Zero Energy Building Definitions and Policy Activity

An International Review

IPEEC Building Energy Efficiency Taskgroup

International
Partnership for
Energy Efficiency
Cooperation

Contents

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Cover image: U.S. National Renewable Energy Laboratory’s (NREL’s) Research Support Facility, Golden, Colorado USA. Image courtesy of NREL.

Executive Summary

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Building energy efficiency policies are an important tool in addressing energy and climate policies. There has been tremendous technical and policy activity in recent years aimed toward improving building energy performance, with a focus on getting to very low energy buildings and targeting "zero" energy or emissions buildings. A variety of governments have established ambitious, and sometimes aspirational, policies and targets for zero energy buildings (ZEBs) to become standard or commonplace. This report, intended for energy and buildings policy-makers, provides an overview of relevant definitions covering all types of zero energy or emissions buildings, regulatory policies aimed to push those standards, implementation approaches and market progress where available, and lessons learned.

ZEB definitions

A variety of different terms have been used to characterize very low energy buildings, aiming toward zero energy (ZE) or emissions from a building, whereby any energy consumed within the building is offset by renewable sources, usually at the building site. While there are many slightly different specific terms (net zero energy, nearly zero energy, zero carbon or emissions, etc.) which are defined and explained in this report, these are usually high performing, highly efficient buildings that use, over the course of a year, renewable technology to produce as much energy as they consume from purchased commercial energy sources. While all of the initiatives aim toward some variation on the term ZEB, in practice most have somewhat different definitions of the actual "zero" metric, along with different energy consumption and production boundaries, which make them hard to compare directly.

To understand energy performance for a ZEB, it is important to carefully establish the "boundaries" of energy use or production included in any definition. Different policies vary in their definitions of "regulated energy," or what end uses are included/excluded in the energy consumed that must be counted. For example, nearly all European standards and definitions exclude "plug loads" from the calculated building energy needs, as those loads are not permanent to the building structure. Other standards and energy accounting systems count all energy consumed within a building; this methodology is usually considered "whole building" energy consumption. There can also be quite wide differences in what is considered "allowable" renewable energy to offset onsite energy consumption. To further complicate matters, different expressions of energy use or consumption are also used among the various definitions, which can have a significant impact on the policy's stringency and buildings' difficulty in meeting the target.

There seems to be an emerging trend to use zero carbon instead of zero energy as the metric, though there can be subtle issues between the two metrics that are significant. As zero carbon grows in uptake, additional research and quantitative analysis will be required to understand the differing impacts of the two standards, interactions between energy and carbon as the metric, and how existing policies may need to be adjusted.

ZEB policies and initiatives, and lessons learned

There have been a growing number of ZEB policies and other initiatives established in recent years by IPEEC member countries, and other leading national and sub-national governments. Governments are implementing ZEB policies, often supported by active engagement from leading non-governmental organizations. It is somewhat challenging to understand lessons learned, in that most policies and targets for widescale ZEB adoption are just now taking effect, and much more will be known about their impacts and issues confronted in a few years, after they have been in place for several years.

The jurisdictions with the most success seem to result from a mix of ambitious regional (e.g., European Union scale), or national/state/provincial policy leadership combined with grassroots local policy activity supported by ZEB and environmental advocates as well as industry leaders. This leads to a virtuous circle of ZE policy where the interaction of leading policies can drive continuous increases in ambition.

Achieving levels of efficiency to bring energy consumption down to where it can be offset by on-site renewable energy production is not overly complex and can have reasonably attractive life-cycle cost economics in the right circumstances, particularly in smaller low-rise buildings in reasonably temperate climates. However, in buildings over four to six floors in height, and in buildings with substantial plug and process loads (if those loads are included in the ZEB definition), it is much harder to get enough on-site generation to cover all of the energy use in even a high performing, very efficient low energy building.

A variety of tools have been established in recent years for tracking ZEB market progress, and as the number of ZEBs around the world continues to grow, access to these tools is very helpful to demonstrate strong market progress. There is substantial market movement in leading regions toward very low energy, ZEB intended buildings, though most of the tangible program activity has been in the "nearly zero" or "zero ready" buildings as opposed to true ZEBs. Concerns have been raised about a performance gap, where buildings are designed to be ZEB, but in actual operation, consume significantly more than had been predicted.

The proliferation of low energy buildings combined with on-site generation in some regions, as well as rapidly increasing penetration of variable renewable sources like wind and solar, leads to new and complex demands on the local electric grid. There is often a mismatch of too much energy generation in a relatively small number of hours in a day feeding into the electric grid, often not coincident with the highest energy demand in the building. Jurisdictions that are grappling with

ingenhoven architects/HGEsch

Freiburg Town Hall, net-surplus-energy building, Freiburg Germany

this issue are starting to initiate research and analysis to figure out the best ways to address this.

