PDHonline Course G243 (1 PDH)

Zero Energy Buildings

Instructor: Steven G. Liescheidt, P.E., CCS, CCPR

2020

PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

National Renewable Energy Laboratory
Innovation for Our Energy Future

Zero Energy Buildings: A Critical Look at the Definition

Preprint

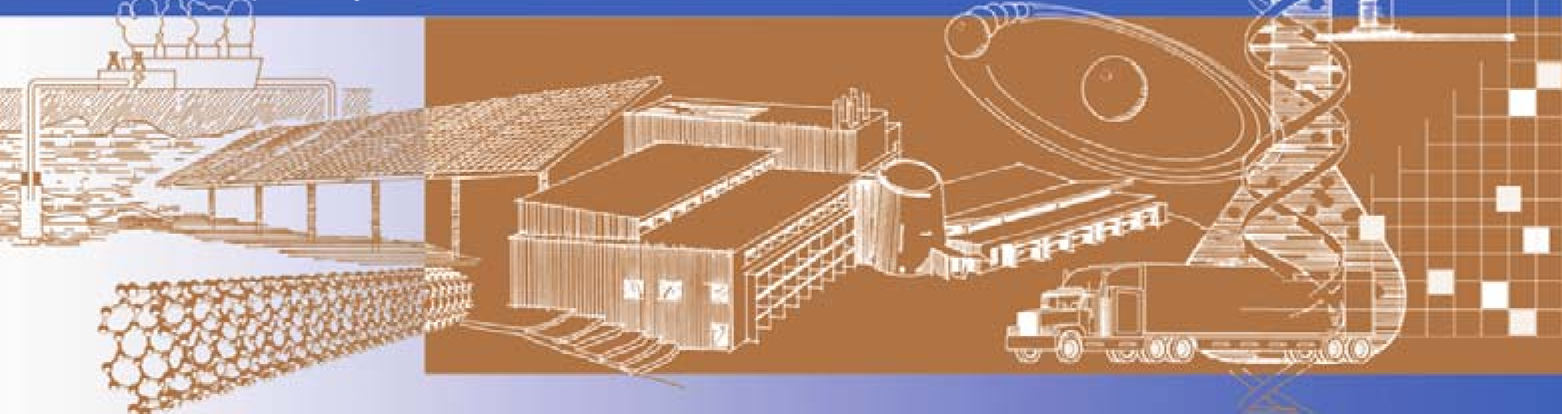
P. Torcellini, S. Pless, and M. Deru
National Renewable Energy Laboratory

D. Crawley
U.S. Department of Energy

To be presented at ACEEE Summer Study
Pacific Grove, California
August 14−18, 2006

Conference Paper
NREL/CP-550-39833
June 2006

NREL is operated by Midwest Research Institute • Battelle Contract No. DE-AC36-99-GO10337



Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Zero Energy Buildings: A Critical Look at the Definition[1]

Paul Torcellini, Shanti Pless, and Michael Deru, National Renewable Energy Laboratory
Drury Crawley, U.S. Department of Energy

ABSTRACT

A net zero-energy building (ZEB) is a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies. Despite the excitement over the phrase "zero energy," we lack a common definition, or even a common understanding, of what it means. In this paper, we use a sample of current generation low-energy buildings to explore the concept of zero energy: what it means, why a clear and measurable definition is needed, and how we have progressed toward the ZEB goal.

The way the zero energy goal is defined affects the choices designers make to achieve this goal and whether they can claim success. The ZEB definition can emphasize demand-side or supply strategies and whether fuel switching and conversion accounting are appropriate to meet a ZEB goal. Four well-documented definitions—net-zero site energy, net-zero source energy, net-zero energy costs, and net-zero energy emissions—are studied; pluses and minuses of each are discussed. These definitions are applied to a set of low-energy buildings for which extensive energy data are available. This study shows the design impacts of the definition used for ZEB and the large difference between definitions. It also looks at sample utility rate structures and their impact on the zero energy scenarios.

Introduction

Buildings have a significant impact on energy use and the environment. Commercial and residential buildings use almost 40% of the primary energy and approximately 70% of the electricity in the United States (EIA 2005). The energy used by the building sector continues to increase, primarily because new buildings are constructed faster than old ones are retired. Electricity consumption in the commercial building sector doubled between 1980 and 2000, and is expected to increase another 50% by 2025 (EIA 2005). Energy consumption in the commercial building sector will continue to increase until buildings can be designed to produce enough energy to offset the growing energy demand of these buildings. Toward this end, the U.S. Department of Energy (DOE) has established an aggressive goal to create the technology and knowledge base for cost-effective zero-energy commercial buildings (ZEBs) by 2025.

