U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

A Common Definition for Zero Energy Buildings

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The National Institute of Building Sciences

NREL Research Support Facility, photo credit: Bill Gillies, NREL

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Project Team

The Project Team consisted of representatives from both the U.S. Department of Energy and the National Institute of Building Sciences.

The primary authors of the Zero Energy Building definitions, nomenclature and guidelines included:

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Introduction

In 2014, the U.S. Department of Energy (DOE) Building Technologies Office contracted with the National Institute of Building Sciences (Institute) to establish definitions, associated nomenclature and measurement guidelines for zero energy buildings, with the goal of achieving widespread adoption and use by the building industry. The Institute prepared this report, A Common Definition for Zero Energy Buildings, to present the results of that work.

Background

A zero energy building (ZEB) produces enough renewable energy to meet its own annual energy consumption requirements, thereby reducing the use of non-renewable energy in the building sector. ZEBs use all cost-effective measures to reduce energy usage through energy efficiency and include renewable energy systems that produce enough energy to meet remaining energy needs. There are a number of long-term advantages of moving toward ZEBs, including lower environmental impacts, lower operating and maintenance costs, better resiliency to power outages and natural disasters, and improved energy security.

Reducing building energy consumption in new building construction or renovation can be accomplished through various means, including integrated design, energy efficiency retrofits, reduced plug loads and energy conservation programs. Reduced energy consumption makes it simpler and less expensive to meet the building's energy needs with renewable sources of energy.

ZEBs have a tremendous potential to transform the way buildings use energy and there are an increasing number of building owners who want to meet this target. Private commercial property owners are interested in developing ZEBs to meet their corporate goals, and some have already constructed buildings designed to be zero energy. In response to regulatory mandates, federal government agencies and many state and local governments are beginning to move toward targets for ZEBs. However, definitions differ from region to region and from organization to organization, leading to confusion and uncertainty around what constitutes a ZEB.

Goals

A broadly accepted definition of ZEB boundaries and metrics is foundational to efforts by governments, utilities and private entities to recognize or incentivize ZEBs. A commonly accepted definition and corresponding methods of measurement for ZEBs would also have a significant impact on the development of design strategies for buildings and help spur greater market uptake of such projects.

The definition of ZEBs needs to include clear and concise language to be effective and accepted. Metrics and measurement guidelines are required to allow verification of the achievement of the key elements of the definition. The definition, nomenclature and measurement guidelines should address how energy consumption is measured and what energy uses and types to include in its determination.

In practice, actual projects seeking to verify zero energy should work to ensure no harm is done in the process of achieving zero energy performance across other, non-energy-related considerations, such as water protection, optimized comfort for low-load buildings, and comprehensive indoor air quality. While these considerations don't affect the definition of zero energy, it is important that in practice a design team ensures that other important building considerations and values are not sacrificed in pursuit of zero energy.

Methodology

Creating a broadly agreed upon and supported definition of ZEB should involve participation from the many organizations that have a stake in the outcome. DOE selected the National Institute of Building Sciences to facilitate this collaboration. A non-profit, non-governmental organization, the Institute was established by the U.S. Congress in 1974 to bring together representatives of government, the professions, industry, labor and consumer interests, and regulatory agencies to focus on the identification and resolution of problems and potential problems that hamper the construction of safe, affordable, efficient and effective structures throughout the United States.

The Institute's High Performance Building Council (HPBC) led the process to develop commonly agreed upon definitions for ZEBs. Formed in April 2007 in response to Section 914 of the Energy Policy Act, the HPBC has representatives from most of the major standards writing organizations, industry trade associations, nonprofit organizations and federal government entities involved with the built environment. It includes representation from all members of the building team, from designers to builders to owners.

Early in 2014, the Institute, with funding and support from the DOE Building Technologies Office, began working through the HPBC to establish a common national ZEB definition. The Institute and DOE formed a Project Team (see Acknowledgements section for a list of Project Team members). During the research phase of the project, the Project Team surveyed existing publications (see Appendix 1 for a list of publications researched) and interviewed subject matter experts (SMEs) working on ZEBs from across the building industry to develop a full list of issues to be addressed and a draft set of definitions and metrics. The Project Team presented these findings to industry stakeholders involved with the creation and advancement of ZEBs, who were invited to participate, contribute their perspective and provide their input. (See Appendix 2 for a list of SMEs and stakeholders who participated in the project.)

In response to the comments received from industry stakeholders, the Project Team refined the initial draft definitions, nomenclature and guidelines. DOE posted the revised material for public comment in the Federal Register, Docket EERE-2014-BT-BLDG-0050 Definition for Zero Energy Buildings. The comment period generated more than 65 comments, which the Project Team then evaluated for relevance and used to further update and refine the definition.

