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Innovation for Our Energy Future

Getting to Net Zero

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Introduction

As the futurist Stewart Brand observed, "Every building is a forecast. Every forecast is wrong."

Making forecasts progressively *less* wrong over time—specifically, forecasts about high-performance buildings—is the purpose of the U.S. Department of Energy's (DOE) Zero Energy Buildings Database. The intent of this article is to provide an overview of the DOE's efforts toward realizing cost-effective net-zero energy buildings (NZEBs).

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. 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 2003 and is expected to increase another 50% by 2025 (EIA 2005).

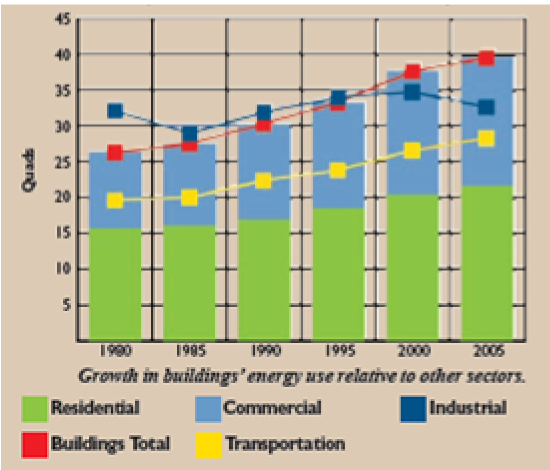

Figure 1 Growth in building energy use relative to other sectors

The vision of NZEBs is compelling. These highly energy-efficient buildings will use, over the course of a year, renewable technology to produce as much energy as they consume from the grid. Building owners and tenants stand to realize attractive returns on their NZEB investments while reducing carbon footprints. And, while today's buildings are our nation's highest energy-consuming and carbon-emitting sector, with NZEBs, our nation can gain a network of clean domestic energy assets (see Figure 1).

Yet, how realistic is this vision? How close do NZEBs come to realizing their design goals? How much does it cost to design and build a net zero energy building? Thanks to data being provided voluntarily by building owners in the Zero Energy Buildings Database, we now have some early insight into these questions and into the drivers of net zero energy performance.

Just as important, we now have an influential community of industry leaders who are committed to pushing the boundaries of building performance and sharing the results. As part of the Net-Zero Energy Commercial Building Initiative, authorized by Congress in the Energy Independence and Security Act of 2007 (EISA 2007), DOE hosts industry-led Commercial Building Energy Alliances focused on specific interests of key sectors. To date, DOE has launched three alliances representing substantial proportions of the square footage in their respective sectors: the Retailer Energy Alliance (17%), the Commercial Real Estate Energy Alliance (21%), and the Hospital Energy Alliance (17%) (DOE 2009a, 2009b, 2009c). EISA 2007 also authorizes the Net-Zero Energy Commercial Building Initiative to support the goal of net zero energy for all new commercial buildings by 2030, and specifies a zero-energy target for 50% of U.S. commercial buildings by 2040 and net zero for all U.S. commercial buildings by 2050.

Some members of the alliances take their commitment to high performance an additional step. With technical support from DOE national laboratories, each of these "National Account" companies pledges to design and construct one new building that is at least 50% more efficient than ASHRAE Standard 90.1-2004 and to renovate a facility to achieve at least 30% savings over standard practices. With these investments—and the detailed measurement and verification that will accompany them—researchers will gain a richer understanding of the best practices and technologies for achieving high performance, along with the operational and cost data for a solid business case. By sharing this knowledge base with peers, industry leaders will spur further investment in high-performance buildings—and, over time, a critical mass of data will enable increasingly precise modeling of building energy performance and greater certainty in net zero energy design.

Building design professional societies also have recognized the vision of net zero energy buildings. For example:

- ASHRAE Vision 2020 report (ASHRAE 2008) sets out requirements for developing the tools by 2020 to enable commercially viable net zero energy buildings by 2030. ASHRAE's recent conference on net zero energy buildings featured more than 25 posters (ASHRAE 2009) of NZEBs, some operating close to or at net zero and others in various stages of design or construction.
- The AIA 2030 Challenge (AIA 2009) calls for incrementally reducing energy use, starting with a 50% reduction over existing buildings' energy use and increasing savings up to 2030, when new buildings will be carbon neutral. Architecture firms, large and small, are beginning to make this voluntary commitment to adopt energy-saving targets in building design and implement steps to reach the carbon-neutral goal.

