega Center for Sustainable Living	Interp Center	Rhinebeck, NY	6,246	0	21	Meas.
	Pringle Creek Painter's Hall	Assembly	Salem, OR	3,600	0	9.5	Meas.
	Putney Field House	Recreation	Putney, VT	16,800	0	9.7	Meas.
2010	Energy Lab at Hawaii Preparatory Academy	Education	Kamuela, HI	5,902	0	11	Meas.
	Magnify Credit Union	Office	Lakeland, FL	4,151	3.5	45	Meas.
	Richardsville Elementary	K-12	Bowling Green, KY	77,000	0	18	Mod.
	NREL Research Support Facility	Office	Golden, CO	222,000	35 ⁽⁴⁾	35	Mod.

- 1 Purchased EUI is the building's total EUI less any on-site generation. Energy Use Intensity is reported in kBtu/sf/yr. A few sites report small annual totals of renewable generation in excess of the amount used on-site, which may be exported to exterior or adjoining uses. Those excesses are not quantified here.
- 2 Total EUI includes both renewable and purchased energy.
- 3 Leslie Shao-Ming Sun Field Station purchased energy omits propane usage because of metering problems.
- 4 NREL Research Support Facility is modeled to reach net zero upon installation of 1.6 MW PV system.

The current zero energy buildings are located in a variety of U.S. climates, as shown in Figure 2. Both California and Hawaii are well represented, with six and two buildings, respectively. The mild climates of these states certainly helps make ZEBs achievable. However, projects have also been completed in the harsher climates of Minnesota, Wisconsin, and New York.

Figure 2. Location of the 21 zero energy projects



Zero Energy-Capable Buildings

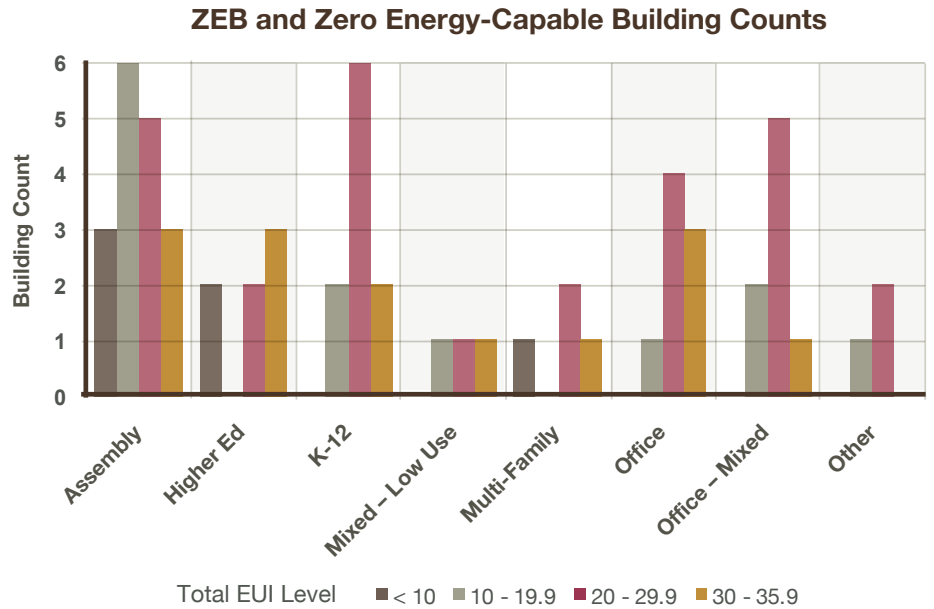
Expanding the search from the same primary sources to zero energy-capable buildings increases the data set to 60, including the 21 already described and an additional 39 zero energy-capable buildings (see list in Appendix A). “Zero energy-capable” is based here on total energy used in the building, including both purchased and on-site renewable sources. A fairly generous eligibility cut-off was used in identifying these cases, taking all buildings with total energy use of 35 kBtu/sf or less. To put this target EUI in context:

- 35 kBtu/sf is the maximum EUI reported in the current ZEB list in Table 1 (with the one exception of the Magnify Credit Union in the particularly PV-capable Florida climate, with an array generating the full 45 kBtu/sf that the building uses). That 35 kBtu/sf level is 62% lower than the 2003 average overall all U.S. commercial building stock, from the last available CBECS study. That CBECS average was 91 kBtu/sf, and the average just for offices was similar, at 93 kBtu/sf.
- DOE’s National Renewable Energy Lab (NREL) considers “highly-energy efficient” buildings as those using 60–70% less than CBECS. They often refer to a target in the 25–30 kBtu/sf range as a practical maximum for most ZEB applications, from the perspective of current PV technology.

Whether or not they are currently using renewables, these ZEC buildings have total EUIs low enough that many would have the potential for achieving net zero through onsite renewables. The ability to take that final step would depend on the assessment of available space for installing PV panels, the abundance of solar radiation for the building location, and financial considerations.

Figure 3 summarizes these cases by EUI level and activity type. As with the smaller group of current ZEBs, activity types in the ZEC cases tend to be in lower use categories. Although they are categorized approximately here using standard activity types, they often have mixed usage characteristics not clearly analogous to the standard labels.

Figure 3. Zero energy and zero energy-capable counts by type and total EUI level



This larger set of cases is still weighted toward small and very small buildings, which is representative of the total commercial building stock. However, this group also includes examples in the important mid-to-large office building categories, as shown in Table 2.

Table 2: Zero energy and zero energy-capable counts by type and size

Type	Size (total square feet)						Total
	1k - 5k	5k - 10k	10k - 25k	25k - 50k	50k - 100k	> 100k	
Assembly	6	4	5	2			17
Higher Ed	2		4	1			7
K-12		1	1		6	2	10
Mixed-Low Use	2		1				3
Multi-Family		2	1			1	4
Office	1	2	3		1	1	8
Office-Mixed	1	2	3	2			8
Other	1		1		1		3
Total	13	11	19	5	8	4	60

Design Strategies Utilized

More than 85% of the studied cases report designs incorporating daylighting.

The following section discusses building design strategies used on high performance buildings. In addition to the buildings in Table 2, NBI includes some modeled information on savings in a medium office building in Appendix B: PNNL Model for 50% Energy Savings to show additional details on possible efficiency strategy choices.

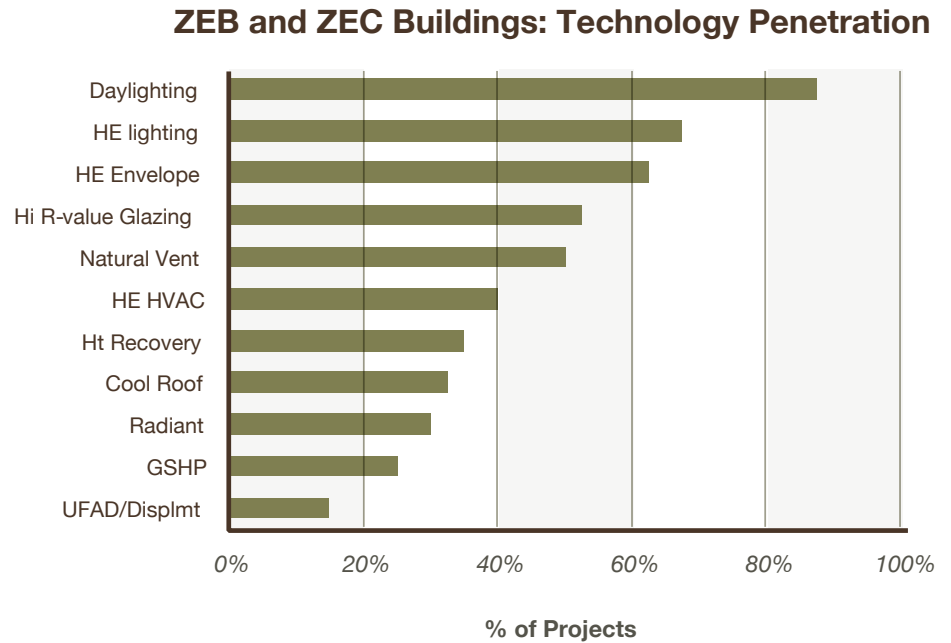
Figure 4 presents the technology penetration of 11 design strategy categories reported in the zero energy-capable buildings. At the literature-review level of this study, a couple caveats are needed. First, the typical case study does not necessarily mention every efficiency measure used, nor does it clearly define the details of measures that are mentioned. Thus, this summary is primarily an indication of the types of strategies that have been considered noteworthy. In addition, these summaries represent the entire set of documented cases, across a wide range of climates. Climate-responsive design is a necessary part of optimized design, but the current data set is not large enough to show differences by region in strategies used. As more documented examples are consolidated, important breakdowns such as analysis by climate will become possible.⁵