A basic issue that needed to be established is what to call buildings that are designed and operated in such a way that energy consumption is reduced to a level that it is balanced by renewable energy production over a typical one-year period. To make the determination, the Project Team reviewed definitions already in use; collected opinions of SME and Stakeholders; and considered other DOE programs and goals. In addition, a key factor came from the DOE Zero Energy Ready Homes program which had received feedback that concluded the term "net" was confusing to consumers. The desire was to have a term that resonated with building owners. The Project Team considered an idea advanced by some that "net" is necessary to be accurate in accounting for energy usage. The team reached the conclusion that the word "net" did not add substantive meaning to the name, since the definition fully describes how to account for delivered and exported energy. Therefore, in striving for simplicity, consistency and to accentuate the core objective, DOE and NIBS selected the term "Zero Energy Building (ZEB)." However, it is recognized that the terms Net Zero Energy (NZE) and Zero Net Energy (ZNE) are in wide use and convey the same meaning as Zero Energy.

During the review process, the Project Team identified the need for additional definitions for related groupings of buildings. The team included definitions for "Zero Energy Campuses," "Zero Energy Communities" and "Zero Energy Portfolios" to expand the reach of the ZEB concept, provide for the collective generation of renewables and account for different energy needs of buildings. Some building industry representatives expressed a need to develop a definition for Zero Energy Ready (ZER) buildings. The team did not include this in the ZEB definitions developed but it could be added in the future.

This document describes a commonly agreed upon definition of ZEBs with supporting nomenclature and measurement guidelines to facilitate their use, and sets a bar for denoting a ZEB that can be relevant into the future. DOE is publishing the results for use by government and industry to support a robust market for zero energy buildings.

Guiding Principles

The Project Team used the following guiding principles in developing a zero energy building (ZEB) defnition for commercial/ industrial/ institutional buildings. The definition should:

- Create a standardized basis for identification of ZEBs for use by industry.
- Be capable of being measured and verified, and should be rigorous and transparent.
- Influence the design and operation of buildings to substantially reduce building operational energy consumption.
- Be clear and easy to understand by industry and policy makers.
- Set a long-term goal and be durable for some time into the future.

Definitions

In addition to establishing a definition for ZEB, shown below, it was clear that definitions were needed to accommodate the collections of buildings where renewable energy resources were shared. To meet this need, the team provided variations on the ZEB definition. The bold text represents key terms that are further addressed in the nomenclature and guidelines.

Zero Energy Building (ZEB)

An energy-efficient **building** where, on a **source energy** basis, the actual **annual delivered energy** is less than or equal to the on-site renewable **exported energy**.

Zero Energy Campus

An energy-efficient **campus** where, on a **source energy** basis, the actual **annual delivered energy** is less than or equal to the on-site renewable **exported energy**.

Zero Energy Portfolio

An energy-efficient **portfolio** where, on a **source energy** basis, the actual **annual delivered energy** is less than or equal to the on-site renewable **exported energy**.

Zero Energy Community

An energy-efficient **community** where, on a **source energy** basis, the actual **annual delivered energy** is less than or equal to the on-site renewable **exported energy**.

Nomenclature

This section provides definitions of key terms applied to the Zero Energy definitions.

Annual: Covering at least one period of 12 consecutive months for all energy measurements.

Building: A structure wholly or partially enclosed within exterior walls, or within exterior and party walls, and a roof providing services and affording shelter to persons, animals or property.

Building Site: Building and the area on which a building is located where energy is used and produced.

Building Energy: Energy consumed at the building site as measured at the site boundary. At minimum, this includes heating, cooling, ventilation, domestic hot water, indoor and outdoor lighting, plug loads, process energy, elevators and conveying systems, and intra-building transportation systems.

Campus: A group of building sites in a specific locality that contain renewable energy production systems owned by a given institution.

Community: A group of building sites in a specific locality that contain renewable energy production systems.

Delivered energy: Any type of energy that could be bought or sold for use as building energyddd , including electricity, steam, hot water or chilled water, natural gas, biogas, landfill gas, coal, coke, propane, petroleum and its derivatives, residual fuel oil, alcohol based fuels, wood, biomass and any other material consumed as fuel.

Energy: The capacity for doing work. Energy takes a number of forms that may be transformed from one into another, such as thermal (heat), mechanical (work), electrical or chemical. Customary measurement units are British thermal units (Btu), Joules (J) or kilowatt-hours (kWh).

Exported Energy: On-site renewable energy supplied through the site boundary and used outside the site boundary.

Geothermal Energy: Deep-earth heat used for either electricity generation or thermal energy.