Policymakers also are embracing net-zero energy buildings as a key strategy for meeting energy and carbon goals. The California Public Utilities Commission, for example, has an energy action plan to achieve net zero energy for all new residential construction by 2020 and net zero for all new commercial construction by 2030. This action plan will provide direction for future development of California's Title 24 building energy codes, as well as incentives for net zero buildings. NZEB goals also were recently announced by the European Parliament in a March 2009 press release (European Parliament 2009). All European Union Member States are to ensure that all newly constructed buildings produce as much energy as they consume on-site no later than December 31, 2018.

It is still early in the collection and analysis of energy-performance data. But it is already clear that high-performance commercial buildings—some NZEBs, some "almost NZEBs"—can be constructed cost effectively, providing productive environments for occupants, reducing operating costs, and enhancing the competitiveness of commercial properties. Here is a synopsis of what we've learned so far.

What Is a Net-Zero Energy Building?

Calibrating expectations is a foundation for success in any net-zero energy building (NZEB) project.

In the broadest sense, an NZEB is a residential or commercial building with greatly reduced energy needs. In such a building, efficiency gains enable the balance of energy needs to be supplied with renewable energy technologies.

But this broad definition leaves plenty of room for interpretation—and for misunderstanding among the owners, architects, and other players in an NZEB project. Agreeing to a common definition of NZEB boundaries and metrics is essential to developing design goals and strategies.

To improve clarity, the National Renewable Energy Laboratory has created two foundational references:

Zero Energy Buildings: A Critical Look at the Definition (August 2006) documents four NZEB definitions: net zero site energy, net zero source energy, net zero energy costs, and net zero energy emissions (Torcellini et al. 2006a).

Zero Energy Buildings: A Classification System Based on Renewable Energy Supply Options (July 2009) classifies NZEBs based on the renewable energy sources used. At the top of the classification system is the NZEB:A—a building that offsets all of its energy use from renewable energy resources available within the footprint. At the lowest end is the NZEB:D—a building that achieves an NZEB definition through a combination of on-site renewables and off-site purchases of renewable energy credits.

Net-Zero Energy Building Definitions

- **Net Zero Site Energy:** A site NZEB produces at least as much renewable energy as it uses in a year, when accounted for at the site.
- **Net Zero Source Energy:** A source NZEB produces (or purchases) at least as much renewable energy as it uses in a year, when accounted for at the source. Source energy refers to the primary energy used to extract, process, 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 based on the utility's source energy type.
- **Net Zero Energy Costs:** In a cost NZEB, the amount of money the utility pays the building owner for the renewable 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 Emissions:** A net zero emissions building produces (or purchases) enough emissions-free renewable energy to offset emissions from all energy used in the building annually. Carbon, nitrogen oxides, and sulfur oxides are common emissions that ZEBs offset. To calculate a building's total emissions, imported and exported energy is multiplied by the appropriate emission multipliers based on the utility's emissions and on-site generation emissions (if there are any).

Table 1 and the sidebar "Net Zero Energy Building Definitions" summarize the four NZEB definitions and four energy-use classifications. All NZEBs must reduce site energy through energy efficiency and demand-side renewable energy technologies such as daylighting, insulation, passive solar heating, high-efficiency HVAC equipment, natural ventilation, evaporative cooling, ground-source heat pumps, and ocean water cooling. In addition, they must use supply-side renewable energy according to one of the four NZEB classifications. Column 3 of the table discusses the ability of each classification to meet the site, source, emissions, and cost definitions of NZEBs.

There is no "best" definition or energy-use accounting method; each has merits and drawbacks, and the approach for each project should be selected to align with the owner's goals. But across all NZEB definitions and classifications, one design rule remains constant: tackle *demand* first, then *supply*.