In concept, a net ZEB is a building with greatly reduced energy needs through efficiency gains such that the balance of the energy needs can be supplied by renewable technologies. Despite our use of the phrase "zero energy," we lack a common definition—or a common understanding—of what it means. In this paper, we use a sample of current generation low-energy buildings to explore the concept of zero energy—what it means, why a clear and measurable definition is needed, and how we have progressed toward the ZEB goal.

[1] This work has been authored by an employee or employees of the Midwest Research Institute under Contract No. DE-AC36-99GO10337 with the U.S. Department of Energy. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for United States Government purposes.

Using ZEB design goals takes us out of designing low-energy buildings with a percent energy savings goal and into the realm of a sustainable energy endpoint. The goals that are set and how those goals are defined are critical to the design process. The definition of the goal will influence designers who strive to meet it (Deru and Torcellini 2004). Because design goals are so important to achieving high-performance buildings, the way a ZEB goal is defined is crucial to understanding the combination of applicable efficiency measures and renewable energy supply options.

Zero-Energy Buildings: Boundary Definitions and Energy Flows

At the heart of the ZEB concept is the idea that buildings can meet all their energy requirements from low-cost, locally available, nonpolluting, renewable sources. At the strictest level, a ZEB generates enough renewable energy on site to equal or exceed its annual energy use. The following concepts and assumptions have been established to help guide definitions for ZEBs.

Grid Connection Is Allowed and Necessary for Energy Balances

A ZEB typically uses traditional energy sources such as the electric and natural gas utilities when on-site generation does not meet the loads. When the on-site generation is greater than the building's loads, excess electricity is exported to the utility grid. By using the grid to account for the energy balance, excess production can offset later energy use. Achieving a ZEB without the grid would be very difficult, as the current generation of storage technologies is limited. Despite the electric energy independence of off-grid buildings, they usually rely on outside energy sources such as propane (and other fuels) for cooking, space heating, water heating, and backup generators. Off-grid buildings cannot feed their excess energy production back onto the grid to offset other energy uses. As a result, the energy production from renewable resources must be oversized. In many cases (especially during the summer), excess generated energy cannot be used.

We assume that excess on-site generation can always be sent to the grid. However, in high market penetration scenarios, the grid may not always need the excess energy. In this scenario, on-site energy storage would become necessary.

Prioritize Supply-Side Technologies to Those Available On Site and within the Footprint

Various supply-side renewable energy technologies are available for ZEBs. Typical examples of technologies available today include PV, solar hot water, wind, hydroelectric, and biofuels. All these renewable sources are favorable over conventional energy sources such as coal and natural gas; however, we have developed a ranking of renewable energy sources in the ZEB context. Table 1 shows this ranking in order of preferred application. The principles we have applied to develop this ranking are based on technologies that:

- Minimize overall environmental impact by encouraging energy-efficient building designs and reducing transportation and conversion losses.
- Will be available over the lifetime of the building.
- Are widely available and have high replication potential for future ZEBs.

This hierarchy is weighted toward renewable technologies that are available within the building footprint and at the site. Rooftop PV and solar water heating are the most applicable supply-side technologies for widespread application of ZEBs. Other supply-side technologies such as parking lot-based wind or PV systems may be available for limited applications. Renewable energy resources from outside the boundary of the building site could arguably also be used to achieve a ZEB. This approach may achieve a building with net zero energy consumption, but it is not the same as one that generates the energy on site and should be classified as such. We will use the term "off-site ZEB" for buildings that use renewable energy from sources outside the boundaries of the building site.

Table 1. ZEB Renewable Energy Supply Option Hierarchy

Option Number	ZEB Supply-Side Options	Examples
0	Reduce site energy use through low-energy building technologies	Daylighting, high-efficiency HVAC equipment, natural ventilation, evaporative cooling, etc.
	On-Site Supply Options	
1	Use renewable energy sources available within the building's footprint	PV, solar hot water, and wind located on the building.
2	Use renewable energy sources available at the site	PV, solar hot water, low-impact hydro, and wind located on-site, but not on the building.
	Off-Site Supply Options	
3	Use renewable energy sources available off site to generate energy on site	Biomass, wood pellets, ethanol, or biodiesel that can be imported from off site, or waste streams from on-site processes that can be used on-site to generate electricity and heat.
4	Purchase off-site renewable energy sources	Utility-based wind, PV, emissions credits, or other "green" purchasing options. Hydroelectric is sometimes considered.

