

# 1. Defining Net-Zero Energy Buildings

By Paul Torcellini, PhD, PE, and Shanti Pless, LEED AP

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**N**et-zero energy buildings (NZEB) have been the subject of research initiatives at the National Renewable Energy Laboratory and in the Department of Energy in recent years. In 2006, we and our NREL colleague Michael Deru and our DOE colleague Drury Crawley published “Zero Energy Buildings: A Critical Look at the Definition,” an early attempt to reach a common definition, or even a common understanding, of what the term “zero energy building” means.<sup>1</sup>

With the passage of the Energy Independence and Security Act of 2007, the pace of activity surrounding net-zero energy buildings quickened. EISA 2007 authorized the Department of Energy to host industry-led Commercial Building Energy Alliances and to establish the Net-Zero Energy Commercial Building Initiative, whose mandate is to support the goal of net-zero energy for all new commercial buildings by 2030.<sup>2</sup> EISA 2007 further specifies a net-zero energy target of 50% of all U.S. commercial buildings by 2040 and a net-zero standard for *all* commercial buildings, new and existing, by 2050. Toward this end, the Department of Energy has set a goal of creating the technology and knowledge base for cost-effective net-zero energy commercial buildings (NZEBs) by 2025.

In response to this aggressive agenda, in 2009 we, along with Dru Crawley, took the next step in our discussion of net-zero energy buildings with the publication, in ASHRAE Journal, of “Getting to Net Zero.”<sup>3</sup> Last year, we added another dimension to the definitions based on a hierarchy of possible renewable energy supply options for NZEBs, in “Net-Zero Energy Buildings: A Classification System Based on Renewable Energy Supply Options.”<sup>4</sup>

This chapter summarizes the key points in our effort to create a workable set of definitions for NZEBs,

based on these three documents. The formulation of the definitions was guided by two basic principles: 1) energy efficiency and demand-side technologies need to be optimized first, before renewable energy supply is considered; it is almost always easier to save energy than to produce it; and 2) the fewer the number of energy transfers, the better. Readers of this White Paper who wish to follow our discussion more closely are invited to access the original articles online.

## SEEKING A WORKABLE CONSENSUS

The quest for ever greater precision in measuring energy performance has uncovered the need for greater precision in the definition of “net-zero energy performance.” What do design and construction professionals, building owners, energy experts, government officials, and others involved in the built environment mean by this term?

In concept, an NZEB is a building with greatly reduced operational energy needs. In such a building, sufficient efficiency gains will have been made such that the remaining portion of the building’s energy needs could be offset by renewable technologies. An NZEB should have no adverse energy or environmental impacts associated with its operation. In other words, an NZEB should be highly energy efficient and capable of producing at least as much energy over the course of a year as it draws from the utility grid.

To arrive at a consensus definition, Building Teams involved in an NZEB project must evaluate two inter-related concerns:

- How will the team account for energy use? Some projects may target net-zero energy at the site. Others might allow purchased renewable energy to supplement

1 Paul Torcellini, Shanti Pless, Michael Deru, Drury Crawley, “Zero Energy Buildings: A Critical Look at the Definition” (2006), NREL Report No. CP-550-39833, presented at 2006 ACEEE Summer Study, 14-18 August 2006, Pacific Grove, Calif. At: [www.nrel.gov/docs/fy06osti/39833.pdf](http://www.nrel.gov/docs/fy06osti/39833.pdf).

2 See Chapter 8 for more on these and other NZEB-related programs.

3 Drury Crawley, Shanti Pless, Paul Torcellini, “Getting to Net Zero,” ASHRAE Journal, September 2009, NREL Report No. JA-550-46382. At: [www.nrel.gov/docs/fy09osti/46382.pdf](http://www.nrel.gov/docs/fy09osti/46382.pdf).

4 Shanti Pless, Paul Torcellini, “Net-Zero Energy Buildings: A Classification System Based on Renewable Energy Supply Options” (2010), NREL Report No. TP-550-44586. At: <http://www.nrel.gov/docs/fy10osti/44586.pdf>

5 See Chapter 6 for an example of a prototype zero emissions project.

The San Ysidro Land Port of Entry, on the border with Mexico, is the busiest such facility in the world. PVs and a closed-loop geo-exchange system contribute to its efficient energy use.