Table 1 Classifying NZEBs by Renewable Energy Supply

ZEB Classification	ZEB Supply-Side Options	ZEB Definitions
On-Site Supply Options		
A	Use renewable energy sources available within the building's footprint and directly connected to the building's electrical or hot/chilled water distribution system. (Examples: Photovoltaic, solar hot water, and wind located on the building.)	YES: Site, Source, Emissions Difficult: Cost If the source and emissions multipliers for a ZEB:A are high during times of utility energy use but low during times the ZEB is exporting to the grid, reaching a source or emissions ZEB position may be difficult. Qualifying as a cost ZEB may be difficult depending on the net-metering policies in the area.
B	Use renewable energy sources as described in ZEB:A and Use renewable energy sources available at the building site and directly connected to the building's electrical or hot/chilled water distribution system. (Examples: Photovoltaic, solar hot water, low-impact hydroelectric, and wind located on parking lots, adjacent open space, but not physically mounted on the building.)	YES: Site, Source, Cost, Emissions Difficult: Cost If the source and emissions multipliers for a ZEB:B are high during times of utility energy use but low during times the ZEB is exporting to the grid, reaching a source or emissions ZEB position may be difficult. Qualifying as a cost ZEB may be difficult depending on the net-metering policies in the area.
Off-Site Supply Options		
C	Use renewable energy sources as described in ZEB:A; ZEB:B, and ZEB:C and Use renewable energy sources available off site to generate energy on site and directly connected to the building's electrical or hot/chilled water distribution system. (Examples: Biomass, wood pellets, ethanol, or biodiesel that can be imported from off-site, or collected from waste streams from on-site processes that can be used on-site to generate electricity and heat.)	YES: Site, Difficult: Source, Cost, Emissions A ZEB:C source and emission position may be difficult if carbon-neutral renewables such as wood chips are used or if ZEB has an unfavorable source and carbon multipliers. This can occur if a ZEB exports energy during times that the utility has low source and carbon impacts, but imports energy when the utility has high source and carbon impacts. ZEB:C buildings typically do not reach a cost ZEB position because renewable materials are purchased to bring on-site—it would be very difficult to recoup these expenses by any compensation received from the utility for renewable energy generation.
D	Use renewable energy sources as described in ZEB:A, ZEB:B, and ZEB:C and Purchase recently added off-site renewable energy sources, as certified from Green-E (2009) or other equivalent renewable-energy certification programs. Continue to purchase the generation from this new resource to maintain ZEB status. (Examples: Utility-based wind, photovoltaic, emissions credits, or other "green" purchasing options. All off-site purchases must be certified as recently added renewable energy (Green-E 2009). A building could also negotiate with its power provider to install dedicated wind turbines or PV panels at a site with good solar or wind resources off-site. In this approach, the building might own the hardware and receive credits for the power. The power company or a contractor would maintain the hardware.)	YES: Source, Emissions NO: Site, Cost ZEB:D buildings may qualify as source and emissions if they purchase enough renewable energy and have favorable source and emissions factors. They will not qualify as site and cost.

NZEB owners and designers should first use all possible cost-effective energy efficiency strategies and then incorporate renewable energy, weighing the many possible supply options available and giving preference to sources available within the building footprint. Use of on-site renewable options over off-site options minimizes the overall environmental impact of an NZEB by reducing energy transportation, transmission, and conversion losses.

In addition to efficiency measures, demand-side strategies may include renewable energy sources that cannot be commoditized, exported, or sold, such as passive solar heating, daylighting, solar ventilation air preheaters, and domestic solar water heaters. Typical supply-side generation options include photovoltaics, solar hot water connected to a district hot water system, wind, hydroelectricity, and biofuels.

From "Real Low" to Zero

Our earliest experiences were with high-performance buildings that were not designed for net zero energy. DOE monitored the performance of six of these "real low energy buildings" (Torcellini et al. 2006b).

What we found is that all of these buildings delivered significant energy and cost savings under actual operating conditions—but that none of them reached the levels of savings modeled in the design. First, design teams were a bit too optimistic about the occupants' behavior and acceptance of systems. Undoubtedly, some of the shortfall also rested with inherent uncertainty of designing buildings and forecasting their performance. Energy consumption was higher and photovoltaic (PV) energy production was lower than simulations predicted. In particular, daylighting contributed less than predicted, which meant more electrical lighting was used (Torcellini et al. 2006).

Again, driving down this uncertainty—and accelerating investments in net zero energy buildings—is the motivation behind the Zero Energy Buildings Database (DOE 2009d).

The database currently houses data on eight commercial buildings, voluntarily reported by owners and architects. Some data sets are modeled for yet-to-be-constructed facilities; others include both modeled and end-use operating data. Each case study provides details on key energy efficiency and renewable energy technologies, a discussion of the NZEB definition(s) used, cost and financing information, and images of the project. In general, buildings with measured data in this database are fairly small (less than 14,000 ft^2 [1300 m^2]) one- or two-floor commercial buildings. The next generation of net zero energy buildings, as evident in the posters mentioned previously, will include larger commercial buildings such as K–12 schools and medium and large office buildings.