A good ZEB definition should first encourage energy efficiency, and then use renewable energy sources available on site. A building that buys all its energy from a wind farm or other central location has little incentive to reduce building loads, which is why we refer to this as an off-site ZEB. Efficiency measures or energy conversion devices such as daylighting or combined heat and power devices cannot be considered on-site production in the ZEB context. Fuel cells and microturbines do not generate energy; rather they typically transform purchased fossil fuels into heat and electricity. Passive solar heating and daylighting are demand-side technologies and are considered efficiency measures. Energy efficiency is usually available for the life of the building; however, efficiency measures must have good persistence and should be "checked" to make sure they continue to save energy. It is almost always easier to save energy than to produce energy.

Determining a project's boundary, which can be substantially larger than the building footprint, is an important part of defining on-site generation sources. The question arises as to whether this larger area should be considered for on-site renewable energy production. Typically, the only area available for on-site energy production that a building has guaranteed as "its own" over its lifetime is within its footprint. To ensure this area is available for on-site production, many states, counties, and cities have solar access ordinances, which declare that the right to use the natural resource of solar energy is a property right. For example, the City of

Boulder, Colorado has a solar access ordinance that guarantees access to sunlight for homeowners and renters in the city. This ordinance protects the solar access of existing buildings by limiting the amount of shadow new development may cast on neighboring buildings, and maintains the potential for using renewable energy systems in buildings (City of Boulder 2006). Using a neighboring field to generate electricity is not as favorable as a roof-mounted PV system; the area outside the building's footprint could be developed in the future; thus, it cannot be guaranteed to provide long-term generation.

Wind resources for ZEBs are limited because of structural, noise, and wind pattern considerations, and are not typically installed on buildings. Some parking lots or adjacent areas may be used to produce energy from wind, but this resource is site specific and not widely available. Similar to PV generation in an adjacent parking lot, the wind resource is not necessarily guaranteed because it could be superseded by future development.

Renewable sources imported to the site, such as wood pellets, ethanol, or biodiesel can be valuable, but do not count as on-site renewable sources. Biofuels such as waste vegetable oil from waste streams and methane from human and animal wastes can also be valuable energy sources, but these materials are typically imported for the on-site processes.

The final option for supply-side renewable energy sources includes purchasing "green credits" or renewable sources such as wind power or utility PV systems that are available to the electrical grid. These central resources require infrastructure to move the energy to the building and are not always available. Buildings employing resources 3 and 4 in Table 1 to achieve zero energy are considered off-site ZEBs. For example, a building can achieve an off-site ZEB for all these definitions by purchasing wind energy. Although becoming an off-site ZEB can have little to do with design and a lot to do with the different sources of purchased off-site renewable energy, an off-site ZEB is still in line with the general concept of a ZEB.

Zero-Energy Buildings: Definitions

A zero energy building can be defined in several ways, depending on the boundary and the metric. Different definitions may be appropriate, depending on the project goals and the values of the design team and building owner. For example, building owners typically care about energy costs. Organizations such as DOE are concerned with national energy numbers, and are typically interested in primary or source energy. A building designer may be interested in site energy use for energy code requirements. Finally, those who are concerned about pollution from power plants and the burning of fossil fuels may be interested in reducing emissions. Four commonly used definitions are: net zero site energy, net zero source energy, net zero energy costs, and net zero energy emissions.

Each definition uses the grid for net use accounting and has different applicable renewable energy sources. The definitions do apply for grid independent structures. For all definitions, supply-side option 2 can be used if this resource will be available for the life of the building. Off-site ZEBs can be achieved by purchasing renewable energy from off-site sources, or in the case of an off-site zero emissions building, purchasing emissions credits. In support of DOE's ZEB research needs, the following definitions refer to ZEBs that use supply-side options available on site. For ZEBs that have a portion of the renewable generation supplied by off-site sources, these buildings are referred to as "off-site ZEBs."

- **Net Zero Site Energy:** A site ZEB produces at least as much energy as it uses in a year, when accounted for at the site.
- **Net Zero Source Energy:** A source ZEB produces at least as much energy as it uses in a year, when accounted for at the source. Source energy refers to the primary energy used to generate and deliver the energy to the site. To calculate a building's total source energy, imported and exported energy is multiplied by the appropriate site-to-source conversion multipliers.
- **Net Zero Energy Costs:** In a cost ZEB, the amount of money the utility pays the building owner for the energy the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year.
- **Net Zero Energy Emissions:** A net-zero emissions building produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources.