More than 85% of the studied cases report designs incorporating daylighting. Most reports, however, do not provide sufficient detail to know whether effective automated controls were installed to maximize the potential energy savings, nor how well the daylighting was balanced with an appropriately managed ratio of window to wall area. Approximately two-thirds reported high efficiency lighting, including occupancy-based controls and/or high efficiency lamps (68%). More than 50% of the buildings also report using a high performance envelope with increased insulation and well-insulated glazing. Half of the buildings use natural ventilation. These strategies align well with the proven design approach of starting with a good building envelope, access to natural light and ventilation, and an integrated design of building systems.

The remaining features are less consistent across all buildings, but still occur with relatively high frequency. High efficiency HVAC systems with heat recovery are cited in about one-third of the cases, as are cool roofs. 30% report using radiant heating/cooling systems, and about that many report the use of ground-source heat pumps. Under floor or displacement ventilation is used in 15% of projects.

⁵ Note that it is possible to search NBI's Getting to 50 Buildings Database by state or climate zone to find specific case studies in a particular area.

Figure 4: Technologies used in ZEB and zero energy-capable buildings



One noteworthy characteristic of the reported strategies is that nearly all refer to measures and equipment that are commercially available today.

One noteworthy characteristic of the reported strategies is that nearly all refer to measures and equipment that are commercially available today.

The above chart is based on the full set of net zero-capable buildings, including the Table 1 ZEBs. The primary difference between the ZEBs and the other ZEC buildings is the addition of PV panels for renewable energy generation, used for each of the 21 ZEB cases listed.

In looking more specifically at the ZEB features:

- Four ZEBs in mild climates have completely eliminated traditional HVAC systems and utilize passive strategies to maintain thermal comfort. This includes natural ventilation, thermal mass to moderate temperature fluctuations, and nighttime flushing with cold air.
- When HVAC systems *are* used, about half of the ZEBs report using a radiant heating/cooling system, often in conjunction with ground-source heat pumps.
- The one example of a multi-family building uses a solar thermal system for domestic water heating — typically a large load in residential buildings. Building use patterns and climate also become important when striving for net zero. Based on anecdotal information, many of the net zero buildings are occupied primarily during daylight hours, resulting in little need for artificial lighting.

Current design approach examples

Example: IDeAs Z2 Design Facility, San Jose, CA



Three examples below show the variety of design approaches used to achieve zero energy.

One good example of a successful NZEB project is the IDeAs Z2 Design Facility. This 6,560-square-foot building in San Jose, CA, reached net zero by renovating a windowless 1960's era bank building. The project team added skylights, high performance windows, and increased insulation. A radiant heating and cooling system is coupled with a ground-source heat pump and displacement ventilation.

Very importantly, extra attention was placed on minimizing plug loads, both through the selection of equipment as well as controls, and designing systems to that managed level of internal loads. Lighting is controlled with occupancy and photosensors. A custom control sequence was also implemented to shut off specified circuits when the security system is armed at night. This eliminates phantom loads and ensures equipment is not left on overnight. This building is an excellent example of how existing building forms can be adapted into functional zero energy office spaces.

Example: Richardsville Elementary School, Bowling Green, KY



The 72,000-square-foot Richardsville Elementary school, located in Bowling Green, KY, provides an excellent case study of how a design team can improve upon their previous experience. Richardsville is the third school in the district that was built using a similar design, and the project team was able to apply the lessons learned from the two previous schools. Effective daylighting and HVAC technologies were carried forward.

In addition, energy monitoring in the preceding schools showed that the kitchen and computer lab were significant energy consumers.

The Richardsville kitchen uses combination ovens and microwaves, which save appliance energy *and* eliminated the need for a high flow fume hood. Instead of a traditional computer lab, a portable set of laptops and computer tablets was used.



Example: NREL Research Support Facility, Golden, CO



Another notable building is the 220,000-square-foot NREL Research Support Facility (RSF) in Golden, CO. Once NREL completes the PV panel installation, this is expected to be the nation's largest ZEB. It is arguably the best example to-date of a "traditional" office building operating at net zero. The facility has a moderately high density of 800 occupants (3.6/1000 sf) working a traditional 40 hour per week schedule.

To accomplish the ZEB goal in a larger and more complex building, NREL has used an array of innovative approaches, considering all aspects of the building with energy efficiency in mind. A narrow floor plate is used to allow daylighting for 100% of the workspaces. The high efficiency envelope includes triple glazed operable windows. HVAC is handled with a radiant heating/cooling system. Ventilation air is provided through an under floor system, and air is preheated with a "transpired solar collector". This is a passive means of using solar energy incident on the south façade to heat the passage through which ventilation air is drawn. Waste heat is also harvested from the onsite data center. Occupant loads are addressed with high efficiency equipment and by restricting the power allocated to each workspace.



Summary: Design Strategies for Zero Energy

The clear statement of objectives at the beginning of the design process, as a guide to decisions and prioritizations throughout the project, is essential to optimized results.

It is difficult to generalize this small but diverse set of net zero buildings. Most of the projects outlined in this study are relatively small buildings, and many have lower than normal occupancy patterns. The net zero buildings are all low-rise, which helps provide enough roof area to install the amount of PV panels required to reach net zero. However, the larger group of ZEC buildings reflects the efficiency savings that are practical even in cases where on-site PVs are not, cases that could be incorporated into regional and community zero energy plans.

The common theme across these ZEBs is their focus on the goal: to build a building that puts at least as much energy into the grid than it uses. The clear statement of objectives at the beginning of the design process, as a guide to decisions and prioritizations throughout the project, is essential to optimized results. In terms of features, each building has taken an integrated, location-specific approach to achieving that goal of net zero energy use. These buildings demonstrate that net zero is feasible, with examples in many different U.S. climates. With this intent, a skilled design team and off-the-shelf building technology, these projects have demonstrated the feasibility of meeting that goal.

Case studies of the NREL and IDeAs buildings also show that net zero is not only a goal for nature centers and boutique buildings, but can be reached on a much broader scale. Further information on these cases can be found in NBI's Getting to 50 Buildings Database.

