Establishing a Common Definition for Zero Energy Buildings: Time to Move the Market

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ABSTRACT

To change the current paradigm from buildings being consumers of energy to producers of energy requires a common language to facilitate market transformation. Common definitions help create market movement by sharing concepts across market actors. While the term 'zero energy buildings' has been in the marketplace for over 20 years, no common definition had been established. US DOE, last year, embarked on a process to evaluate current definitions and solicit industry input to formulate a common definition and nomenclature for zero energy buildings. This definition uses commonly available site measurements and national conversion factors to define zero energy buildings on a source energy basis for a variety of boundary conditions including building, portfolio, campus, and community. Issues addressed include multiple fuel types, cogeneration, and renewable energy certificates. This paper describes the process used to arrive at the definition, looks at methods of calculating site to source energy conversions, and how boundary decisions affect a robust and stable definition that can be used to direct programs and policies for many years to come. This stability is critical to move building investments towards buildings that produce as much energy as they consume.

INTRODUCTION

Even with today's technology and capital constraints it is possible to make a substantial reduction in building energy consumption. The cost of renewable energy has decreased dramatically over the last 10 years such that investors will lease roof tops for renewable energy generation. The result is a strong interest in the concept of zero energy buildings (ZEB)—a paradigm shift from buildings being consumers to producers of energy. These zero energy buildings have tremendous potential to reduce or eliminate the use of non-renewable energy for a more sustainable future. A broadly accepted definition of ZEB boundaries and metrics is foundational to efforts by governments, utilities and private entities to recognize or incentivize ZEBs. Having a commonly accepted definition and corresponding methods of measurement for ZEBs will help create market alignment; having consistency will spur the development of better design strategies, procurement methodologies, and operational methods for buildings and should increasing market uptake. A stronger market pull will create increased knowledge to implement zero energy buildings and ultimately should reduce the cost to turn conventional buildings into ZEBs.

While the term zero energy building has been in the marketplace for over 20 years, no common definition had been established. The US Department of Energy (USDOE) embarked on a process to evaluate current definitions and solicit industry input to formulate a common

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definition for zero energy buildings. This project expanded initial zero energy definition efforts that were established from NREL (Torcellini 2010).

The resulting definition and accompanying nomenclature uses commonly available measurements and national conversion factors to define a zero energy buildings on a source energy basis as well as definitions for zero energy portfolios, campuses, and communities.

Industry receives the following benefits from a commonly accepted ZEB definition:

- Provides guidance to building owners wanting or required to meet ZEB requirements
- Allows public entities and utilities to recognize or incentivize ZEBs in a consistent manner.

DEFINITION DEVELOPMENT: PROJECT GOALS

The primary goal was to bring the market together around the concept of buildings producing as much energy as they consume. Two important aspects had to be considered when developing the common definition. The metrics or measurements and the boundary condition to apply to those measurements. Reducing the ambiguity of any term facilitates communication which, in turn, supports common goal setting and provides market direction.

The Project Team used the following guiding principles in developing a ZEB definition for commercial/ industrial/ institutional buildings. The definition should:

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

Moreover, the definition should be able to be applied to new and existing buildings. In broad terms, two key elements need strong definitions: boundaries and metrics. The boundary provides the location(s) where energy flows will be measured and the metrics determines what will be measured. In addition, the definition of a zero energy building needs to capture a time-element such that it can be verified. Thus the definition is an attribute of the operation of the building as the environmental impact is largely a result of building operations and not a model created during design. A definition that requires measurement provides an additional assurance that the building will be operated in the future to continue to meet the ZEB definition.

ENGAGING INDUSTRY EXPERTISE

Early in 2014, the National Institute of Building Sciences, with funding and support from the US DOE Building Technologies Office, began working to establish a common national ZEB definition. Creating a broadly agreed upon and supported definition of ZEB required participation from many subject matter experts and organizations with a stake in the outcome.

During the research phase of the project, the project team surveyed existing publications in North America and Europe. Numerous ZEB subject matter experts (SMEs) from across the building industry were interviewed on various issues including:

- Role of energy efficiency in a ZEB
- Importance of various measurement metrics
- Building energy to be included or excluded in energy accounting
- Inclusion of off-site energy to process water and wastewater
- Allowable measurement boundaries for various scenarios
- Definition of on-site renewable energy
- Role of off-site renewable energy in ZEBs

The SME included owners, architects, engineers, researchers, energy efficiency advocates, and utility representatives. These SMEs were given a set of icons, shown in Figure 1, and asked to place these into or out of the boundary to indicate which items should be considered within the boundary of a ZEB. A similar exercise was used to determine which metrics should be considered. Further questions probed into the "whys?" of selection.