Low- and Zero-Energy Buildings: Examples

To study the impacts of these ZEB definitions, we examined seven low-energy commercial buildings that had been monitored extensively with respect to the definitions. Each was designed to minimize energy and environmental impacts and used a combination of low-energy and renewable energy technologies. The buildings represent several climates and uses. They are all good energy performers; site energy savings range from 25% to 68% compared to conventional buildings that are minimally energy-code compliant (ASHRAE 2001). Understanding the energy performance of the current stock of high-performance buildings is an important step toward reaching the ZEB goal. The lessons learned from these seven buildings are used to guide future research to meet DOE's goal for facilitating marketable ZEBs by 2025. The buildings studied are (Torcellini et al. 2004; Barley et al. 2005):

- "Oberlin"—The Adam Joseph Lewis Center for Environmental Studies, Oberlin College.
- "Zion"—The Visitor Center at Zion National Park, Springdale, Utah.
- "Cambria"—The Cambria Department of Environmental Protection Office Building, Ebensburg, Pennsylvania.
- "CBF"—The Philip Merrill Environmental Center, Chesapeake Bay Foundation, Annapolis, Maryland.
- "TTF"—The Thermal Test Facility, National Renewable Energy Laboratory, Golden, Colorado.
- "BigHorn"—The BigHorn Home Improvement Center, Silverthorne, Colorado.
- "Science House" Science Museum of Minnesota, St. Paul, Minnesota.

These buildings were further investigated to determine additional PV system array area and capacity requirements to meet the ZEB goals (see Table 2). Annual electricity and natural gas site-to-source conversion multipliers (3.2 for electricity and 1.07 for natural gas) were applied to each building to determine source energy use (EIA 2005). For the all-electric buildings (Oberlin, Zion, Cambria, and the Science House), the site ZEB and source ZEB are the same. CBF used a minimal amount of propane, and the TTF and BigHorn used natural gas for space and water heating. Zion, TTF, BigHorn, and the Science House are single-story buildings; Oberlin, Cambria, and CBF are two stories. We used the PV system simulation tool PVSyst v3.3

(Mermoud 1996) to calculate the expected annual performance of the PV system. Single-crystalline PV modules were modeled with 0.0° tilt, as we assumed the PV system would be mounted on a flat roof of each building. These modules provide the best available output per unit area of commercially available PV modules. The Science House is the only building in this list that is currently a site, source, and emissions ZEB; it is a net exporter with approximately 30% more generation than consumption.

Table 2. ZEB Example Summary

Building and PV System (DC Rating Size)	Site Energy Use (w/o PV) (MWh/yr)	Source Energy Use (w/o PV) (MWh/yr)	Actual Roof Area (footprint) (ft^2)	Flat Roof Area (ft^2) Needed for Source ZEB and Site ZEB with PV	PV System DC Size Needed for Source ZEB and Site ZEB
Oberlin-60 kW	118.8	380.2	8,500	10,800	120 kW
Zion-7.2 kW	91.6	293.1	11,726	6,100	73 kW
Cambria-17.2 kW	372.1	1,190.7	17,250	37,210	415 kW
CBF-4.2 kW	365.2	1,142.0	15,500	25,316 Source ZEB 25,640 Site ZEB	282 kW Source ZEB 286 kW Site ZEB
TTF-No PV	83.5	192.5	10,000	4,010 Source ZEB 5,550 Site ZEB	45 kW Source ZEB 62 kW Site ZEB
BigHorn-8.9 kW	490.4	901.0	38,923	18,449 Source ZEB 31,742 Site ZEB	206 KW Source ZEB 354 kW Site ZEB
Science House-8.7 kW	5.9	18.8	1,370	1,000	6 kW

Zero-Energy Buildings: How Definition Influences Design

Depending on the ZEB definition, the results can vary substantially. Each definition has advantages and disadvantages, which are discussed below.

Net Zero Site Energy Building

A site ZEB produces as much energy as it uses, when accounted for at the site. Generation examples include roof-mounted PV or solar hot water collectors (Table 1, Option 1). Other site-specific on-site generation options such as small-scale wind power, parking lot-mounted PV systems, and low-impact hydro (Table 1, Option 2), may be available. As discussed earlier, having the on-site generation within the building footprint is preferable.

A limitation of a site ZEB definition is that the values of various fuels at the source are not considered. For example, one energy unit of electricity used at the site is equivalent to one energy unit of natural gas at the site, but electricity is more than three times as valuable at the source. For all-electric buildings, a site ZEB is equivalent to a source ZEB. For buildings with significant gas use, a site ZEB will need to generate much more on-site electricity than a source ZEB. As an example, the TTF would require a 62-kWDC PV system to be a site ZEB, but only a 45-kWDC PV system for a source ZEB (Table 2); this is because gas heating is a major end use. The net site definition encourages aggressive energy efficiency designs because on-site generated electricity has to offset gas use on a 1 to 1 basis.