Reported First Costs

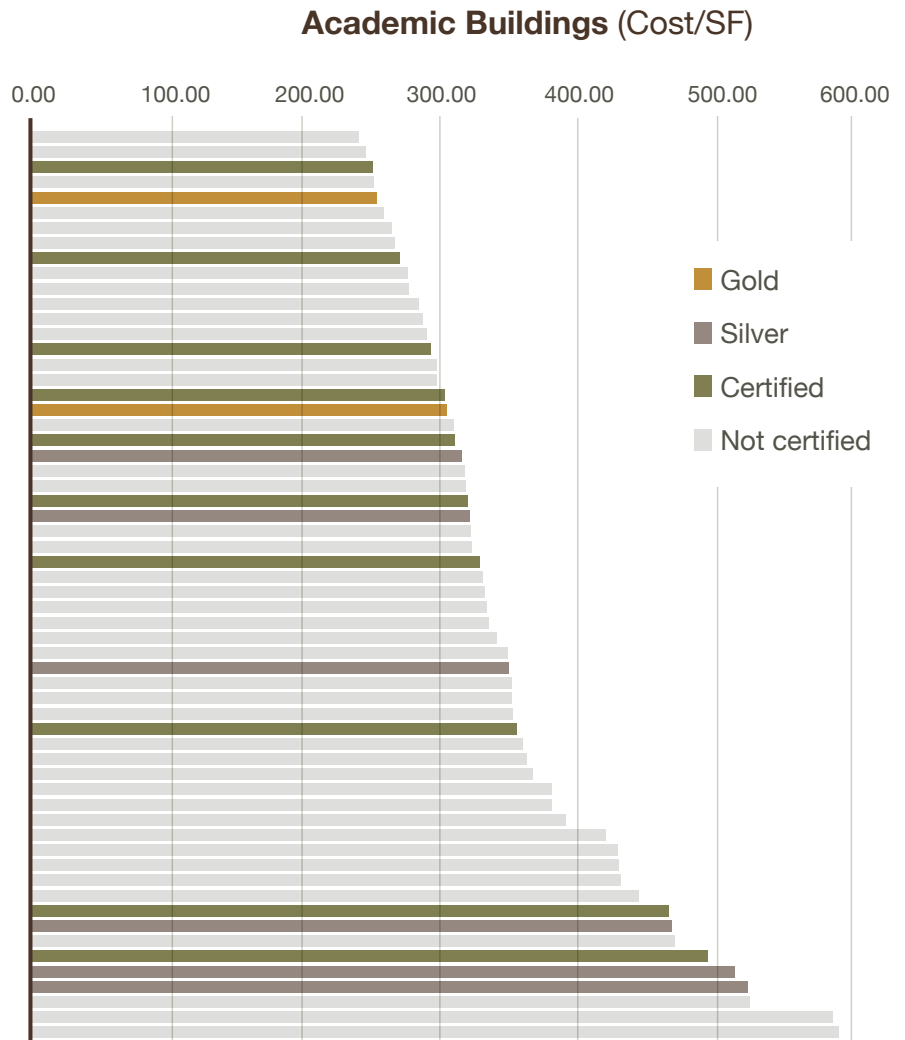
Deep energy savings require an integrated design approach considering interactive effects of multiple physical, mechanical, and behavioral measures. It is often hard to isolate the incremental cost of individual measures.

The design and construction process always includes many iterations of changes and trade-offs to balance owner wishes with budget limitations. Within this framework, quantifying the incremental cost of energy-saving features is problematic from several perspectives.

- Deep energy savings require an integrated design approach considering interactive effects of multiple physical, mechanical, and behavioral measures. It is often hard to isolate the incremental cost of individual measures. For example, the designer can quantify the specific cost of installing higher efficiency windows or the well field for a ground-source heat pump, but may overlook offsetting construction savings. It may be possible to downsize or even eliminate some HVAC equipment as a result of siting, shading, and building designs that reduce heating and cooling loads.
- For a high efficiency building, the incremental cost estimate must be based on a comparison to a hypothetical “what would have been built” alternative, requiring at least some subjectivity. Just one of the flawed assumptions is that the hypothetical “just-to-code” baseline is cost-optimized, while that level of analysis has typically not been incorporated.
- Even in the rare cases where sound initial attempts are made to quantify total initial incremental costs *and* savings of a green building, changes are often not tracked through the many revisions that occur before completion.
- Building costs vary over time, by climate, and by location, making it hard to create a national dataset of comparable numbers from a small set of disparate data.
- Reported costs are sometimes labeled by loosely defined categories such as project costs, hard costs, soft costs and construction costs. In other cases, they aren’t labeled at all.

Some of the most well-known studies of the actual costs of building green have been done by Davis Langdon (Mathiessen and Morris, 2007, which expands and updates their original study done in 2004). The research found it impractical to quantify incremental costs, but instead compared the total construction cost per square foot of buildings that were certified at various LEED levels. Figure 5 shows their results for academic buildings. The pattern seen here, with no clear relationship between total construction costs and LEED level, is typical of the various activity types they examined. All costs were normalized to reflect 2006 cost levels and for construction in a consistent location.

Figure 5: Academic buildings – normalized cost/sf (from Davis Langdon 2007)



Energy efficiency is just one of the many categories in which LEED points are awarded, and the report notes that many of the buildings in the dataset achieved just two to four energy reduction points out of the maximum (at the time) of 10. Thus, the Davis Langdon analysis shows the difficulty of seeing any green building impact in total construction cost numbers, but does not really address the question of whether deep energy efficiency would present a much different picture.

Current ZEB and ZEC Building Cost Examples

Example: Leslie Shao-Ming Sun Field Station (ZEB), Woodside, CA



Of the existing net zero and net zero-capable buildings discussed above, only a few document construction cost or incremental construction cost information. The available information differs for each building, but collectively provides some valuable insights. The sections below summarize their findings.

This 13,000-square-foot Stanford University building in the Jasper Ridge Biological Preserve is far from a typical office building, but gives an instructive example of quantifying green building costs. The project team compared the total cost per square foot for this building with the cost of two other campus buildings. All three buildings have similar usage requirements and were constructed during roughly the same time period. By establishing this identifiable peer group of comparable buildings within the university, the team avoided the complication of attempting to compare buildings constructed in different time periods, located in dissimilar climates, or (to some extent) with different use patterns and occupant densities.

On the basis of *hard construction costs*, the Field Station cost 3.6% more per square foot than one of the comparables and 10% more than the other.

Including soft costs such as design fees and development charges, the *total cost per square foot* for the Field Station was 6.6% less than one and 11% more than the other site.

The university also attempted to identify specific incremental costs and noted that the basic shell/insulation and orientation design permitted elimination of almost all air-conditioning, resulting in substantial system savings.

Example: Aldo Leopold Legacy Center (ZEB), Baraboo, WI



This 12,000-square-foot office and interpretive center in rural, central Wisconsin was built as the headquarters of the Aldo Leopold Foundation (ALF). As with all net zero projects, the PV system was a significant cost. The 40-kW PV array constituted 6.1% of the total project cost. The ALF reports that the payback period for this investment is nearly 100 years, based on local electricity rates at the time of construction. However, if the electricity rates for Milwaukee had been used in the same calculation, the payback period would have been reduced to only 14 years. This analysis highlights the importance of utility cost levels in any calculation of long-term payback or life cycle costs.

Example: IDeAs Z2 (ZEB), San Jose, CA



This 6,600-square-foot renovated office in San Jose, CA, was built as the new headquarters of the IDeAs electrical and lighting design services company. IDeAs reported a premium of about 7% of the renovation construction costs for energy efficiency related upgrades, equating to about \$23/sf. Over half of the incremental costs covered installation of a radiant floor slab and the associated ground-source heat pump system.

An additional 2% cost premium, or \$6.40/sf, was incurred for the building-integrated, 28-kW PV system. This includes the PV system and supporting structures. This cost premium was calculated as the net of rebates and tax incentives, which were substantial in this case. Before those credits, the total cost of the PV was reported to be about 25% of the construction costs.



Example: Hudson Valley Clean Energy Headquarters (ZEB), Rhinebeck, NY



This 4,000-square-foot New York office building expressed their incremental costs as equating to an additional \$680/month in higher mortgage payments. These payments cover better insulation, a ground-source heat pump, and onsite energy systems. In comparison, the owners are avoiding \$841/month in monthly energy bills. This amounts to a net savings of \$139/month with a fixed-rate mortgage. If consideration is given to the prospect of increasing utility rates, the future savings could be even greater.

Example: Richardsville Elementary (ZEB), Bowling Green, KY



This 72,000-square-foot school in Bowling Green, KY, was completed for approximately \$195/sf, which was below the state allocated budget for general new school construction. As noted in the features section, the school district benefited from the ability to build on lessons learned in previous construction projects, carrying forward effective approaches.