On-site Renewable Energy: Includes any renewable energy collected and generated within the site boundary that is used for building energy and the excess renewable energy could be exported outside the site boundary. The renewable energy certificates (RECs) associated with the renewable energy must be retained or retired by the building owner/lessee to be claimed as renewable energy.[1]

Portfolio: A collection of building sites that contains renewable energy production systems owned/leased by a single entity.

Renewable energy: Energy resources that are naturally replenishing but flow-limited. They are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time. Renewable energy resources include biomass, hydro, geothermal, solar, wind, ocean thermal, wave action and tidal action. [DOE Energy Information Administration Glossary]

Renewable Energy Certificate (REC): Represents and conveys the environmental, social and other non-power qualities of one megawatt-hour of renewable electricity generation and can be sold separately from the underlying physical electricity associated with a renewable-based generation source.

Site Boundary: Line that marks the limits of the building site(s) across which delivered energy and exported energy are measured.

Site Energy: Same as building energy.

Source Energy: Site energy plus the energy consumed in the extraction, processing and transport of primary fuels such as coal, oil and natural gas; energy losses in thermal combustion in power generation plants; and energy losses in transmission and distribution to the building site.

[1] *Federal Trade Commission Green Guides (16 C.F.R. § 260.15(d)*

Measurement and Implementation Guidelines

The guidelines that follow identify the methodology for establishing boundary conditions, conducting energy measurements and achieving energy balances that support applying the Zero Energy Building, Zero Energy Campus, Zero Energy Portfolio and Zero Energy Community definitions. The guidelines address:

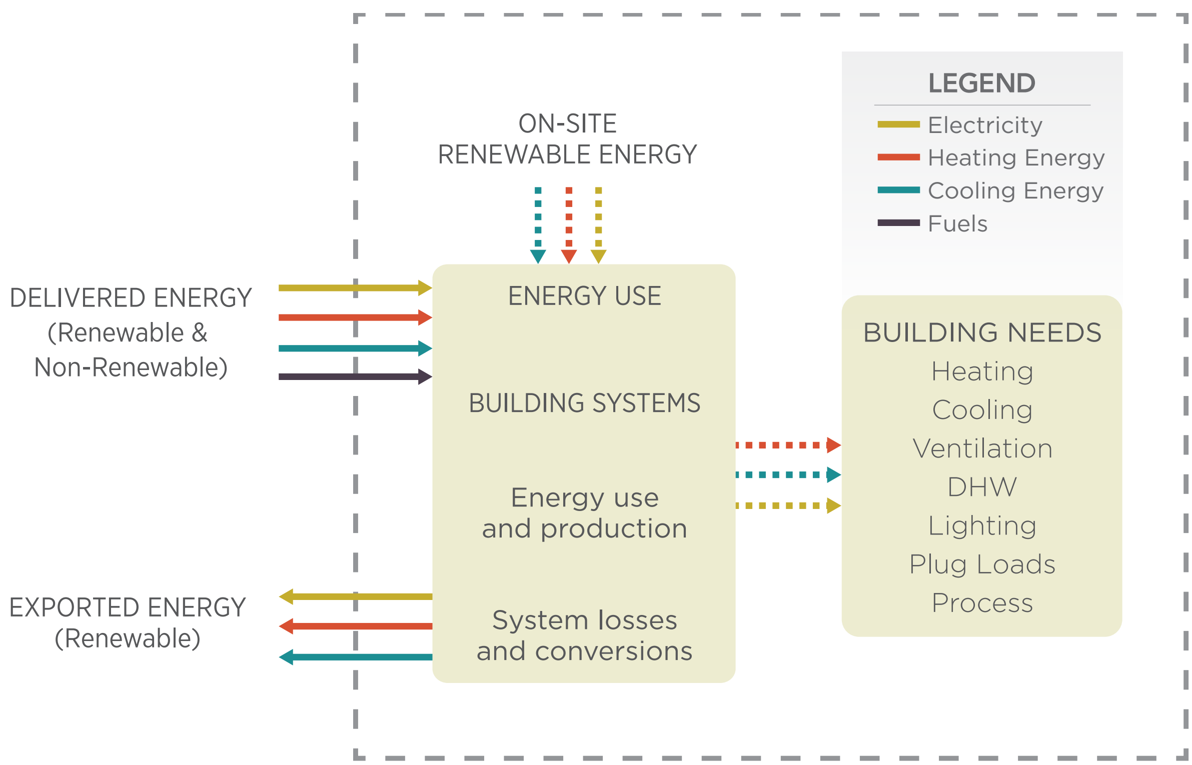
- Measurement boundaries for all definitions
- Energy accounting and measurements
- Source energy calculations
- Using the "Zero Energy Building" designation
- Using Renewable Energy Certificates

Note: Throughout the section, terms defined in the ***Nomenclature*** *are italicized.*

Boundaries

The definitions require the use of a defined *site boundary*. The *site boundary* represents a meaningful boundary that is functionally part of the building(s). For a single *building* on a single property, the *site boundary* is typically the property boundary. The *site boundary* should include the point of utility interface. Figure 1 shows the *site boundary* of *energy* and how it forms from *building energy*, *on-site renewable energy* production, *delivered energy* and *exported energy*.