A site ZEB can be easily verified through on-site measurements, whereas source energy or emissions ZEBs cannot be measured directly because site-to-source factors need to be determined. An easily measurable definition is important to accurately determine the progress toward meeting a ZEB goal.

A site ZEB has the fewest external fluctuations that influence the ZEB goal, and therefore provides the most repeatable and consistent definition. This is not the case for the cost ZEB definition because fluctuations in energy costs and rate structures over the life of a building affect the success in reaching net zero energy costs. For example, at BigHorn, natural gas prices varied 40% during the three-year monitoring period and electricity prices varied widely, mainly because of a partial shift from coal to natural gas for utility electricity production. Similarly, source energy conversion rates may change over the life of a building, depending on the type of power plant or power source mix the utility uses to provide electricity. However, for all the ZEB definitions, the impact of energy performance can affect the success in meeting a ZEB goal.

A building could be a site ZEB but not realize comparable energy cost savings. If peak demands and utility bills are not managed, the energy costs may or may not be similarly reduced. This was the case at Oberlin, which realized a 79% energy saving, but did not reduce peak demand charges. Uncontrolled demand charges resulted in a disproportionate energy cost saving of only 35%.

An additional design implication of a site ZEB is that this definition favors electric equipment that is more efficient at the site than its gas counterpart. For example, in a net site ZEB, electric heat pumps would be favored over natural gas furnaces for heating because they have a coefficient of performance from 2 to 4; natural gas furnaces are about 90% efficient. This was the case at Oberlin, which had a net site ZEB goal that influenced the design decision for an all-electric ground source heat pump system.

Net Zero Source Energy Building

A source ZEB produces as much energy as it uses as measured at the source. To calculate a building's total source energy, both imported and exported energy are multiplied by the appropriate site-to-source energy factors. To make this calculation, power generation and transmission factors are needed. *Source Energy and Emission Factors for Energy Use in Buildings* (Deru and Torcellini 2006) used a life cycle assessment approach and determined national electricity and natural gas site-to-source energy factors of 3.37 and 1.12. Site gas energy use will have to be offset with on-site electricity generation on a 3.37 to 1 ratio (one unit of exported electricity for 3.37 units of site gas use) for a source ZEB. This definition could encourage the use of gas in as many end uses as possible (boilers, domestic hot water, dryers, desiccant dehumidifiers) to take advantage of this fuel switching and source accounting to reach this ZEB goal. For example, the higher the percent of total energy used at a site that is gas, the smaller the PV system required to be a source ZEB. At BigHorn, for a source ZEB, 18,500 ft^2 of PV are required; however, 31,750 ft^2 of PV are required for a site ZEB (Table 2).

This definition also depends on the method used to calculate site-to-source electricity energy factors. National averages do not account for regional electricity generation differences. For example, in the Northwest, where hydropower is used to generate significant electricity, the site-to-source multiplier is lower than the national number. In addition, national site-to-source energy factors do not account for hourly variations in the heat rate of power plants or how utilities dispatch generation facilities for peak loading. Electricity use at night could have fewer source impacts than electricity used during the peak utility time of day. Further work is needed to determine how utilities dispatch various forms of generation and the corresponding daily variations of heat rates and source rates. Using regional time-dependent valuations (TDVs) for determining time-of-use source energy is one way to account for variations in how and when energy is used. TDVs have been developed by the California Energy Commission to determine the hourly value of delivered energy for 16 zones in California (CEC 2005). Similar national TDVs would be valuable to accurately calculate source energy use to determine a building's success in reaching a source ZEB goal. A first step in understanding regional site-to-source multiplier differences is available (Deru and Torcellini 2006); multipliers are provided for the three primary grid interconnects and for each state.

There may be issues with the source ZEB definition when electricity is generated on site with gas from fossil fuels. The ZEB definitions state that the building must use renewable energy sources to achieve the ZEB goal; therefore, electricity generated on site from fossil fuels cannot be exported and count toward a ZEB goal. However, this is unlikely, because buildings are unlikely to need more heat than electricity and the inefficiencies of on-site electricity generation and exportation make this economically very unattractive. The best cost or energy pathways will determine the optimal combination of energy efficiency, on-site cogeneration, and on-site renewable energy generation.