One example under construction is the new Research Support Facilities (RSF) at DOE's National Renewable Energy Laboratory (NREL) in Golden, Colorado (see Figure 2). This 218,000 ft^2 (20,253 m^2) administration and executive office space and data center will rely solely on renewable energy available on the roof and in the parking lot (NZEB:B Classification). At the point of building turnover, the energy goals are whole building energy use intensity of 25 $kBtu/ft^2 \cdot yr$ (284 $MJ/m^2 \cdot yr$), LEED Platinum, and 50% energy savings. By including energy performance in the design/build acquisition process, NREL is attempting to ensure the energy models represent what is actually built. For example, to ensure the as-installed wall insulation represents the R-value in the energy model, installation preconstruction meetings are held to ensure the insulation is installed to minimize thermal breaks. NREL also specified plug loads to be used in the energy models, and encouraged the design team to identify efficiency strategies in the purchasing, control, and operations of the plug and process loads.

NREL PIX 16277

Figure 2 Proposed orientation of the NREL Research Support Facilities

Calibrating Expectations

In the quest for ever-greater precision in energy-performance measurement, we've uncovered the need for greater precision in definitions. What do people mean by net zero energy performance? Are they talking the same language and making the same assumptions? Aligning goals and expectations—as well as measurements—requires specificity.

Conceptually, an NZEB is one that has no adverse energy or environmental impact associated with its operation. It is a building that is highly energy efficient and that is capable of fulfilling the balance of its energy needs using renewable energy technologies, producing at least as much energy over the course of a year as it draws from utility grids. It is also possible to have a grid-independent NZEB, with back-up energy needs supplied from renewable resources such as wood pellets or biodiesel.

To hone this concept into a measurable and verifiable definition, the National Renewable Energy Laboratory has developed a series of papers drawing on real-world experiences, including data reported through the Zero Energy Buildings Database.

To arrive at a shared definition, parties in an NZEB project must evaluate two interrelated questions:

- **How will we account for energy use?** Some projects target net zero energy use at the site. Others allow for purchased renewable energy to supplement on-site renewables, with that energy use accounted for at the source. In other cases, energy cost is the predominant factor, with the goal being to offset any purchased energy with revenues realized through the sale of on-site renewables. Still others target net zero emissions of carbon, nitrogen oxides, and sulfur dioxide.

- **What are our boundaries for choosing among renewable energy options?** If a project targets net zero energy use at the site, that necessarily limits the renewable energy choices to sources and technologies available within the building footprint or at the site. Some projects use renewable energy sources from beyond the site (e.g., biomass) to produce power at the site, while others incorporate purchased renewable energy.

Clearly, getting to an agreement on energy-use accounting and renewables options is pivotal to determining NZEB design goals and strategies.

The Future for Net-Zero Energy Buildings

Ongoing measurement and verification are essential in realizing the full benefits of a net zero energy design. DOE recommends that NZEB status be reviewed and tracked each year through utility bills or submetering.

Realistically, a building may be designed to achieve one or more NZEB definitions but may not achieve a net zero energy position in actual operations every year. Any NZEB may fall into the near-NZEB category in a given year, depending on weather, the condition of the building, operations, and other factors. A well-operating NZEB also may become a near NZEB during abnormal weather years that have above-average heating and cooling loads, with below-average solar and wind resources.

An area under study at DOE and the national laboratories is the potential for net zero energy use at a community or campus level. Clearly, buildings do not stand alone, and more data is needed to determine optimal ways to extend the boundaries of net zero energy to most effectively use the renewable energy sources available within a broader footprint.

Another area of study, initiated in partnership with utilities, is the longer-term impact of NZEBs on energy production. Utilities are concerned about how large-scale application of NZEBs will affect grid stability. A primary lesson learned from some of the initial NZEBs is that peak demand issues are even more pronounced than in typical buildings (Torcellini et al. 2006b). While NZEBs have large PV systems that offset significant energy use, their demand for grid power peaks in the evening, during morning warm-up, or when a cloud blocks the sun. As a result, NZEBs often do not offset peak demand.

To address the potential poor load factors of NZEBs, more research is needed on energy storage and its effect on large-scale NZEB penetration scenarios. With energy-storage integration, flatter load profiles, and better load factors, utilities will be much more agreeable to the concept of large numbers of buildings with significant on-site generation capacity.

Energy consumption in our nation’s commercial building sector will continue to increase until buildings can be designed to use energy efficiently and produce enough energy to offset their growing energy demand. DOE has set an aggressive goal to create the technology and knowledge base for cost-effective net zero energy commercial buildings by 2025, and we are gratified to have many industry leaders joining us in this quest.

We invite commercial architects, engineers, and owners to use the Zero Energy Buildings Database and to contribute their own data to make it an increasingly useful tool.

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