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on-site renewables, with that energy accounted for at the source. Still others might put primary emphasis on energy cost, with the goal being to offset any purchased energy with the sale of revenues from on-site renewable energy. Lastly, some might target net-zero emissions of greenhouse gases.<sup>5</sup>

- What are the physical boundaries for choosing among renewable energy options? If a project targets net-zero energy use at the site, that limits the choice of renewables to sources and technologies available within the building footprint or at the site. Other projects might use renewable energy sources from beyond the site (e.g., biomass) to produce power at the site, while others might incorporate purchased renewables, such as renewable energy certificates (RECs).

Agreeing on energy-use accounting and the choice of renewables is pivotal to determining the design goals and strategies of NZEBs.

These factors guided us in formulating the following definitions for various types of net-zero energy buildings (note: NZEBs are assumed to be grid-connected):

**Net Zero Site Energy:** A site NZEB produces at least as much 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 sources. 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 NZEBs offset. To calculate a building's total emissions, imported and exported energy is multiplied by the appropriate emissions multiplier, based on the utility's emission and on-site generation emissions (if any).

## CLASSIFICATION SYSTEM BASED ON RENEWABLES

More recently, we have added to our definitions by developing a classification system based on the renewable energy sources used in the four types of NZEBs. This classification system starts with the premise that all

NZEBs must first reduce site energy use through energy efficiency and demand-side renewable building technologies, including such strategies as daylighting, insulation, passive solar heating, high-efficiency HVAC equipment, natural ventilation, evaporative cooling, and ground-source heat pumps.

As shown in Table 1-1, the classification system breaks down NZEBs into two groups, one that uses on-site supply options, another that uses off-site renewables. At the highest level of the classification system is NZEB:A, a building that offsets all its energy use from renewable sources within its footprint. Next in rank is NZEB:B, which obtains some or all of its renewable energy from the project site—for example, photovoltaics that are mounted on the ground.

NZEB:C buildings use renewables from off the site, such as biomass or wood pellets. At the lowest end is NZEB:D, which uses a combination of on-site renewables and off-site purchases of renewable energy credits.

There is no “best” definition of net-zero energy buildings, nor is there a “best” method for accounting for energy use. Each has its merits and drawback, and Building Teams should select the appropriate approach for each project to align with the client's goals.

**However, across all NZEB definitions and classifications, one design rule remains constant: reduce energy demand to the lowest possible level first, then address energy supply.** NZEB teams should use all possible cost-effective energy-efficiency strategies first before incorporating renewables. Preference should be given to sources available within the footprint, such as solar hot water. Using on-site renewables minimizes the NZEB's overall environmental impact by reducing losses incurred from transportation, transmission, and conversion losses of off-site renewable energy sources.

## OFF-GRID NET-ZERO ENERGY BUILDINGS

Achieving an NZEB without the grid is very difficult, largely because the current generation of energy storage technologies is limited. Most off-grid buildings rely on outside energy sources such as propane for 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.

It is possible, though, to have a grid-independent NZEB. To do this, any backup energy needs would have to be supplied from renewable resources such as wood pellets or biodiesel. An off-grid building that uses no fossil fuels could be considered a pure NZEB, as no fossil fuels or net annual energy balances would be needed or used.

**NET-ZERO ENERGY BEYOND SINGLE BUILDINGS**

As NZEBs become technically and economically feasible, extending their boundaries to groups of buildings—net-zero energy campuses, communities, towns, bases, and cities—may become more and more realistic. Extending the net-zero energy boundary beyond a single building addresses the emergence of communities, neighborhoods, and campuses that would generate renewable energy for a certain group of buildings; however, the energy would not necessarily connect directly to a specific building’s utility meter. This would be considered a community-based renewable energy system that would be connected

to the grid or to a district heating or cooling system.

For a large organization or neighborhood, it is often more cost-effective and efficient to generate renewable energy in a central location on campus or in the community, rather than on (or in addition to) individual buildings. Community-scale systems allow for a single point for all maintenance and offer economies of scale—larger, central systems can be better optimized and cost less per kilowatt of generation capacity.