The stated cost includes \$39/sf for the PV array, which has on its own an expected 14 year pay-back period (and a 20 warranty on the PV panels themselves).



Example: IAMU Office and Training Headquarters (Zero Energy-Capable), Ankeny, IA



For this Ankeny, IA, project, the total construction costs were reportedly no higher than a conventional building. The cost analysis carefully noted both incremental cost items and offsetting areas of resulting savings. For example, daylighting design increased the south wall height, but this was offset by a decrease in the north wall height. Optimized window placement produced net savings by decreasing the total window area. The largest individual cost increase was for their ground-source heat pumps, but the sum of all the incremental costs and savings was near zero.



Example: EcoFlats Building (Zero Energy-Capable), Portland, OR



This newly constructed 16,000-square-foot mixed-use apartment/retail building in Portland, OR, targeted net zero energy for no increase in total costs. Their design decisions were based on the zero energy objective balanced with expected income from typical rents in the low-to-moderate income neighborhood. Increased costs associated with high performance construction were partially offset by tradeoffs in amenities offered to tenants. Some no-cost changes were also incorporated, such as exterior entries that eliminate the need for conditioned common hallways. Tenants are encouraged to live a low energy lifestyle, with features such as energy dashboards, indoor bicycle parking, a walkable location, and no parking lot.

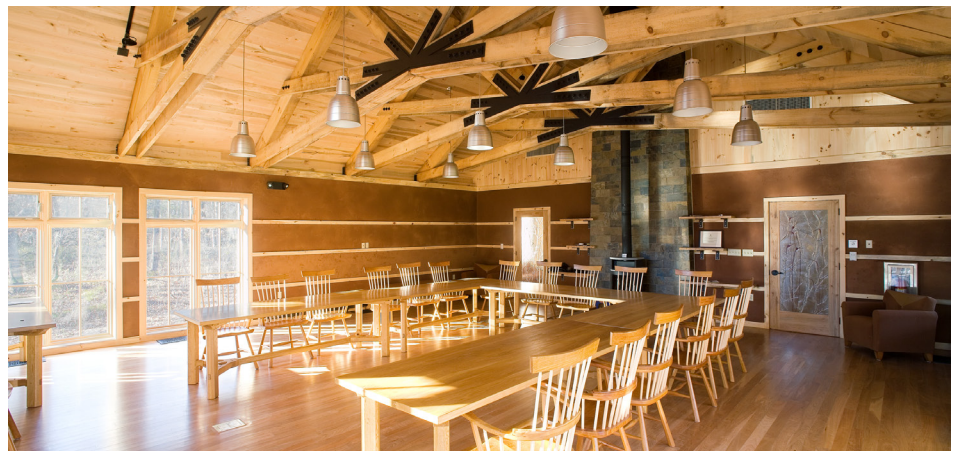
This project offers an example of how creative design driven by local market conditions can be economically viable. The building's extremely fast lease rate, with all units leased even before construction was completed, has also helped local lenders realize the market value of low energy buildings and potentially set a precedent to ease future financing of this type of building.

Summary: First Costs of Current Buildings

The limited anecdotal information provided, and lack of detail on what soft costs or incentives and credits may be included, precludes drawing meaningful averages in these cases. Recurring themes include the use of creative trade-offs in the design and construction process to manage total project costs within budget. The NREL Research Support Facility, for example, kept total costs per square foot in line with other recent large office buildings in the area. They noted a shift in cost allocation, with savings in mechanical and electrical costs made possible by greater architectural expenditure on the integrated design of the building.

The few incremental cost percentages reported fall into the 0% to 10% range. Payback periods, where mentioned, are 11 years or less, except for the PV system at the Aldo Leopold Center.

Aldo Leopold Legacy Center;
Baraboo, WI



Although these voluntarily published figures are likely skewed toward cases at the lower end of the cost spectrum, they do provide some examples of what can be accomplished. In addition, the published numbers focus mostly on hard costs, although accompanying narratives often refer to time required for research, locating desired materials and components, and trouble-shooting unfamiliar products and procedures. Such challenges are typical in the early years of implementing new approaches and can be addressed most quickly if experience is communicated within and between design, construction, and owner/property manager teams.

Design Model- Based Cost Estimates

Living Buildings

To supplement the limited case study information, we also reviewed a series of modeling studies that included both cost and energy estimates.

Packard Study

In 2002, the David and Lucille Packard Foundation funded the pioneering effort in estimating the cost of a Living Building, one with net zero energy use, as well as full utilization of site rainwater and treatment of wastewater. In a study for a new 90,000-square-foot office building, they modeled six scenarios spanning the range from typical San Francisco area market construction, with an EUI of 92 kBtu/sf, to a Living Building with a 40,000-square-foot PV array. The total cost increment estimate for the Living Building office over the base case was 43% with about one-fourth of that total cost premium for PVs. Although the total cost increment appears high relative to the results seen from more recent work, this early study set a good framework for future analysis.

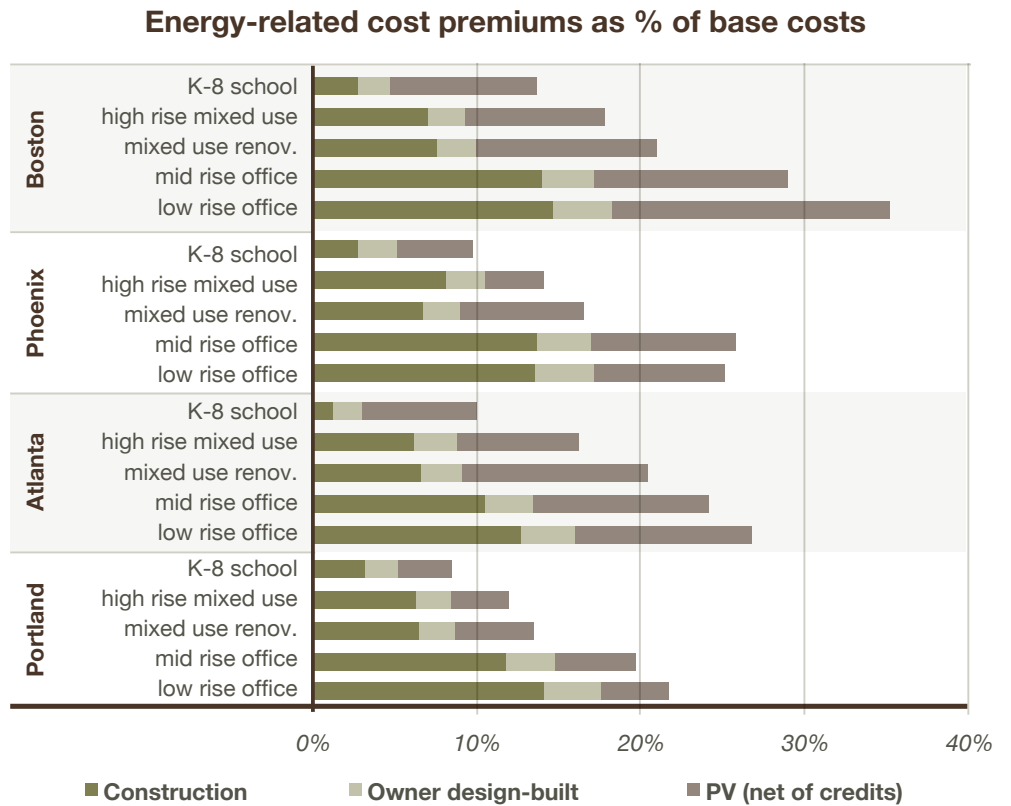
Cascadia Green Building Council Study

In 2009, the Cascadia Green Building Council commissioned a broader study investigating the economics and design strategies for creating Living Buildings. The project looked at four different climate regions, with analysis performed for nine different building types in each climate. The study team, led by SERA Architects with Skanska USA, Gerding Edlen Development, Interface Engineers, and New Buildings Institute participating, started with actual projects of each type that were occupied or, at a minimum, completed through final design. The team then normalized these starting points for standard base construction practices, location, and a 2009 construction year. From that base, they determined efficiency measures and related costs for LEED Gold and Living Building performance levels.⁶

⁶ Cost increments in this study are expressed relative to LEED Gold, citing the Davis Langdon total cost studies' conclusion that there are minimal total cost increments for the lower LEED certification levels.