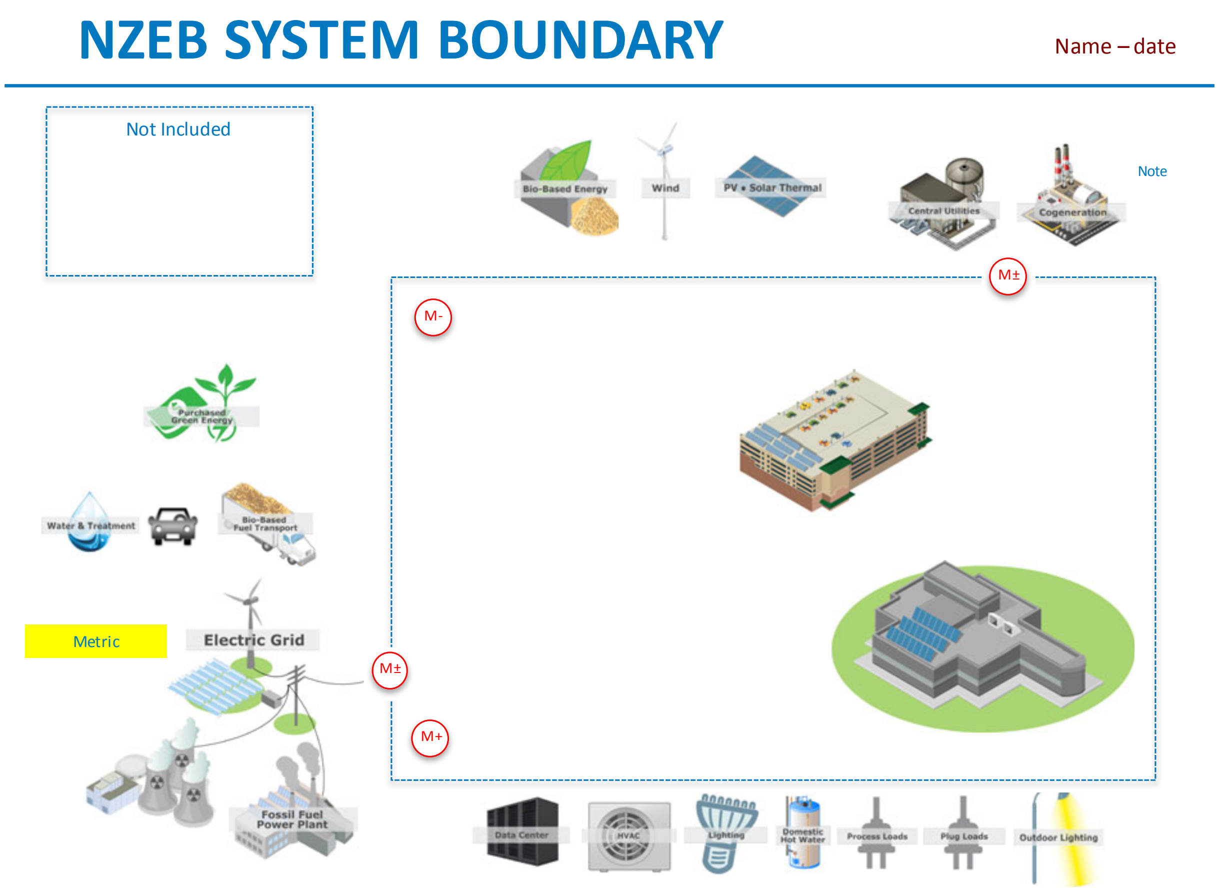

Figure 2. Subject Matter Expert Template

More than 95% of the SMEs agreed that a ZEB should include all energy within the boundary except transportation outside the building and off-site water and treatment energy. 100% agreed that all energy sources imported should be counted including energy from district energy systems. More than 95% agreed that all on-site renewable energy systems should be allowed with 60% believing that purchased renewable energy certificates (RECs) should be allowed to offset imported energy by a ZEB.