Figure 1 – Site Boundary of Energy Transfer for Zero Energy Accounting



Notes

1. The dashed lines represent energy transfer within the boundary
2. The solid lines represent energy transfer entering/leaving the boundary used for zero energy accounting

The *site boundary* for a Zero Energy Building (ZEB) could be around the *building* footprint if the *on-site renewable energy* is located within the *building* footprint, or around the *building site* if some of the *on-site renewable energy* is on-site but not within the *building* footprint. *Delivered energy* and e*xported energy* are measured at the *site boundary*.

The *site boundary* for a *Zero Energy Campus* allows for the *building sites* on a *campus* to be aggregated so that the combined *on-site renewable energy* could offset the *combined building energy* from the buildings on the *campus*. The *site boundary* for a *Zero Energy Community* or *Zero Energy Portfolio* would allow a group of project sites at different locations to be aggregated so that the combined *on-site renewable energy* could offset the combined *building energy* from the aggregated project sites. *Zero Energy Communities* can share the benefit of *renewable energy* projects in the *community* that pool investments from multiple *building* owners and provide power benefits in return.

Energy Accounting and Measurements

A ZEB is typically a grid-connected *building* that is very *energy* efficient. The premise is that ZEBs use the electric grid or other *energy* networks to transfer any surplus of *on-site renewable energy* to other users.

ZEB *energy* accounting would include *energy* used for heating, cooling, ventilation, domestic hot water (DHW), indoor and outdoor lighting, plug loads, process *energy* and transportation within the *building*. Vehicle charging *energy* for transportation inside the *building* would be included in the *energy* accounting. *On-site renewable energy* may be exported through transmission means other than the electricity grid such as charging of electric vehicles used outside the building.

Delivered energy to the *building* includes grid electricity, district heat and cooling, renewable and non-renewable fuels. A ZEB balances its *energy* use so that the *exported energy* to the grid or other energy network (i.e., *campus* or *facility*) is equal to or greater than the *delivered energy* to the *building* on an *annual* basis.

A ZEB may only use *on-site renewable energy* in offsetting the *delivered energy*. *On-site renewable energy* is *energy* produced from *renewable energy* sources within the *site boundary*. Renewable fuels delivered to the *site boundary* are not included in this term, because they are treated as *delivered energy* to the *building*, i.e. off-site renewables. For example, wood chips or biofuel harvested on-site would be considered on-site renewable energy, while wood or biofuel/biomass delivered to the site would not be considered *on-site renewable energy*. The ZEB *energy* accounting does not allow non-renewable *energy* that is exported from the *site boundary* to offset *delivered energy*.

On-site renewable energy production systems may supply *building energy*, thus reducing the need for the *delivered energy* to the *building*, and/or may be directly exported to *energy* networks. This is taken into account in the net *delivered energy* balance. *Zero Energy Campuses*, *Portfolios* and *Communities* can combine the *on-site renewable energy* among different sites under an aggregated *site boundary* to balance the *delivered energy*.

Source Energy Calculations

Most *building managers* are familiar with *site energy*, the amount of *energy* consumed by a *building* as measured by utility meters. *Site energy* consumption can be useful for understanding the performance of the *building* and the *building* systems, but it does not tell the whole story of impacts from resource consumption and emissions associated with the *energy* use. In addition, *site energy* is not a good comparison metric for *buildings* that have different mixes of *energy* types, *buildings* with on-site *energy* generation, such as photovoltaics, or *buildings* with cogeneration units. Therefore, to assess the relative efficiencies of *buildings* with varying fuel types, it is necessary to convert these types of *energy* into equivalent units of raw fuel consumed in generating one unit of *energy* consumed on-site. To achieve this equivalency, the convention of *source energy* is utilized.

When *energy* is consumed on-site, the conversion to source energy must account for the energy consumed in the extraction, processing and transport of primary fuels such as coal, oil and natural gas; energy losses in thermal combustion in power generation plants; and energy losses in transmission and distribution to the building site. The Zero Energy Building definition uses national average ratios to accomplish the conversion to source energy because the use of national average source-site ratios ensures that no specific building will be credited (or penalized) for the relative efficiency of its energy provider(s).