Living Buildings must meet a number of prerequisites, including requirements for net zero energy, net zero water, sustainable water discharge, health, biophilia, sustainable materials, and local material sourcing. While the study team estimated costs in all these categories, this report focuses on the energy-related increments. Figure 6 displays the energy-related cost premium, with the costs associated with the other Living Building requirements removed. Energy efficiency measures are typically 5-15% of total costs, while PV adds another 5-15%.

Figure 6: *Living Building Study* energy cost premiums as % of base cost



Owner design, build costs are primarily development charges and A&E

PV costs shown net of credits, in most cases about 50% of gross (higher credits assumed in Portland)

The study authors warn against generalizing too broadly from the specific cost increment results of the analysis, stressing instead the general conclusion that living buildings can be cost effective in today's economy. Beyond that, the specific solutions must take into account the actual client goals, climate, building scale, and building use. The economics of any given project clearly depend on current incentives available and current and future cost of energy.

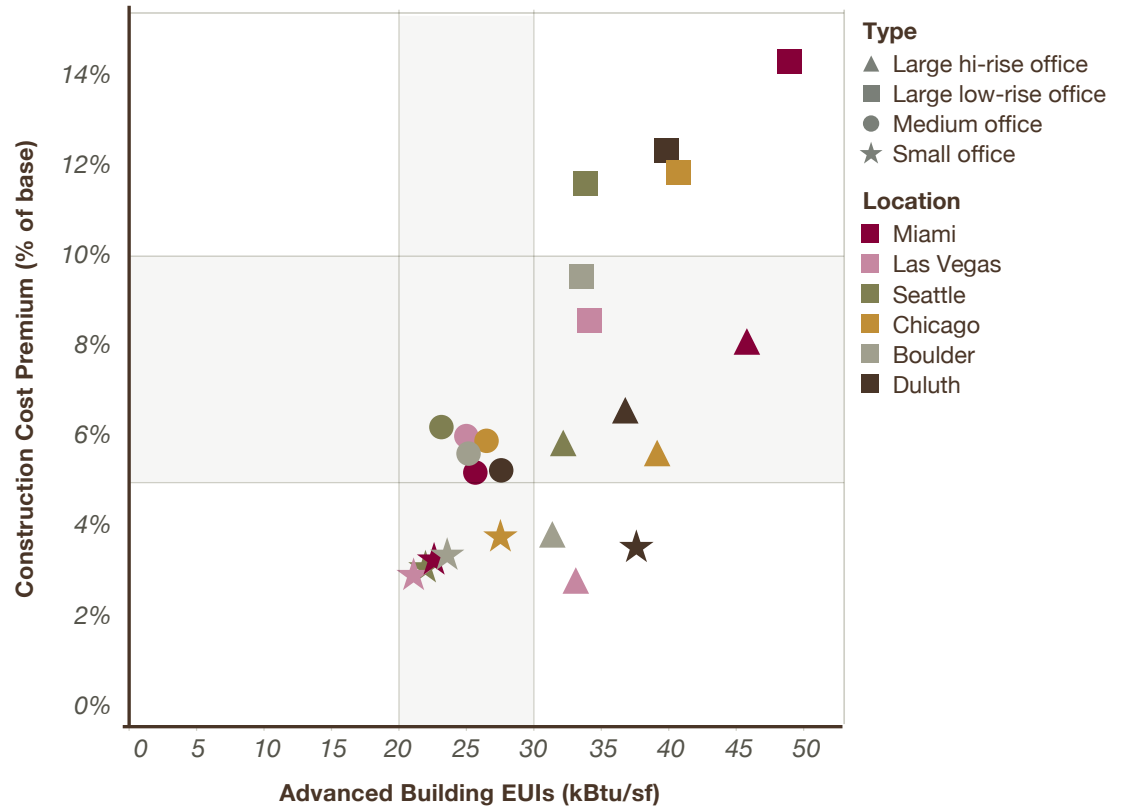
National Labs Design Studies for 50% Savings

The Pacific Northwest National Lab (PNNL) and the National Renewable Energy Lab (NREL) have produced a series of studies aimed at achieving energy use 50% below ASHRAE 90.1-2004. Measures used to achieve these savings for one building type are summarized in Appendix B: PNNL Model for 50% Energy Savings. Bottom line results are presented here for small, medium, and large offices (Thornton et al, 2010, Thornton et al, 2009, Leach et al, 2010). Similar reports are available for general retail and highway lodging.⁷ While the studies were not designed specifically to achieve zero energy buildings, the *small and medium office* models do produce modeled EUIs below 30 kBtu/sf in almost all climates. That puts them within reach of achieving net zero energy from onsite renewables.

As summarized in Figure 7, these models show construction cost premiums below 5% for the 20,000-square-foot small offices (shown by ★s) and in the 5-7% range for the 50,000-square-foot medium offices (shown by ●s). All but the Duluth small office achieved EUIs below 30 kBtu/sf. However, for the 460,000-square-foot large offices, most variations are between 31 and 40 kBtu/sf, with even higher values for Miami. The cost increments for the large offices range from 3-8% for the 12-story high rise versions (▲), and from 8-14% for the four-story low rise version (■).

⁷ As of April 2011, reports are also available for several other types that identify packages of efficiency measures but do not include the full economic analysis that provides estimated incremental costs for those measures.

Figure 7: Models 50% lower energy: Cost premium percentages and resulting EUIs



Other Model-based Efforts

The large office 50% savings analysis above showed particular challenges in reducing the EUI below 30 kBtu/square foot in Miami. Continuing the investigation of hot, humid climate challenges, Julie Hendricks did a study based on six real buildings in the Texas Gulf Coast, which showed the potential of all six for getting to net zero energy. The relatively long payback periods, ranging from 14 to 29 years, reflect the challenges such climates present for true ZEB in some cases. However, they also demonstrate how the ZEB goal can define effective paths to deep energy savings and how communication of current results can help set realistic interim steps as experience, design strategies and technologies improve further. (Hendricks, 2011)

For a 10-story, 250,000-square-foot spec office building, all the following strategies were incorporated in the modeled extreme energy efficiency version: an active chilled beam cooling system, dedicated outside air-handling with energy recovery, a ground-source heat pump, triple glazing (because of the 43% window-to-wall ratio in the base building), reduced lighting power density and daylighting. That modeled design concluded a 15 year payback.

HOK and the Weidt group have published extensive information on the design of a market-rate, zero-emissions, class A large office building in St. Louis. Their modeling shows a total EUI, before renewables, of just 22 kBtu/sf for this 170,000-square-foot building. Their cost estimates showed a total construction cost of \$223/sf, and a payback period for the incremental costs of 12 years (assuming energy costs outpace general inflation by 4% per year).

Summary: Cost Analysis

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.

Because of the limited number and atypical building types of the ZEB 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. Soft costs related to design and implementation of innovative approaches were typically not tracked, although anecdotally noted in case study narratives.

The modeling studies begin to show some more specific patterns. Foremost among these patterns is that achieving the levels of efficiency needed to support ZEB buildings appears to require only limited additional costs for some building types. In larger buildings, the costs of moving to advanced types of HVAC increased costs more significantly.

- The Cascadia Living Buildings study shows the importance of climate and climate-related efficiency strategies to manage the cost of PV and thus the total project cost.
- The PNNL study shows incremental costs in the 5-7% range for getting to the ZEC level for covered types other than large, high-rise offices.
- The final two studies, which were more building- and climate-specific, indicate a potential to move to ZEBs with paybacks in the range of 12 to 15 years for carefully designed buildings, even for larger and more complex building types and/or climates.