The research and interview process supported the development of a comprehensive list of issues to be addressed as part of the draft set of definitions and metrics. The project team presented these findings to industry stakeholders and asked to contribute their perspective and provide feedback. After posting the revised definitions document in the Federal Register (Federal Register Vol. 80 – 2015) the project team further considered public comments and refined the final definitions, nomenclature, and guidelines.

A critical part of any definition is the exact meaning of the words used, or nomenclature. Nomenclature was developed and appears in Table 1. As part of the word choice, the term was established to be a “zero energy building.” One of the findings of background research and interviews with SMEs was that people are passionate about names, perhaps even more so than the content of the name. Regional differences place the word “net” before or after “zero.” While we will discuss energy crossing the boundary later, it is important to note here that the energy flows are carefully picked to be flows that are commoditized and—that is, can be purchased or sold. Typically, there is an environmental footprint with many of the purchased energy sources. The reality is, thermodynamically, all buildings are net zero to satisfy the first law of thermodynamics, but we choose the energy sources to measure based on an overarching objective to minimize the environmental footprint of buildings. We found that people were passionate about what to call it which causes some market division and market confusion when talking to people that are not in the industry.

ZEB DEFINITION

Robust and stable zero energy building definitions required boundary conditions and the terms used in the definition to be defined. Table 1 shows the definitions for the nomenclature used in defining ZEBs. The following is the resulting common definition for a zero energy building, or what is also referred to as a “net zero energy” or “zero net energy” building.

Zero Energy Building – 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.

The Project Team believes the designation Zero Energy Building (ZEB), Zero Net Energy Building (ZNEB), and Net Zero Energy Building (NZEB) 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.

Table 1: Zero Energy Nomenclature

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 energy, 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.

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.

UNDERSTANDING BOUNDARIES

The new common definition document (U.S. DOE – 2015) provides guidelines identifying the methodology for establishing boundary conditions, conducting energy measurements and accounting, calculating source energy, and the use of Renewable Energy Certificates (RECs). RECs were originally created for utilities to track the energy and the renewable attribute of the electrical energy. For every 1,000 kWh of renewable energy generated, a REC is created. It is important that the RECs are owned by the building or, at minimum, have been retired. They cannot have been resold to others to meet their renewable energy requirements. This would be double-dipping the renewable energy attributes of the power and is the subject of several rulings by the Federal Trade Commission (FTC Green Guides). The concept of electricity having attributes is not common to most people, and the implications of the FTC rules are very broad in terms of what can be claimed for renewable energy. Just because a building has solar panels on a roof, does not entitle the owner of the building or the owner of the panels the right to claim that renewable energy is being used by the building. In many cases, these RECs have been "sold" as part of accepting state and/or utility incentives especially for financial instruments such as leases or power purchase agreements.

Figure 2 illustrates the site boundary of energy transfer for zero energy accounting. The site boundary for a 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 exported energy are measured at the site boundary. A ZEB may only use on-site renewable energy when offsetting delivered energy through the site boundary. The key is to define the boundary for the building and closely related functions. Typically, this boundary is at the point of the utility meters or the point of delivery of fuel (such as oil and propane).