Source energy is calculated from *delivered energy* and *exported energy* for each *energy* type using source *energy conversion* factors. *Source energy* conversion factors are applied to convert *energy* delivered and exported on-site into the total equivalent *source energy*. The *source energy* conversion factors utilized are from ASHRAE Standard 105 . While *on-site renewable energy* is a carbon-free, zero-energy-loss resource, when it is exported to the grid as electricity, it displaces electricity that would be required from the grid. In ZEB accounting, the *exported energy* is given the same *source energy* conversion factor as the *delivered energy* to appropriately credit its displacement of delivered electricity. Table 1 summarizes the national average *source energy* conversion factors for various energy types.

Table 1 – National Average Source Energy Conversion Factors

Energy Form	Source Energy Conversion Factor (r)
Imported Electricity	3.15
Exported Renewable Electricity	3.15
Natural Gas	1.09
Fuel Oil (1,2,4,5,6,Diesel, Kerosene)	1.19
Propane & Liquid Propane	1.15
Steam	1.45
Hot Water	1.35
Chilled Water	1.04
Coal or Other	1.05

Source energy would be calculated using the following formula:

$$E_{source} = \sum_i (E_{del,i} r_{del,i}) - \sum_i (E_{exp,i} r_{exp,i})$$

Where

$E_{del,i}$ is the delivered energy for energy type i;

$E_{exp,i}$ is the exported on-site renewable energy for energy type i;

$r_{del,i}$ is the source energy conversion factor for the delivered energy type i;

$r_{exp,i}$ is the source energy conversion factor for the exported energy type i;

Example Calculation for All Electric ZEB

A *building* has the following actual *annual delivered energy* of 300,000 kBtu electricity. The on-site renewable *exported energy* is 320,000 kBtu electricity from photovoltaics. (Note: The equation is using *energy* transferred across the *site boundary* and does not include *on-site renewable energy* consumed by the building.)

Using the formula above, the *annual* source energy balance would be:

$$E_{source} = (300{,}000kBtu \times 3.15) - (320{,}000kBtu \times 3.15)$$

$$= 945{,}000kBtu - 1{,}008{,}000kBtu$$

$$= -63{,}000kBtu$$

Since $E_{source} \leq 0$, the building would be a *Zero Energy Building*.

Example Calculation for ZEB with Multiple Delivered Energy Types

A *building* has the following actual *annual delivered energy* types: 200,000 kBtu electricity, 60,000 kBtu natural gas and 100,000 kBtu chilled water. The on-site renewable *exported energy* is 260,000 kBtu electricity from photovoltaics.

Using the formula above, the *annual source energy* balance would be:

$$E_{source} = [(200{,}000kBtu \times 3.15) + (60{,}000kBtu \times 1.09) + (100{,}000kBtu \times 1.04)] - (260{,}000kBtu \times 3.15)$$

$$= 799{,}400\ kBtu - 819{,}000kBtu$$

$$= -19{,}600kBtu$$

Since $E_{source} \leq 0$, the building would be a *Zero Energy Building*.

Example Calculation for ZEB with Combined Heat and Power (CHP)

A *building* with CHP has the following actual *annual delivered energy* types: 120,000 kBtu electricity and 260,000 kBtu natural gas. The on-site renewable *exported energy* is 210,000 kBtu electricity from photovoltaics.

Using the formula above, the *annual source energy* balance would be:

$$E_{source} = [(120{,}000\ kBtu \times 3.15)+(260{,}000\ kBtu \times 1.09)]-(210{,}000\ kBtu \times 3.15)$$

$$= 661{,}400\ kBtu-661{,}500\ kBtu$$

$$= -100\ kBtu$$

Since $E_{source} \leq 0$, the building would be a *Zero Energy Building*.

Using Renewable Energy Certificates (REC)

Renewable Energy Certificates (RECs) are tradable instruments that can be used to meet voluntary *renewable energy* targets. Energy users can meet voluntary *renewable energy* goals and support the deployment of green power through the purchase of RECs. RECs are a credible and easy means to keep track of who can claim the environmental attributes of renewable electricity generation on the grid. Once a buyer makes an environmental claim based on a REC, the buyer can no longer sell the REC and the REC is considered permanently "retired".

The ZEB definition and its variations (*Campus*, *Portfolio*, *Community*) require *on-site renewable energy* to be used to fully offset the actual *annual delivered energy* and require the RECs to be retained or retired. The definitions do not allow *renewable electricity* purchased through the use of *renewable energy certificates* (RECs) to be used in the ZEB *energy* accounting.