The issue of unmanaged energy costs in a site ZEB is similar for a source ZEB. A building could be a source ZEB and not realize comparable energy cost savings. If peak demands and utility bills are not managed, the energy costs may or may not be similarly reduced.

Net Zero Energy Cost Building

A cost ZEB receives as much financial credit for exported energy as it is charged on the utility bills. The credit received for exported electricity (often referred to net energy generation) will have to offset energy, distribution, peak demand, taxes, and metering charges for electricity and gas use. A cost ZEB provides a relatively even comparison of fuel types used at the site as well as a surrogate for infrastructure. Therefore, the energy availability specific to the site and the competing fuel costs would determine the optimal solutions. However, as utility rates can vary widely, a building with consistent energy performance could meet the cost ZEB goal one year and not the next.

In wide-scale implementation scenarios, this definition may be ineffective because utility rates will change dramatically. As energy-efficient building technologies and renewable energy installations increase, the effects of large numbers of energy-efficient buildings must be considered in a given utility's service area. In addition to purchasing fuel to generate electricity, electric utilities must provide dependable service, maintain capacity to meet potential loads, meet obligations for maintaining and expanding infrastructure, and provide profitability for shareholders. The fixed costs associated with these activities result in rate structures that provide only limited incentive for consumers to create cost ZEBs. Trends in other utility sectors, such as water districts, indicate that as buildings become more efficient, and consequently have lower consumptive charges, the costs associated with infrastructure are increased. If significant numbers of buildings achieved a zero energy cost, financial resources would not be available to maintain the infrastructure, and the utility companies would have to raise the fixed and demand charges.

For commercial buildings, a cost ZEB is typically the hardest to reach, and is very dependent on how a utility credits net electricity generation and the utility rate structure the building uses. One way to reach this goal in a small commercial building might be to use a utility rate that minimizes demand charges. For example, at Zion, a 73-kW PV system is needed for a site and source ZEB at current performance levels (about 65% energy savings without PV).

To be a cost ZEB, with the utility providing credit for net electricity generation at avoided generation costs, a 100-kW PV system would be needed. A cost ZEB may be technically possible in this case, but the following characteristics would all be required to achieve this ZEB definition:

- High energy savings (Zion's measured energy savings approach 65%).
- Aggressive demand management to allow PV to help offset demand. Without demand-responsive controls, PV systems cannot be relied upon to reduce peak demand charges (Torcellini et al. 2004). Additionally, the low peak demands enable the building to qualify for the small commercial rate structure.
- A favorable utility rate structure weighted toward energy use, not peak demand charges. Standard commercial rate structures often result in electricity charges that are typically split between peak demand and energy charges. The small building commercial rate structure for Zion, which has comparatively low peak demand rates and higher consumption rates, would not apply if the building used more than 35 kW for any 15-minute period over any time of the year. This small commercial rate includes a low demand charge of $6.30/kW for all usage that exceeds 15 kW, and an energy charge of $0.08/kWh for the first 1500 kWh and $0.045/kWh for all additional kilowatt-hours. A time-of-use rate would also be advantageous for a cost ZEB.
- A net-metering agreement that credits excess electricity generation at avoided generation costs ($0.027/kWh in this case), without capacity eligibility limits to PV system sizes. Avoided generation costs refer to how the utility credits the customer for net generation and is based on the costs associated with the utility not having to generate this energy. A far more favorable net-metering agreement would credit the net generation at the full retail rate. This is considered "true" net metering, and would be the favored net metering arrangement in a cost ZEB. The net-metering agreement also must allow the excess generation credit to be used for offsetting energy-related and nonenergy charges, such as monthly meter charges, demand charges, and taxes.

In the Zion net cost ZEB example, a PV system 30% larger than a site or source ZEB PV system would be required to reach the net cost ZEB goal. For utility rates that do not allow the net generation credit to be applied to nonenergy charges, a net cost ZEB would not be possible, irrespective of the size of the PV system, the energy or demand savings, or how the rates weight energy and nonenergy charges.

If demand charges account for a significant portion of the utility bills, a net cost ZEB becomes difficult. For example, Oberlin's rate structure is not weighted toward energy rates combined with minimal demand savings. A 430-kW PV system would be required for a cost ZEB at Oberlin at current levels of performance. This is 3.6 times the size of the PV system Oberlin would need to be a site or source ZEB. For this 13,600 ft^2 building to be a net cost ZEB, a PV system approaching 40,000 ft^2 would be required—much larger than the building footprint.