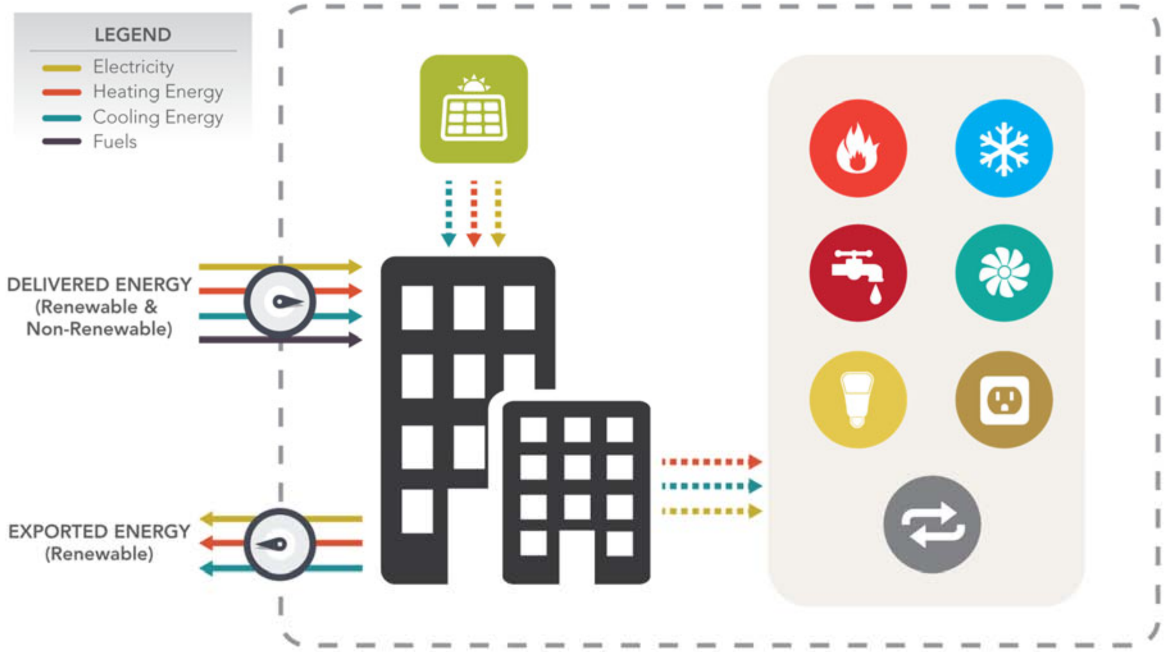

Figure 2. Site Boundary of Energy Transfer

ZEB energy accounting for delivered energy through the boundary includes energy used for heating, cooling, ventilation, domestic hot water, indoor and outdoor lighting, plug loads, process energy and transportation within the building. Note there is a distinction between transportation used within the site boundary (such as forklifts in a ware house, conveyor systems or people transport versus transportation that is used to bring people, materials, and services to the building. Therefore, if vehicle charging energy for transportation outside the building is included in the imported energy it is also included in the exported energy. Often a grid-independent building refers to a building that is detached from the electric utility. Often these buildings purchase non-renewable fuels such as oil or propane. This energy must be accounted as delivered energy when making the determination for a zero energy building. These energy flows must be metered where they cross the boundary. In many cases, this measurement would be at utility meters or the point of delivery for propane and fuel oil. Note that renewable energy used on-site need not be metered as it is does not cross the site boundary. Electricity from cogeneration systems must be used within the building as it does not count as renewable exported energy if it is generated with non-renewable energy. In a practical sense, electricity generated from co-generation must be metered separately and be shown to be less than the instantaneous power consumption of the building. Another viewpoint is that the renewable power generated at any moment in time must not be larger than the renewable energy exported. On-site battery storage, when not tied to the renewable generation, will complicate this metering as you have to show that if exported, it can be traced back to the original renewable energy generation.

It became clear through the SME interviews and stakeholder input that definitions were needed for collections of buildings and shared renewable energy resources. In some cases, buildings and renewable energy sources may be co-located on campuses. In other cases, a portfolio of buildings and renewable energy resources in different geographic areas may be owned/leased by a single entity. Not all buildings can achieve being a zero energy building; however, all buildings can reduce their energy consumption and produce some of their energy and receive the rest of their energy from "another" building or a common renewable energy resource. An NREL study on the potential of zero energy buildings showed that with technology from 10 years ago, we could get close to zero across the entire commercial portfolio with rooftop PV (Griffith 2007). To meet this need of multiple buildings, the following variations on the ZEB definition were provided to expand the boundary around multiple buildings.

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.

THE ENERGY METRIC

Site energy consumption is useful for understanding the performance of the building and the building systems, but it does not tell the whole story of resource consumption and emissions associated with the building's 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 ZEB definition uses national average source energy conversion factors to accomplish the conversion to source energy because the use of these factors ensures that no specific building will be credited (or penalized) for the relative efficiency of its energy provider(s). This goes back to the original project goals. Utility electrical grids are highly complex and interconnected such that it is very difficult, on a localized basis, to determine their source of the energy. National averages for site to source conversions capture the fuel impacts while rewarding local and owner decision making.

Source energy is calculated from delivered energy and exported energy for each energy type using site-to-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 used are from Table J2-A in ASHRAE Standard 105 (ASHRAE 105 – 2015). While on-site renewable energy is a carbon-free, zero-energy-loss resource, when it is exported from the building, it displaces electricity that would be required from the grid. Table 2 summarizes the national average source energy conversion factors for various energy types. Note that exported non-renewable energy has no value in the calculation method.