Conclusions and Recommendations

Despite the limitations of the data, it appears that ZEBs are beginning to be a realistic option for smaller buildings especially in moderate climates. For larger or more complex buildings in more challenging climates, modeling studies are showing positive paybacks that, while outside the financial parameters of the general development community, might still appeal to a class of owner-occupiers.

Soft costs related to the design and construction on these innovative buildings are not well documented; they certainly will be higher than for conventional construction, though not to the degree that is often perceived. There is still much groundbreaking work to be done. Continued innovation and dedicated pursuit of ZEBs will create cost reductions over the long term, result in more ZEB and ZEC buildings entering the market, and move advanced practices more swiftly to standard practice improving the energy efficiency of the entire building stock over time.

Extending the goal of ZEBs to a broader range of building types, climates and use patterns will likely prove challenging. In dense urban areas, it may not be possible to locate sufficient PV (or other renewable) on each site, but the ZEC pathway still enables deep energy efficiency, making district and equivalent renewable strategies feasible.

Recommendations

To continue to accelerate the development of ZEBs and begin to integrate lessons from these buildings into general design and construction activities, NBI recommends the following actions to assure that meaningful information is available:

Practical guidance to help identify opportunities: The marketplace needs clear summaries of the *conditions where ZEB's are most feasible* (anticipated loads, climate), and the path to move toward those goals. Ongoing communication can be fostered by continually updating a set of case studies showing clear definition of the processes and techniques used, results, and lessons learned with varying climates, building types and settings. Clear *studies of avoided costs* (both initial design and construction savings and ongoing energy savings) from energy efficiency-focused integrated design can help explain the potential and support needed financing of first costs.

Leslie Shao-Ming Sun Field Station;
Woodside, CA



Encourage measurement and communication of results: ZEBs are already entering a “second generation” of more typical building types and ownership patterns, and lessons learned from these examples could accelerate the interest at both the market and policy levels towards zero energy and zero energy-capable buildings. For the most useful lessons, ZEB owners must measure their total energy use in a way that gives insight into successful strategies and to areas for further improvement.

Knowing the annual totals for on-site energy use and purchased energy is the essential first step. Submetering or other analysis to identify areas for further improvement is also required to put that information to good use. Communication of these results should extend beyond the owner/operator, going back to the design team for incorporation into their future efforts, and to program sponsors for evaluating overall results.

Develop a better basis for benchmarking performance: As more successful zero energy-capable buildings emerge, we can shift the benchmarking focus from a broad peer group based on past commercial building national average EUIs to a forward-looking target based on demonstrated results of industry leaders. Two things are needed to improve the relevance of this forward-looking basis. Clearly, a larger pool of documented very high performance results will help demonstrate

achievable levels for a greater portion of building situations. Meaningful benchmarking also requires being able to identify true efficiency across buildings with a wide range of occupancy schedules and plug load requirements. (Eley, 2009)

As noted in this report, many early zero energy-capable buildings appear to have relatively short schedules and/or low office equipment needs, but those characteristics are not well-captured by the traditional building use type categorization. Consistent reporting of each the building's weekly hours of use, average number of occupants, and approximate number of computers might begin to fill that need.

Glossary

<i>Term</i>	<i>Definition</i>
Building Envelope	The building's exterior structure, including walls, windows, doors, roof, floor, and insulation. Also called a building shell.
CBECS	Commercial Building Energy Consumption Survey, a quadrennial survey done by the Department of Energy's Energy Information Administration, which is used as a standard reference point for commercial building energy usage. [As of 2011, the 2003 survey is the most recent available. Data problems prevented publication of the 2007 results, and the scheduled 2011 survey was suspended for budgetary reasons.]
Climate Responsive Design	An approach to energy efficient building design that considers the local climate. Climate responsive design makes maximum use of natural ventilation, passive cooling, and passive heating when possible, and uses landscaping, building orientation and configuration, to make maximum use of natural ventilation and passive heating and cooling while minimizing the impact of excessive heat, cold, or humidity.
Construction Costs	Usually refers to the actual costs of the contractor and subcontractors in building the facility to the specifications provided, including site preparation and construction. May or may not include all interior fit-out/TI level improvements.
Daylighting	The design of a building to use natural light to reduce the amount of electric lighting energy needed. Effective daylighting consists of good placement of windows and skylights, appropriate shading to avoid glare, and control systems that assure that lights are off when not needed.
Energy Dashboards	Real time displays of a building's energy use, often showing trends over time and comparisons with prior years or other buildings.
Energy Use Intensity (EUI)	Annual building energy use per square foot. Expressed in this report as energy used at the site in units of kBtu/sq ft/year.
Ground-Source Heat Pump	A heat pump system that uses fluid circulated through a large system of underground pipes. By taking advantage of the constant underground temperature throughout the year, the system reduces the heating and cooling energy needed.
Incremental Construction Cost	Additional cost of: hardware, labor, change orders, and engineering resulting from the incorporation of energy efficiency measures.

Integrated Design	An approach to building design that incorporates the interplay between location, siting, layout, structure, systems, and anticipated use patterns. Early collaboration on overall objectives among representatives of the entire design team, and regular meetings throughout design and construction, create solutions that work well together to minimize total energy use.
Hard Costs	Often the same as “construction costs.”
Heat Recovery	A process of transferring heat between a building’s exhaust air and the incoming fresh air, to reduce the amount of heating or cooling that needs to be applied to the fresh air.
High Performance Buildings	Buildings designed and operated in ways that reduce energy use.
LEED	Leadership in Energy and Environmental Design. The most widely used green building rating and benchmark system in the U.S. Maintained by the US Green Building Council.
Life Cycle Costs	Total costs related to a building or system over its entire life, including initial purchase and installation as well as ongoing operating and maintenance expenses.
Living Building	A structure that “generates all of its own energy with renewable nontoxic resources, captures and treats all of its water, and operates efficiently and for maximum beauty.”(Cascadia Green Building Council)
Measured Energy	Measured energy use gives the true indication the performance level achieved, and provides valuable feedback on successful strategies and areas of improvement.
Modeled Energy	Estimated building energy use, from sophisticated computer models that take into account details of the building’s configuration, shell, systems, and lighting, as well as anticipated schedules and occupant plug and process loads.
Natural Ventilation	Use of the natural airflow patterns, operable windows, etc, to move air within a building without use of fans. (as opposed to mechanical ventilation)
Normalized Cost	Adjusting costs based on standard base construction practices, location, and construction year.
Payback Period	The number of years required for the savings from an efficiency measure to offset the initial incremental costs of acquisition and installation.

Phantom Loads	Equipment that uses energy even when they appear to be turned off, such as appliances with electronic clocks, “instant on” display monitors, etc.
Plug Loads	Equipment and appliances plugged into electric outlets. Basically the energy use of the occupants in the building, as distinguished from heating, cooling, and ventilation energy.
Project Costs	Total costs including soft and hard costs plus land acquisition.
PVs	Photovoltaic Panels, which convert sunlight to electric energy
Occupant Loads	Energy used directly by the occupants of a building, as from computers and other equipment.
Radiant Heating & Cooling	A system that heats or cools large surfaces in a room, rather than blowing conditioned air through the space. Examples include the use of heated or cooled fluids piped through a floor or chilled overhead beams.
Shell	The building’s exterior structure, including walls, windows, doors, roof, floor, and insulation.
Soft Costs	Usually includes costs for design (architectural and engineering), permitting and other government fees, legal, financing, etc.
Solar Thermal System	A system that absorbs solar energy for heating purposes, such as for domestic hot water.
Submetering	Non-utility company energy meters installed to track just a portion of the energy being used in the total account. Submetering may be used, for example, to identify the energy used by each tenant within an office building, or to identify energy used for a specific purpose, such as heating or lighting, within a building.
Waste Heat	Unwanted heat generated as a byproduct of use of equipment, as from a refrigerator or computer.
Zero Energy Building (ZEB) & Net Zero Energy Building	Refers to a building that generates onsite at least as much energy as it uses over the course of a year using renewable resources.
Zero Energy-Capable (ZEC) & Net Zero Energy-Capable	A building with total energy use per square foot low enough that there is the potential for achieving net zero through onsite or offsite renewables.