If two-way or net metering is not available, on-site energy storage and advanced demand-responsive controls to manage peak demand charges should be included in the design and operation of cost ZEBs. It may be more effective to store excess PV energy and use it at a later time to reduce demand charges rather than export the energy to the grid.

Net Zero Energy Emissions Building

An emissions-based ZEB produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources. An on-site emission ZEB offsets its emissions by using supply-side options 1 and 2 in Table 1. If an all-electric building obtains all its electricity from an off-site zero emissions source (such as hydro, nuclear, or large scale wind farms), it is already zero emissions and does not have to generate any on-site renewable energy to offset emissions. However, if the same building uses natural gas for heating, then it will need to generate and export enough emissions-free renewable energy to offset the emissions from the natural gas use. Purchasing emissions offsets from other sources would be considered an off-site zero emissions building.

Success in achieving an emissions ZEB depends on the generation source of the electricity used. Emissions vary greatly depending on the source of electricity, ranging from nuclear, coal, hydro, and other utility generation sources. One could argue that any building that is constructed in an area with a large hydro or nuclear contribution to the regional electricity generation mix would have fewer emissions than a similar building in a region with a predominantly coal-fired generation mix. Therefore, an emissions ZEB would need a smaller PV system in areas with a large hydro or nuclear contribution compared to a similar building supplied by a utility with a large coal-fired generation contribution.

The net zero emissions ZEB definition has similar calculation difficulties previously discussed with the source ZEB definition. Many of these difficulties are related to the uncertainty in determining the generation source of electricity. Like the source definition, one would need to understand the utility dispatch strategy and generation source ratio to determine emissions from each of these sources.

Conclusions

ZEB Definitions Applied to a Sample of Current Generation Low-Energy Buildings

Each of these leading-edge case study buildings demonstrates the progress toward achieving ZEB goals in real-world examples. Only the Science House has achieved the site and source ZEB goal because it is a small building with a relatively large PV system. The other one-story buildings—Zion, BigHorn, and TTF—could achieve ZEB within their roof areas for all the definitions except cost ZEB. ZEB is not feasible for the two-story buildings unless their loads are further reduced. For Oberlin (currently closest to meeting a ZEB goal in a two-story building), the annual PV production is still less than the best-case energy consumption scenario. Oberlin is currently installing another 100-kW PV system in the parking lot (total installed DC capacity will be 160 kW), which will be tied into the building's electrical system. We expect that the building will achieve a site, source, and emissions ZEB, but that a cost ZEB will be difficult to reach without further demand management controls. To accomplish a ZEB, the PV system has been extended past the building footprint.

None of our sample commercial buildings could clearly be cost ZEBs with the current rate structures. Zion could be the closest because of its aggressive demand management, favorable utility rate structure, and efficient use of energy. A cost ZEB is the most difficult ZEB goal to reach because typical commercial rate structures do not allow for net metering such that exported electricity can offset all other utility charges. To reach a cost ZEB goal, the credit received for exported electricity would have to offset energy, distribution, peak demand, taxes, and metering charges for both electricity and gas use.

The ZEB Definition Selected Can Have an Impact on Future ZEB Designs

The zero energy definition affects how buildings are designed to achieve the goal. It can emphasize energy efficiency, supply-side strategies, purchased energy sources, utility rate structures, or whether fuel-switching and conversion accounting can help meet the goal. Table 3 highlights key characteristics of each definition.

Table 3. ZEB Definitions Summary

Defini-tion	Pluses	Minuses	Other Issues
Site ZEB	• Easy to implement. • Verifiable through on-site measurements. • Conservative approach to achieving ZEB. • No externalities affect performance, can track success over time. • Easy for the building community to understand and communicate. • Encourages energy-efficient building designs.	• Requires more PV export to offset natural gas. • Does not consider all utility costs (can have a low load factor). • Not able to equate fuel types. • Does not account for nonenergy differences between fuel types (supply availability, pollution).	
Source ZEB	• Able to equate energy value of fuel types used at the site. • Better model for impact on national energy system. • Easier ZEB to reach.	• Does not account for nonenergy differences between fuel types (supply availability, pollution). • Source calculations too broad (do not account for regional or daily variations in electricity generation heat rates). • Source energy use accounting and fuel switching can have a larger impact than efficiency technologies. • Does not consider all energy costs (can have a low load factor).	• Need to develop site-to-source conversion factors, which require significant amounts of information to define.
Cost ZEB	• Easy to implement and measure. • Market forces result in a good balance between fuel types. • Allows for demand-responsive control. • Verifiable from utility bills.	• May not reflect impact to national grid for demand, as extra PV generation can be more valuable for reducing demand with on-site storage than exporting to the grid. • Requires net-metering agreements such that exported electricity can offset energy and nonenergy charges. • Highly volatile energy rates make for difficult tracking over time.	• Offsetting monthly service and infrastructure charges require going beyond ZEB. • Net metering is not well established, often with capacity limits and at buyback rates lower than retail rates.
Emis-sions ZEB	• Better model for green power. • Accounts for nonenergy differences between fuel types (pollution, greenhouse gases). • Easier ZEB to reach.		• Need appropriate emission factors.