Multi-story *buildings* that occupy entire lots located in dense urban areas, or *buildings*, such as hospitals with high process loads, may not be able to balance *annual delivered energy* with *on-site renewable energy* simply because the site is not large enough to accommodate all the *on-site renewable energy* required. These *building* owners may choose to have off-site renewable electricity utilizing RECs help balance the *annual delivered energy* since their built-up area may result in a commensurate *energy* requirement that is difficult to meet with a small *building site*. The following REC-ZEB definition allows RECs to be used to supplement, after *on-site renewable energy* sources have been employed, and balance the *annual delivered energy* to the *building*.

Renewable Energy Certificate - Zero Energy Building (REC-ZEB)

An energy-efficient building where, on a *source energy* basis, the actual *annual delivered energy* is less than or equal to the on-site renewable *exported energy* plus acquired *Renewable Energy Certificates (RECs)*.

Using the terms "Zero Energy Building" and "Renewable Energy Certificate Zero Energy Building"

The designation *Zero Energy Building (ZEB)* should be used only for *buildings* that have demonstrated through actual annual measurements that the *delivered energy* is less than or equal to the *on-site renewable exported energy*. Buildings designed to be *zero energy*, but that have not had a full year of operation demonstrating that they meet the requirements, are encouraged to identify their intent to be or return to being a *Zero Energy Building*.

The designation *Renewable Energy Certificate Zero Energy Building (REC-ZEB)* should be used only for *buildings* that have demonstrated through actual *annual* measurements that the *delivered energy* is less than or equal to the *on-site renewable exported energy* plus *Renewable Energy Certificates*.

Appendix 1 - Research Materials

Resource	Description	Author(s)	Publisher	Pub. Date
2014 Getting to Zero Status Report	The research report is a look at the projects, policies and programs driving zero net energy performance in commercial buildings. It examines the numbers, locations, types, ownership, and policy and program drivers for ZNE.	Cathy Higgins, Amy Cortese, Mark Lyles	New Buildings Institute	Jan 2014
ANSI/ASHRAE Standard 105-2014	Standard Methods of Determining, Expressing, and Comparing Building Energy Performance and Greenhouse Gas Emissions	ASHRAE	ASHRAE	Jan 2014
ASHRAE Vision 2020	This document describes the vision held by members of the American Society of Heating, Refrigerating and Air-Conditioning Engineers of a future when buildings will produce as much energy as they use. These are net zero energy buildings (NZEBs). The ASHRAE membership believes such buildings can be market-viable by the year 2030.	ASHRAE 2020 Ad Hoc Committee	ASHRAE	Jan 2008
Clean Energy Trends 2014	Review of developments in clean energy in 2013, including a section on Net Zero Energy Buildings Gaining Ground.	Ron Pernick, Clint Wilder, James Belcher	Clean Edge	Mar 2014
Definition of a "Zero Net Energy" Community	This paper begins with a focus solely on buildings and expands the concept to define a zero-energy community, applying the ZEB hierarchical renewable classification system to the concept of community.	Nancy Carlisle, Otto Van Geet, Shanti Pless	NREL	Nov 2009
DOE Challenge Home Why Zero Energy Ready is Readily Achievable: **Technical Specifications for DOE Challenge Home**	Overview of the U.S. Department of Energy Challenge Home Program and requirements for creating Zero Energy Ready Homes.	Jamie Lyons	U.S. Department of Energy	Feb 2010
Energy Star Portfolio Manager Technical Reference: Source Energy	Evaluation of Source vs. Site Energy as a metric for measuring energy use by a building.	U.S. Environmental Protection Agency	U.S. Environmental Protection Agency	Jul 2013
Getting to Net Zero	The intent of this article is to provide an overview of the DOE's efforts toward realizing cost-effective net zero energy buildings (NZEBs).	Drury Crawley, Shanti Pless, Paul Torcellini	NREL/ASHRAE Journal	Sept 2009
Getting to Zero	Final Report of the Massachusetts Zero Net Energy Buildings Task Force.	Massachusetts Zero Net Energy Buildings Task Force	Massachusetts Zero Net Energy Buildings Task Force	Mar 2009