References

1. (BD+C) Building Design + Construction, 2011. *Zero and Net Zero Energy Buildings + Homes*. <http://www.bdcnetwork.com/article/2011-zero-and-net-zero-energy-buildings-homes>
2. Cascadia Green Building Council, 2009. *Living Building Financial Study: The Effects of Climate, Building Type and Incentives on Creating the Buildings of Tomorrow*. <http://ilbi.org/education/reports/financial-study>
3. Eley, Charles, 2009. *Rethinking Percent Savings: The Problem with Percent Savings and the New Scale for a Zero Net-Energy Future* Report by the Architectural Energy Corporation to Southern California Edison. http://www.newbuildings.org/sites/default/files/Rethinking_Percent_Savings.pdf
4. Hendricks, J and Upadhyaya, K, 2011. *Zero Energy Buildings: When Do They Pay Off in a Hot and Humid Climate?* Building Design + Construction, February 2011. <http://www.bdcnetwork.com/hotandhumid>
5. HOK and the Weidt Group, 2011. *The Path to Net Zero Co₂urt: Where form follows performance*. <http://netzerocourt.com/> (See also Chapter 6, Lessons from a Zero Carbon Prototype, in the BD+C white paper above.)
6. Leach, M, Lobato, C, Hirsch, A., Pless, S, and Torcellini, P., 2010. *Technical Support Document: Strategies for 50% Energy Savings in Large Office Buildings*. National Renewable Energy Laboratory, NREL/TP-550-49213
7. Matthiessen, LF and Morris, P, 2007. *Cost of Green Revisited: Reexamining the Feasibility and Cost Impact of Sustainable Design in the Light of Increased Market Adoption*, Davis Langdon <http://www.davislangdon.com/USA/Research/ResearchFinder/2007-The-Cost-of-Green-Revisited/>
8. (Packard Foundation) David and Lucile Packard Foundation, 2002. *Building for Sustainability Report: Six Scenarios for The David and Lucile Packard Foundation* Los Altos Project.
9. Thornton, BA, Wang, W, Huang, Y, Land, and Liu, B, 2010. *Technical Support Document: 50% Energy Savings for Small Office Buildings*. Pacific Northwest National Laboratory, PNNL-19341.
10. Thornton, BA, Wang, W, Land, MD, Rosenberg, MI, and Liu, B, 2009. *Technical Support Document: 50% Energy Savings Design Technology Packages for Medium Office Buildings*. Pacific Northwest National Laboratory, PNNL-19004.

Appendix A: Zero Energy-Capable Buildings and Recent Emerging Cases

Table 3 lists 39 zero energy-capable buildings that were identified and included in the analysis for this report. Table 4 lists 39 additional projects targeting net zero that were identified, but not included in the report because they are currently under construction or had insufficient initial documentation available to confirm energy performance. However, the emerging cases do reflect credible efforts that will augment the continually growing list of examples and lessons in the future.

Table 3: Zero energy-capable buildings

	Building	Type	Location	Square Feet
1994	Wampanoag Headquarters	Office	Gay Head, MA	8,700
1995	Durant Road Middle School	Education- K-12 School	Raleigh, NC	148,500
	Ridgehaven Office Building	Office	San Diego, CA	78,000
1996	Claiborne & Churchill Winery	Office	San Luis Obispo, CA	2,585
1998	Vermont Law School Oakes Hall	Education- general	South Royalton, VT	23,500
2000	IAMU Office & Training Headquarters	Office	Ankeny, IA	12,500
	Zion Comfort Station	Other	Springdale, UT	2,400
2002	Georgina Blach Intermediate School	Education- K-12 School	Los Altos, CA	71,741
2003	Rinker Hall	Education- general	Gainesville, FL	47,470
	Bazzani Associates Headquarters	Office	Grand Rapids, MI	9,480
	EcoDorm at Warren Wilson College	Lodging - Residential - Multifamily	Swannanoa, NC	9,000
	Lower Windsor Township Community Center	Social/Meeting	Wrightsville, PA	37,100
	Schlitz Audubon Nature Center	Entertainment/Culture	Bayside, WI	35,387
	South Rim Maintenance & Warehouse Facility	Storage- general	Grand Canyon, AZ	72,000
	Southern York County Library	Library	Shrewsbury, PA	10,095
	Woods Hole Research Center	Office	Falmouth, MA	19,200

Appendix A (cont.)

	Building	Type	Location	Square Feet
2004	Lovejoy Opsis Building	Office	Portland, OR	20,000
	Doyle Conservation Center	Office	Leominster, MA	22,000
	Escalante Science Center	All Other- not classified	Escalante, UT	21,101
	Henry, the	Lodging - Residential - Multifamily	Portland, OR	211,700
	Suwannee River Visitor Center	Entertainment/Culture	Fargo, GA	7,015
	Wind NRG Partners, LLC	All Other- not classified	Hinesburg, VT	46,000
2005	Denali Visitor Center	Entertainment/Culture	Denali National Park, AK	13,991
	Kirsch Center For Environmental Studies at De Anza College	Education- general	Los Altos, CA	21,600
	Melink Corporation Headquarters	Office	Milford, OH	30,000
	Jane D'Aza House of Formation	All Other- not classified	San Rafael, CA	6,200
2006	Chartwell	Education- K-12 School	Seaside, CA	21,227
	Kinard Junior High	Education- K-12 School	Fort Collins, CO	112,735
	Stoller Winery	All Other- not classified	Dayton, OR	23,000
2007	AIA Portland Center for Architecture	Office	Portland, OR	5,000
	Center for Children & Families-CSU San Marcos	Education- general	San Marcos, CA	20,200
	Garthwaite Center for Science & Art	Education- K-12 School	Weston, MA	22,000
	Plano Elementary School	Education- K-12 School	Bowling Green, KY	81,147
2008	Sycamore Canyon Modernization	Education- K-12 School	Santee, CA	52,000
	Carlton Hills Modernization	Education- K-12 School	Santee, CA	56,159
	Carlton Oaks Modernization	Education- K-12 School	Santee, CA	61,675
	Eco Office	Office	Atlanta, GA	10,100
2009	ORNL Office Building 3156	Office	Oak Ridge, TN	6,900
2011	EcoFlats Building	Lodging - Residential - Multifamily	Portland, OR	19,860

Appendix A (cont.)

Table 4: Recent emerging cases

	Building	Type	Location	Square Feet
2005	Rag Flats	Lodging, Residential, Multi-family	Philadelphia, PA	25,000
2009	Alameda County Library	Library	Castro Valley, CA	34,000
	Marin County Day School Learning Resources Center	Education - K-12 School	Corte Madera, CA	23,592
2010	North Kohala Public Library	Library	North Kohala, HI	6,000
	Palmetto Bay Municipal Center	Office	Palmetto Bay, FL	25,000
2011	Rice Fergus Miller Office & Studio	Office	Bremerton, WA	18,550
	Centre of Excellence at Okanagan College	Education - general	Kelowna, BC	76,223
	June Key Delta Community Center	Public Assembly - other	Portland, OR	2,700
	ZHome - Issaquah	Lodging, Residential, Multi-family	Issaquah, WA	-
2012	Abondance - Montreal Multi-Family Net Zero	Lodging, Residential, Multi-family	Montreal	-
	North Shore Community College Health and Student Services Building	Education - general	Danvers, MA	58,000
	Paisano Green Community	Lodging, Residential, Multi-family	El Paso, TX	-
Under Construction or Limited Data	Bagley Classroom University of Minnesota Duluth	Education - general	Duluth, MN	2,000
	Bullitt Foundation Cascadia Center for Sustainable Design and Construction	Office	Seattle, WA	52,000
	Center for Energy Efficient Design	Education - K-12 School	Rocky Mount, VA	-
	Chevron net-zero gas station - Beaverton	All Other - not classified	Beaverton, OR	-
	Coastal Maine Botanical Gardens Bosarge Family Education Center	Public Assembly - other	Boothbay, ME	8,000
	David and Lucile Packard Foundation	Office	Los Altos, CA	-
	Dovetail Construction HQ Barn	Office	Richmond, VA	-
DPR Boutique (Phoenix Office)	Office	Phoenix, AZ	-	

Appendix A (cont.)