A source ZEB definition can emphasize gas end uses over the electric counterparts to take advantage of fuel switching and source accounting to reach a source ZEB goal. Conversely, a site ZEB can emphasize electric heat pumps for heating end uses over the gas counterpart. For a cost ZEB, demand management and on-site energy storage are important design considerations, combined with selecting a favorable utility rate structure with net metering. An emissions ZEB is highly dependent on the utility electric generation source. Off-site ZEBs can be reached just by purchasing off-site renewable energy—no demand or energy savings are needed. Consistent ZEB definitions are needed for those who research, fund, design, and evaluate ZEBs.

References

ASHRAE. (2001). *ANSI/ASHRAE/IESNA Standard 90.1-2001 Energy Standard for Buildings Except Low-Rise Residential.* Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Barley, C.D.; Deru, M.; Pless, S.; Torcellini, P. (2005). *Procedure for Measuring and Reporting Commercial Building Energy Performance*. Technical Report NREL/TP-550-38601. Golden, CO: National Renewable Energy Lab www.nrel.gov/docs/fy06osti/38601.pdf

CEC. (2005). *Time Dependent Valuation (TDV) Economics Methodology*. www.energy.ca.gov/title24/ 2005standards/archive/rulemaking/documents/tdv/. Sacramento, CA: California Energy Commission.

City of Boulder. (2006). Solar Access Guide, Building Services Center, Boulder, Colorado http://joomla.ci.boulder.co.us/files/PDS/codes/solrshad.pdf, last accessed May 2006.

Deru, M. and P. Torcellini. (2004). *Improving Sustainability of Buildings through a Performance-Based Design Approach: Preprint*. NREL Report No. CP-550-36276. World Renewable Energy Congress VIII, Denver, CO: August 29−September 3, 2004. Golden, CO: National Renewable Energy Laboratory, 8 pp. www.nrel.gov/docs/fy04osti/36276.pdf.

Deru, M. and P. Torcellini. (2006). *Source Energy and Emission Factors for Energy Use in Buildings*. Technical Report NREL/TP-550-38617. Golden, CO: National Renewable Energy Laboratory. www.nrel.gov/docs/fy06osti/38617.pdf.

EIA. (2005). *Annual Energy Review 2004.* www.eia.doe.gov/emeu/aer/contents.html. Washington, DC: U.S. Department of Energy, Energy Information Administration.

Mermoud, A. (1996). *PVSYST Version 3.3. User's Manual*. Geneva, Switzerland: University of Geneva, University Center for the Study of Energy Problems. www.pvsyst.com/. Last accessed September 2005.

Torcellini, P., M. Deru, B. Griffith, N. Long, S. Pless, R. Judkoff, and D. Crawley. (2004). Lessons Learned from Field Evaluation of Six High-Performance Buildings. Paper #358, Proceedings (CD-ROM), ACEEE Summer Study on Energy Efficiency in Buildings, August 22-27, 2004, Pacific Grove, CA. Golden, CO: National Renewable Energy Laboratory, 16 pp. www.nrel.gov/docs/fy04osti/36290.pdf.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
June 2006	Conference Paper	

4. TITLE AND SUBTITLE
Zero Energy Buildings: A Critical Look at the Definition; Preprint

5a. CONTRACT NUMBER
DE-AC36-99-GO10337

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
P. Torcellini, S. Pless, M. Deru, and D. Crawley

5d. PROJECT NUMBER
NREL/CP-550-39833

5e. TASK NUMBER
BEC61012

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/CP-550-39833

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*
A net zero-energy building (ZEB) is a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies. Despite the excitement over the phrase "zero energy," we lack a common definition, or even a common understanding, of what it means. In this paper, we use a sample of current generation low-energy buildings to explore the concept of zero energy: what it means, why a clear and measurable definition is needed, and how we have progressed toward the ZEB goal.

15. SUBJECT TERMS
zero energy building; zeb; commercial building; low-energy building

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
Unclassified	Unclassified	Unclassified	UL		
					19b. TELEPHONE NUMBER *(Include area code)*

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18