Community-based renewable energy systems, however, have some transmission and distribution losses when providing energy directly to a building. Inefficiencies

**Table 1-1. CLASSIFYING NZEBs BY RENEWABLE ENERGY SUPPLY**

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NZEB Classification	NZEB Supply-side Options	NZEB Definitions
ON-SITE SUPPLY OPTIONS	<p><b>A</b></p> <p>Use renewable energy sources available within the building’s footprint and directly connected to the building’s electrical system or hot chilled water distribution system.</p> <p>Examples: PVs, solar hot water, building-integrated wind systems.</p>	<p>Feasible for: Site, Source, and Emissions NZEBs Less feasible for: Cost NZEBs</p> <ul style="list-style-type: none"> <li>• If the source and emissions multipliers for an NZEB:A are high during times of utility energy use but low during times the NZEB is exporting to the grid, reaching a source or emissions NZEB position may be difficult.</li> <li>• Qualifying as a cost NZEB may be difficult depending on the net metering policies in the area.</li> </ul>
	<p><b>B</b></p> <p>Use renewable energy sources as described in NZEB: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.</p> <p>Examples: PVs, solar hot water, low-impact hydroelectric, and wind located on parking lots or adjacent open space, but not physically mounted on the building.</p>	<p>Feasible for: Site, Source, Cost, and Emissions NZEBs Less feasible for: Cost NZEBs</p> <ul style="list-style-type: none"> <li>• If the source and emissions multipliers for an NZEB:B are high during times of utility energy use but low during times the NZEB is exporting to the grid, reaching a source or emissions NZEB position may be difficult.</li> <li>• Qualifying as a cost NZEB may be difficult depending on the net-metering policies in the area.</li> </ul>
OFF-SITE SUPPLY OPTIONS	<p><b>C</b></p> <p>Use renewable energy sources as described in NZEB:A, NZEB:B, and NZEB: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.</p> <p>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.</p>	<p>Feasible for: Site NZEBs Less feasible for: Source, Cost, and Emissions NZEBs</p> <p>An NZEB:C source and emission position may be difficult if carbon-neutral renewables such as wood chips are used or if the NZEB has an unfavorable source and carbon multipliers. This can occur if an NZEB 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. NZEB:C buildings typically do not reach a cost NZEB 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.</p>
	<p><b>D</b></p> <p>Use renewable energy sources as described in NZEB:A, NZEB:B, and NZEB: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 NZEB status.</p> <p>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.</p>	<p>Feasible for: Source NZEBs, Emissions NZEBs Less feasible for: Site NZEBs, Cost NZEBs</p> <p>NZEB: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 or Cost NZEBs.</p>

Source: “Getting to Net Zero,” ASHRAE Journal, September 2009. NREL Report No. JA-550-46382.

and costs such as distribution piping and wiring, pumping losses, distribution transformers, and thermal losses are often associated with district distribution systems, whereas this is generally not the case with a building-based renewable energy generation systems.

The energy use accounting methods and renewable energy supply hierarchy concepts we have developed for standalone NZEBs still apply to net-zero energy communities. A parallel definition system further defines net-zero energy communities and extends the single-building net-zero concepts to multiple buildings with districtwide renewable energy systems.<sup>6</sup>

### ENCOURAGING BUILDING TEAMS TO ACT

This classification system begins ranking energy supply options in the NZEB context. As Building Teams and property owners look to design NZEBs, they must begin a discussion of which classification to seek in order to set workable goals for their projects. Since the publication of the initial NZEB definition paper we have applied these definitions to multiple real-world NZEB examples with various renewable energy options. Some of the buildings used to evaluate these definitions can be found in the Zero Energy Buildings Database, which was developed by the U.S. Department of Energy.<sup>7</sup>

In addition to refining the definitions, we felt that it would be beneficial to classify buildings based on how well they achieve NZEB status by considering which renewable energy supply options they use. We have developed a simple flow chart that illustrates how to navigate the prerequisites and classification requirements to classify NZEBs.<sup>8</sup>

This classification system is meant to encourage, when possible, energy-efficiency strategies, followed by the use of footprint and on-site renewable energy to power buildings. The long-term benefits of these options are numerous:

1. Optimized usability of power-generation capacity in the NZEB context
2. Less reliance on the grid (and therefore less need for investment in the grid)
3. Less energy required because energy losses through conversion, transmission, and distribution would be minimized
4. Fewer peak demand problems with utilities

Ultimately, it is our hope that Building Teams will be encouraged to create more energy-efficient, high-performance structures if the buildings must generate their own energy. **BD+C**

6 Nancy Carlisle, AIA, Otto Van Geet, PE, and Shanti Pless, LEED AP, "Definition of a 'Zero Net Energy' Community," NREL Report No. TP-7A2-46065. At: <http://www.nrel.gov/docs/fy10osti/46065.pdf>.