Table 2 – 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

The source energy calculation uses the following formula:

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

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 ENERGY ACCOUNTING

The following example buildings are provided to understand how to calculate the energy balance using site and source energy to better understand the impact on the size of on-site renewable energy systems. Source energy ZEBs generally require less on-site renewable energy than site energy ZEBs when multiple fuel sources are used. Source energy and site energy ZEBs require the same amount of on-site renewable energy for all electric ZEBs since the source energy conversion factor is the same for imported and exported electricity.

Gas/Electric Building

A hypothetical building has the following annual delivered energy of 364,795 kWh electricity and 2,999 therms. The building utilizes PV renewable energy installed on the roof and over the parking lot. The *site boundary* would include both the building and parking lot, therefore, the *delivered energy* would also include the parking lot lighting. The equation is using energy transferred across the *site boundary* and does not include *on-site renewable energy* consumed by the building. Both annual delivered site energy and annual delivered source energy can be calculated using the source energy conversion factors above:

$$E_{del-site} = \left(364{,}795\ kWh \times \frac{3.412\ kBtu}{kWh}\right) + \left(2{,}999\ Therms \times \frac{100\ kBtu}{Therm}\right) = 1{,}544{,}581\ kBtu$$

$$E_{del-source} = \left(364{,}795\ kWh \times \frac{3.412\ kBtu}{kWh} \times 3.15\right) + \left(2{,}999\ Therms \times \frac{100\ kBtu}{Therm} \times 1.09\right) = 4{,}247{,}635\ kBtu$$

In order for the building to generate enough on-site renewable energy using photovoltaics (assuming 1,500 kwh per installed kW) to offset the delivered energy, the building would need approximately:

$$PV\ Required_{site} = \frac{1{,}544{,}581\ kBtu}{\frac{1500\ kwh}{kW} \times \frac{3.412\ kBtu}{kWh}} = 302\ kW$$

$$PV\ Required_{source} = \frac{4{,}247{,}635\ kBtu}{3.15 \times \frac{1500\ kwh}{kW} \times \frac{3.412\ kBtu}{kWh}} = 263\ kW$$

As fossil fuels will be on the utility grid for the foreseeable future, the implication is that it is more efficient to use fossil fuels at the site versus using them at a central power plant which has to “throw away” the waste heat into the environment.

Combined Heat and Power Building

A building with combined heat and power has the following actual annual delivered energy of 68,371 kWh electricity and 3,042 therms. All the PV renewable energy will be installed on the roof of the building. The *site boundary* would be around the building perimeter. The energy accounting would need to measure the on-site renewable energy exported since the CHP electricity cannot be exported per the definition. Both annual delivered site energy and annual delivered source energy can be calculated using the source energy conversion factors above:

$$E_{del-site} = \left(68{,}371\ kWh \times \frac{3.412\ kBtu}{kWh}\right) + \left(3{,}042\ Therms \times \frac{100\ kBtu}{Therm}\right) = 537{,}482\ kBtu$$

$$E_{del-source} = \left(68{,}371\ kWh \times \frac{3.412\ kBtu}{kWh} \times 3.15\right) + \left(3{,}042\ Therms \times \frac{100\ kBtu}{Therm} \times 1.09\right) = 1{,}066{,}416\ kBtu$$

In order for the building to generate enough on-site renewable energy using photovoltaics (assuming 1,500 kwh per installed kW) to offset the delivered energy, the building would need approximately:

$$PV\ Required_{site} = \frac{537{,}482\ kBtu}{\frac{1500\ kwh}{kW} \times \frac{3.412\ kBtu}{kWh}} = 105\ kW$$

$$PV\ Required_{source} = \frac{1{,}066{,}416\ kBtu}{3.15 \times \frac{1500\ kwh}{kW} \times \frac{3.412\ kBtu}{kWh}} = 66\ kW$$

SUMMARY

Zero Energy Buildings provides the inspiration to change how we think about energy in buildings. It also provides for a goal that can be measured—which is the first step in achieving any mass market shift. A common definition for zero energy buildings provides unity in which building owners, utilities, and government agencies can march in the same direction to provide clean energy for the future. This common definition provides for metrics and establishment of boundaries to assist in verification and consistency of messaging.

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