Living Building Challenge 2.1	Description of the Living Building Challenge program, including a definition and measurement system for Net Zero Energy Buildings.	International Living Futures Institute	International Living Futures Institute	May 2012
Main Street Net-Zero Energy Buildings: The Zero Energy Method in Concept and Practice	This presentation discusses ways to achieve large-scale, replicable NZEB performance. Many passive and renewable energy strategies are utilized, including full daylighting, high-performance lighting, natural ventilation through operable windows, thermal mass, transpired solar collectors, radiant heating and cooling, and workstation configurations to maximize daylighting.	Paul Torcellini, Shanti Pless, Chad Lobato, Tom Hootman	ASME 2010 4th International Conference on Energy Sustainability	May 2010
Net Zero and Living Building Challenge Financial Study: A Cost Comparison Report for Buildings in the District of Columbia	The purpose of the Net Zero and Living Building Challenge Financial Study: A Cost Comparison Report for Buildings in the District of Columbia was twofold: First, to investigate costs, benefits and approaches necessary to improve building performance in the District of Columbia, from LEED Platinum to zero energy, zero water and Living Building status, and second, to advise District government on policy drivers related to deep green buildings and to analyze the opportunities for the District to offer incentives to advance most rapidly toward zero energy, zero water and Living Buildings.	International Living Futures Institute New Buildings Institute Skanska	District Department of the Environment	Feb 2014
Net Zero Blueprint	This article presents the process used for delivering the Research Support Facility as a replicable blueprint to achieve a large reduction in building energy use and to adopt a net zero energy approach for large-scale commercial buildings without increasing cost.	Tom Hootman; David Okada; Shanti Pless; Michael Sheppy; and Paul Torcellini	NREL/ ASHRAE High Performance Buildings Journal	Nov 2012
Net Zero Energy Buildings	Book	Karsten Voss, Eike Musall	Detail Green Books	Feb 2013
Net Zero Energy Buildings	Page on the Whole Building Design Guide portal with an overview of NZEBs, including links to related resources and publications - http://www.wbdg.org/resources/netzeroenergybuildings.php	Steven Winter Associates	National Institute of Building Sciences Whole Building Design Guide	Sept 2013
Net Zero Energy Buildings White Paper	White Paper on Sustainability to inspire architects, engineers, contractors, building owners, developers, building product manufacturers, environmentalists, policymakers, government officials, corporate executives, officeholders, and the public to foster the development of net zero energy buildings and homes.	Rob Cassidy, Editor with various chapter authors	Building Design & Construction	Mar 2011
Net-Zero Energy Buildings: A Classification System Based on Renewable Energy Supply Options	A classification system for NZEBs based on the renewable sources a building uses.	Shanti Pless, Paul Torcellini	NREL Technical Report	Jun 2010

Pursuit of Net Zero: The Walgreens Experience	Webinar on Walgreen's experience with developing and operating a net zero store in Chicago, Illinois.	Jamie J. Meyers	Energy Center of Wisconsin	Mar 2014
The Technical Feasibility of Zero Net Energy Buildings in California	This study is a forward-looking "stress test" of the Zero Net Energy (ZNE) new construction goals set forth by California's energy agencies. This study assesses the potential performance of best-in-class building designs in 2020 for both residential and commercial structures.	ARUP. Davis Energy Group, Sun Light & Power, New Buildings Institute, Engineering 350, Sustainable Design + Behavior	Pacific Gas & Electric Company	Dec 2012
Toward Fully Functional Net Zero Buildings: An Engineering Perspective	In this article, current concepts of NZEB are analyzed; an operational definition (OZEB) of "Net-Zero Energy Commercial Buildings" is proposed; a design approach toward achieving site-specific OZEBs is presented; and examples of evidence-based results are reviewed and analyzed.	Boggarm S. Setty, James E. Woods	Unpublished, pending review	Apr 2014
Zero Energy Buildings: A Critical Look at the Definition	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.	Paul Torcellini, Shanti Pless, and Michael Deru, National Renewable Energy Laboratory Drury Crawley, U.S. Department of Energy	NREL	Jun 2006

European				
How to define nearly net zero energy buildings nZEB	A technical definition for nearly zero energy buildings required in the implementation of the energy performance of buildings directive recast. It provides an energy calculation framework and system boundaries associated with the definition to specify how different kinds of energy flow, which is taken into account in the energy performance assessment.	Jarek Kurnitski, Francis Allard, Derrick Braham, Guillaume Goeders, Per Heiselberg, Lennart Jagemar, Risto Kosonen, Jean Lebrun, Livio Mazzarella, Jorma Railio, Olli Seppänen, Michael Schmidt, Maija Virta	REHVA Journal	May 2011