7 At: [www.eere.energy.gov/buildings/commercial\\_initiative/zero\\_energy\\_projects.html](http://www.eere.energy.gov/buildings/commercial_initiative/zero_energy_projects.html).

8 At: [www.BDCnetwork.com/NZEBflowchart](http://www.BDCnetwork.com/NZEBflowchart).

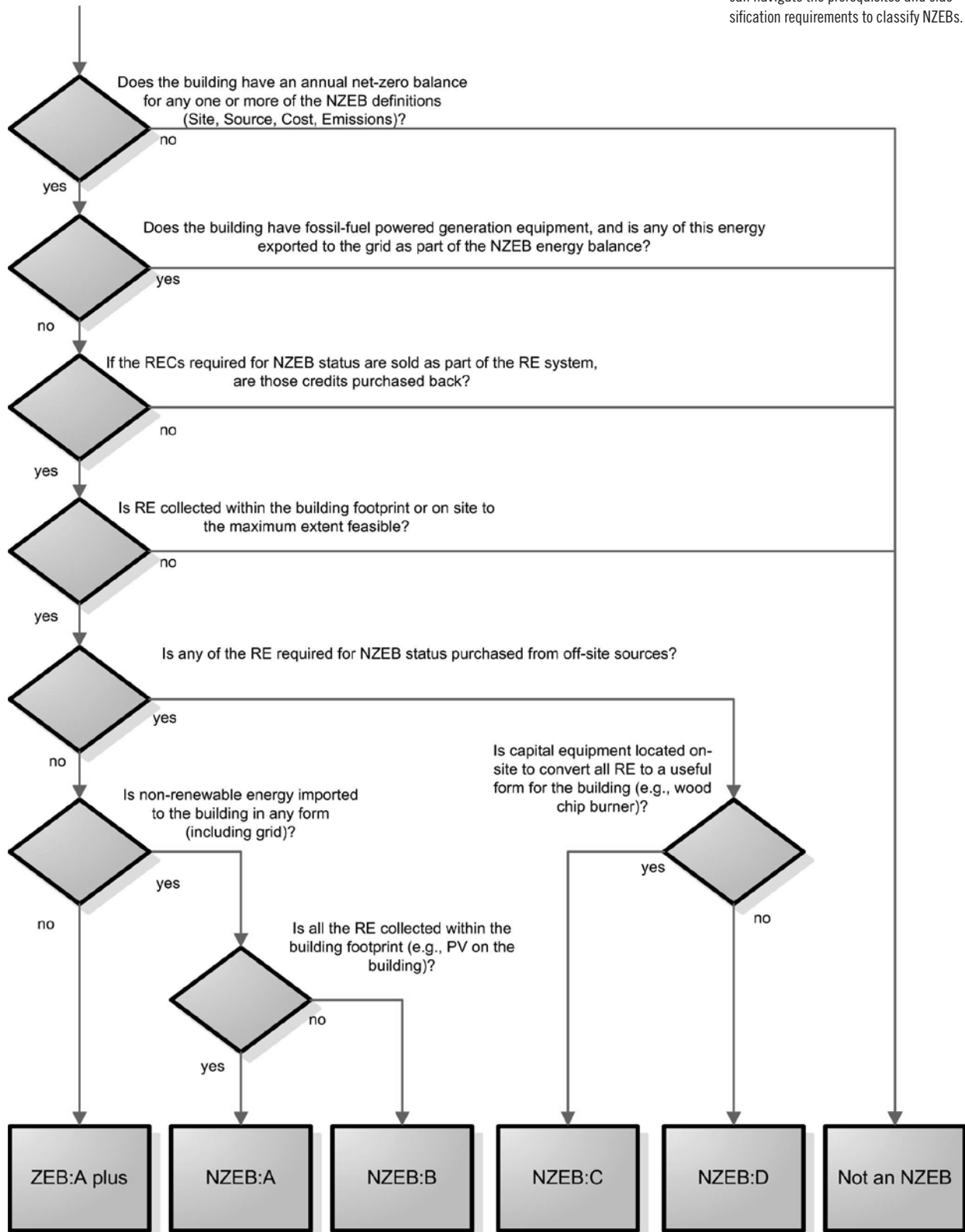
**Table 1-2. PLUSSES AND MINUSES OF NZEB DEFINITIONS**