	Building	Type	Location	Square Feet
Under Construction or Limited Data	DPR Construction San Diego Net Zero Office	Office	San Diego, CA	24,000
	Electrical and Computer Engineering Building and University of Illinois	Education - general	Urbana/Champaign, IL	250,000
	Evie Garrett Dennis E12 Campus (Denver Schools)	Education - K-12 School	Denver, CO	-
	Ewa Elementary School Portable Classroom - Oahu	Education - K-12 School	Oahu, HI	-
	Georgia Peanut Comission HQ	Office	Tifton, GA	-
	Green Garage	All Other - not classified	Detroit, MI	12,000
	Hood River Middle School Net-Zero Addition	Education - K-12 School	Hood River, OR	-
	Lady Bird Johnson Middle School	Education - K-12 School	Irving, TX	150,000
	Mt. Vernon Unitarian Church	Religious Worship	Alexandria, VA	-
	NASA Sustainability Base	Office	Mountain View, CA	50,000
	Phipps Center for Sustainable Landscapes	Public Assembly - other	Pittsburgh, PA	-
	Salt Lake City Public Safety Building	Public Safety - other	Salt Lake City, UT	-
	TD Bank Branch - Ft. Lauderdale	Office	Fort Lauderdale, FL	-
	UC Davis West Village (eco district)	Lodging - Residential - Multifamily	Davis, CA	-
	University of British Columbia Center for Interactive Research on Sustainability	Education - general	British Columbia	60,000
	University of South Carolina Darla Moore School of Business	Education - general	SC	250,000
	VanDusen Botanical Garden Visitor Centre		Vancouver, BC	19,000
	Wayne Aspinall Federal Building and Courthouse	Courthouse	Grand Junction, CO	41,117
West Irving Library	Library	Irving, TX	-	

Appendix B: PNNL Model for 50% Energy Savings

The Pacific Northwest National Lab (PNNL) and the National Renewable Energy Lab (NREL) have published a series of Technical Support Documents illustrating how a recommended set of design features could be implemented to achieve 50% savings below ASHRAE 90.1-2004 levels. For several building types, these design strategies have also formed the basis of ASHRAE's 50% savings Advanced Energy Design Guides. Following these guidelines provides one approach to developing a high performance building upon which renewable energy can be added to reach net zero. In most cases, the 50% savings results result in building performance at the ZE-Capable level, and the incremental cost analysis was covered in the report section on National Labs Design Studies for 50% Savings. The features used for the 50,000 sf Medium Office Building are summarized here. Similar features and strategies are utilized for other building types.

The Medium Office efficiency measures are broken into five categories: building envelope, lighting, HVAC, service water heating and plug loads. PNNL used energy modeling to show how savings in these five areas could be combined to achieve the desired 50% reduction. Table 4 summarizes the key features identified in that report. The primary configuration specifies a radiant heating and cooling system with dedicated outside air and an enthalpy wheel. Variations were also developed using a variable air volume system; however, the VAV system did not achieve 50% savings in all climates.

The design strategies used represent well-developed existing technologies. This analysis demonstrates how an integrated design approach that thoughtfully implements existing technology is capable of generating substantial energy savings. Implementing this package of strategies shows the potential to reduce energy use by at least 50% in every US climate zone. The resultant site EUI for these high performance buildings ranges from 22 to 32 kBtu/ft² (reduced from 48-75 kBtu/ft² in the baseline model). With energy use intensities in this range, it is feasible to add enough renewable onsite power generation to achieve net zero.

Appendix B (cont.)

Table 5: Key strategies used for 50% savings in modeled energy use of medium buildings

	Feature	Baseline Model	50% Savings Mode
Envelope	Insulation	R-13 wall	R-13 wall + R-7.5 continuous insulation
	Roof	Typical roof w/ albedo = 0.23	Cool Roof w/ albedo = 0.69
	Windows	U = 0.55, SHGC = 0.43	U = 0.44, SHGC = 0.24
	Shading	None	Permanent overhangs on south facing windows
Lighting	Power Density	1.0 W/ft ²	0.75 W/ft ²
	Occupancy Sensors	Minimal	Additional sensors used. 16.8% savings in lighting energy
	Daylighting Control	None	Dimming ballast w/ photosensor
	Exterior Lighting	Typical	Minimal exterior lighting used
HVAC	System Selection	Variable Air Volume with gas furnace and electric reheat	Hydronic radiant heat/cool with condensing boiler, dedicated outdoor air system and enthalpy wheel
	Ventilation	Simple schedule	Demand Controlled
Water	Service Water Heating	Gas-fired, typ. efficiency	High eff. condensing unit
Plug Loads	Plug Loads	0.75 W/ft ²	Laptop computers, energy star equipment and controls to achieve 0.61 W/ft ²

Information for climate zone 4 is shown. Slightly different features are used in other climates.

Appendix C: Programs and Resources

Examples of programs or policy documents supporting zero energy-capable construction are listed below.

Energy Trust of Oregon: Net Zero Design Strategies | www.energytrust.org

The Energy Trust of Oregon offers a Path to Net Zero Pilot program of enhanced energy incentives for owners achieving exceptional levels of energy savings and those aiming for net zero energy use. The pilot program was immediately fully subscribed with 15 projects, including four schools or college facilities, four multi-unit residential buildings, three community centers/event spaces, two government/municipal buildings, one retail space, and one office building. Of these projects, seven are recently constructed or are nearing completion.

Living Building Challenge | <https://ilbi.org/lbc>

Managed by the International Living Future Institute, the Living Building Challenge is intended to inspire design and construction of zero impact, restorative buildings. Several commercial projects have been completed and more are in progress.

California's Savings by Design program | www.savingsbydesign.com

Savings by Design is providing support for buildings that achieve at least 40% energy savings above Title 24 code. This includes support for design teams, help with additional modeling and assistance with technical resources. The program also provides seminars on Net Zero Energy commercial and residential. For more information see the Savings by Design website or contact:

Zero Energy Commercial Buildings Consortium | <http://zeroenergycbc.org>

The Zero Energy Commercial Buildings Consortium (CBC) published two reports in 2011. The first, "Next Generation Technologies Barriers and Recommendations," describes barriers to achieving net zero energy related to key building systems, as well as recommendations for system improvements that would accelerate the transition to net zero energy. The second, "Analysis of Cost & Non-Cost Barriers and Policy Solutions", analyzes barriers due to market and policy conditions and provides policy, financing, and other recommendations to address these barriers.

The CBC reports can be downloaded at: <http://zeroenergycbc.org/resources/cbc-reports>

Massachusetts Executive Office of Energy and the Environment

The Massachusetts Zero Net Energy Buildings Task Force has developed a plan for transforming the building sector by creating a pathway toward zero net energy buildings in the Commonwealth.

Find the report at: <http://www.mass.gov/eea/docs/eea/press/publications/zneb-taskforce-report.pdf>

Appendix C (cont.)

CPUC Zero Net Energy Commercial Action Plan

As part of the CA Long Term Energy Efficiency Strategic Plan, the California Public Utilities Commission (CPUC) developed the Zero Net Energy Commercial Action Plan to help achieve the strategic plan goals and engage industry leaders, relevant agencies, stakeholders, utilities and other key influencers. An ongoing group continues to coordinate Action Plan activities.

Find both plans at: <http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/eesp/>