Nearly-zero, Net zero and Plus Energy Buildings	The topic of Zero Energy Buildings (ZEBs) has received increasing attention in recent years, up to inclusion in strategic energy policy papers in several countries. However, despite the emphasis placed on the goals, the various ZEB definitions applied mostly remain generic and are not yet standardized.	Karsten Voss, Igor Sartori, Roberto Lollini	REHVA Journal	Dec 2012
Principles for Nearly Zero-Energy Buildings	The study builds on existing concepts and building standards, analyses the main methodological challenges and their implications for the nZEB definition, and compiles a possible set of principles and assesses their impact on reference buildings. Subsequently the technological, financial and policy implications of these results are evaluated. Finally, the study concludes by providing an outlook on necessary further steps towards a successful implementation of nearly Zero-Energy Buildings.	Thomas Boermans, Andreas Hermelink, Sven Schimschar, Jan Grözinger, Markus Offermann, Kirsten Engelund Thomsen, Jørgen Rose, Søren O. Aggerholm	Building Performance Institute Europe (BPIE)	Nov 2011
Technical definitions for nearly zero energy buildings	The Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) has revised its nZEB technical definition, until now the only available methodology suitable for the implementation in national building codes for the primary energy indicator calculation. The 2013 version was prepared in cooperation with the European Committee for Standardization (CEN) and it replaces the 2011 version with the intention to help the experts in the member states define the nearly zero energy buildings in a uniform way. The 2013 version is complemented with specifications for nearby renewable energy and for the contribution of renewable energy use. A set of the system boundaries and equations are given for energy need, energy use, delivered and exported energy, primary energy and for renewable energy ratio calculation. With these definitions and energy calculation framework, primary energy indicator and renewable energy ratio can be calculated as required by the directive. Calculation principles are explained with worked examples in order to assure uniform understanding of the definitions.	Jarek Kurnitski	REHVA Journal	May 2013
Towards nearly zero-energy buildings: Definition of common principles under the EPBD	The project supports the European Commission in its activities to: give guidance to member states on how to interpret requirements for nearly zero energy buildings; develop a common reporting format on nearly zero energy buildings to be used by member states and evaluate the adequacy of measures and activities reported by member states in their national plans on nearly zero energy buildings; link cost optimality and the nearly zero energy buildings principle in a consistent way and facilitate their convergence until 2021.	Andreas Hermelink, Sven Schimschar, Thomas Boermans, Lorenzo Pagliano, Paolo Zangheri, Roberto Armani, Karsten Voss, Eike Musall	Ecofys: Politecnico di Milano / eERG: University of Wuppertal	Feb 2013

Appendix 2 – Industry Participants

The following individuals representing key industry organizations contributed input and comments in the research and analysis phases of the project. Their responses were used to formulate the initial definitions and supporting materials and subsequent versions.

Name	Organization
Get W. Moy, PE, LEED AP	AECOM, Inc., and Chair of the National Institute of Building Sciences High Performance Building Council
Brian Castelli	Alliance to Save Energy
Harry Misuriello	American Council for an Energy Efficient Economy
Pamela Sams, AIA, LEED AP BD+C	American Institute of Architects
Daniel Lapato	American Public Gas Association
Tanzina Islam	American Public Power Association
Edward Mazria, FAIA, FRAIC	Architecture 2030
Vincent Martinez	Architecture 2030
Scott Shell, FAIA, LEED AP BD+C	Architecture Interiors Planning Urban Design
Doug Read	ASHRAE
Rob Cassidy	Building Design & Construction
Nadav Malin	Building Green/Green Source/ Environmental Building News
Ron Burton	Building Owners and Managers Association International
Paul Bertram, FCSI, CDT, LEED AP BD+C, GGP	Business Council for Sustainable Energy
Rick Hermans, PE, HFDP	Daikin Applied/ASHRAE
Bill Updike	District of Columbia Department of the Environment
Daniel White	District of Columbia Department of the Environment
Steve Rosenstock, PE	Edison Electric Institute
Neil Leslie	Gas Technology Institute
Jerry Yudelson, PE, LEED Fellow	Green Building Initiative
James Woods, PhD, PE	Indoor Environments Consultant
John Andary, PE, LEED AP	Integral Group
David Kaneda, PE, FAIA, LEED AP BD+C	Integral Group
Jeff Johnson	International Facility Management Association
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Sandy Fazeli	National Association of State Energy Officials
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Cathy Higgins	New Buildings Institute
Carolyn Sarno Goldthwaite	Northeast Energy Efficiency Partnerships
Peter Turnbull	Pacific Gas & Electric (PG&E)
Walter Grondzik, PE, LEED AP	Passive House Institute US
Peter Rumsey, PE, FASHRAE, CEM, LEED AP	Peter Rumsey
Lawrence Miltenberger	PNC Bank Corporation
Scott Williams	Target Corporation
David Del Rossi, LEED AP BD+C	TD Bank Corporation
Kristine Kingery	U.S. Army
Kristen Thomas	U.S. Army
Cindy Jacobs	U.S. Environmental Protection Agency
Kevin Powell	U.S. General Services Administration, Office of Chief Greening Officer
Hal Alguire	U.S. Army Ft. Carson Colorado
Mark Hunsiker	U.S. Army Ft. Carson Colorado
Joe Wyka	U.S. Army Ft. Carson Colorado
James McClendon, PE	Walmart Stores, Inc.
Kathy Loftus	Whole Foods

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