Definition	Pluses	Minuses	Other concerns
<b>Site NZEB</b>	<ul style="list-style-type: none"> <li>• Easy to implement</li> <li>• Verifiable through on-site measurements</li> <li>• Conservative approach to achieving NZEB</li> <li>• No externalities affect performance, can track success over time</li> <li>• Easy for the building community to understand and communicate</li> <li>• Encourages energy-efficient building designs</li> </ul>	<ul style="list-style-type: none"> <li>• Requires more PV export to offset natural gas</li> <li>• Does not consider all utility costs (can have a low load factor)</li> <li>• Not able to equate fuel types</li> <li>• Does not account for non-energy differences between fuel types (availability of supply, pollution)</li> </ul>	
<b>Source NZEB</b>	<ul style="list-style-type: none"> <li>• Able to equate energy value of fuel types used at the site</li> <li>• Better model for impact on national energy system</li> <li>• Easier NZEB to reach</li> </ul>	<ul style="list-style-type: none"> <li>• Does not account for non-energy differences between fuel types (availability of supply, pollution)</li> <li>• Source calculations too broad (does not account for regional or daily variations in electricity-generation heat rates)</li> <li>• Source energy use accounting and fuel switching can have a larger impact than efficiency technologies</li> <li>• Does not consider all utility costs (can have a low load factor)</li> </ul>	<ul style="list-style-type: none"> <li>• Need to develop site-to-source conversion factors, which require significant amounts of information to define</li> </ul>
<b>Cost NZEB</b>	<ul style="list-style-type: none"> <li>• Easy to implement and measure</li> <li>• Market forces result in a good balance between fuel types</li> <li>• Allows for demand-responsive control</li> <li>• Verifiable from utility bills</li> </ul>	<ul style="list-style-type: none"> <li>• May not reflect impact to national grid for demand, as extra PV generation could be more valuable for reducing demand with on-site storage than exporting to the grid</li> <li>• Requires net-metering agreements such that exported electricity an offset energy and non-energy charges</li> <li>• Highly volatile energy rates make for difficult tracking over time</li> </ul>	<ul style="list-style-type: none"> <li>• Offsetting monthly service and infrastructure charges requires going beyond NZEB</li> <li>• Net metering is not well established, often with capacity limits and at buyback rates lower than retail rates</li> </ul>
<b>Emissions NZEB</b>	<ul style="list-style-type: none"> <li>• Better model for green power</li> <li>• Accounts for non-energy differences between fuel types (pollution, GHGs)</li> <li>• Easier NZEB to reach</li> </ul>		<ul style="list-style-type: none"> <li>• Need appropriate emissions factors</li> </ul>

Source: "Zero Energy Buildings: A Critical Look at the Definition" (June 2006). NREL Report No. CP-550-39833.

**FIGURE 1-1.**  
**NZEB FLOW CHART**

Flow chart illustrates how Building Teams can navigate the prerequisites and classification requirements to classify NZEBs.





### **Net Zero Offers an Inspiring Goal**

Net-zero energy buildings offer a clear and inspiring goal for both new and existing buildings. The pursuit of this goal will take us a long way toward reducing energy use in buildings, while also significantly reducing the impact that buildings have on the environment.

Net-zero energy commercial buildings exist today. When designed and built using an integrated design approach, net and near-zero energy buildings can be cost-effective when compared to traditionally constructed buildings. Our experience with the IDEAs commercial building retrofit project has demonstrated that net-zero buildings are technically feasible today and will be increasingly cost-effective in the future. More experience with zero energy buildings will also lead to an awareness of best practices that will reduce costs as well as the perception of risk associated with the concept.

Johnson Controls supports the goal of targeting “net and near-zero” energy use in all commercial buildings. This worthy and achievable goal benefits building owners, who will realize lower life-cycle costs and a hedge against higher energy prices. It benefits society by minimizing the impact of the building on the environment. Finally, it also benefits the economy by creating new jobs, stimulating investment in clean energy technology and enhancing energy security.

A handwritten signature in black ink, appearing to read "C. David Myers".

C. David Myers  
President  
Johnson Controls, Building Efficiency