Many ZEB policies begin with a quite ambitious target several years away, to allow time for capacity building and experience understanding what is needed to achieve the major energy reductions. In most of the early cases where these targets had been set for 2020 or earlier, it is not clear whether the original goals will be met (many experts are very skeptical about all new buildings meeting established ZEB related goals by the established target date). However, it is clear that having aspirational targets has made a very significant difference in accelerating the penetration of ZE or very low energy buildings, relative to other regions or jurisdictions without such ambitious policies. Having these targets in place has proved to set a "future-proof" vision for the sector and mobilize stakeholders accordingly.

The policies and incentives supporting ZEBs matter. Most of the growth and progress have been seen in areas where there is strong supranational, national, state/provincial or local support, including access to financing. Going forward, understanding how the progress continues in these leading areas will be important to help refine and improve future policies. In the coming years, it will be important to prove the ZEB concept after large numbers of buildings have been occupied for a period of time—and to communicate that effectively to industry associations, governments and the public—to enable future growth and progress.

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Introduction

Despite broad policy activity in most regions of the world, building energy consumption globally continues to grow, from final energy consumption of 119 exajoules (EJ) in 2010 to nearly 125 EJ in 2016. Buildings sector energy intensity measured as energy use per square meter continues to improve at an average annual rate of 1.5%, yet global built floor area is increasing at rate of 2.3% per year, offsetting those energy efficiency and intensity improvements.[1] Building energy efficiency policies are an important tool in addressing energy and climate policies.

There has been tremendous technical and policy activity in recent years aimed toward improving building energy performance, with a focus on getting to very low energy buildings and targeting "zero" energy or emissions buildings. This report, intended for energy and buildings policy-makers, provides an overview of relevant definitions covering all types of zero energy or emissions buildings, regulatory policies aimed to push those standards, and implementation approaches and market progress where available, and lessons learned.

A variety of governments have established ambitious, and sometimes aspirational, policies and targets for zero energy buildings (ZEBs) to become standard or commonplace. Some of the earlier of these goals and policies, set 10 to 15 years ago, established that new buildings built after 2020 (or 2030, or a different year) would be zero energy (or nearly or net zero), as defined as part of that policy or scheme.

While there are many slightly different specific terms (net zero energy, nearly zero energy, zero emissions, etc.) with definitions as noted later in this report, we use the term "zero energy building," or "ZEB" as the generic term for this report, though as we discuss later in the report there can be some material differences in the technical requirements and resulting energy performance and emissions based on those definitions.

The earliest major economy to focus on "nearly ZEB" standards came in the European Union (EU) in 2010, when the recast of the European Commission's Energy Performance of Buildings Directive (EPBD, 2010/31/EU) introduced the definition of nearly ZEB as a building with very high energy performance where the nearly zero or very low amount of energy required should be covered to a significant extent by renewable sources produced on-site or nearby. The EPBD foresees that after December 31, 2020, all new buildings in the EU will be nearly ZEBs, starting with public buildings having a deadline of December 31, 2018.

Outside of Europe, the United States (US), Japan and Korea have also established ZEB policies and goals, and some leading subnational governments, most

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[1] UN Environment and International Energy Agency 2017: Towards a zero-emission, efficient, and resilient buildings and construction sector. Global Status Report 2017.

notably the States of California and Massachusetts in the US, have set ambitious ZEB targets. Japan has established targets for ZE in new public buildings by 2020 and all newly constructed buildings by 2030. Korea in 2014 established the "Activation Plan of Zero Energy Buildings," and set up a roadmap to achieve targets, along with a financing strategy and subsidies for pilot projects.

In addition, state, provincial, and local governments are setting even more ambitious policies. As an example, the US State of California has set the ambitious goal that "all new residential buildings in California will be zero net energy (ZNE) by 2020; and all new commercial buildings will be ZNE by 2030."

On a similar timeframe, other building industry and environmental stakeholder groups have launched initiatives to promote ZEBs, including the World Green Building Council's Coordinated Action toward 100% Net Zero Carbon Buildings by 2050.[2] In many regions of the world, these non-governmental stakeholder groups, sometimes led by a regional Green Building Council, are collaborating with government bodies to promote voluntary initiatives for zero energy or emission (more often zero emission) buildings development. As an example, the Green Building Council Australia (GBCA) has collaborated with the Australian federal government to expand the Australian National Carbon Offset Standard (NCOS) to include zero emissions buildings and precincts in operation.[3]

In the US, several non-governmental organizations have emerged to drive ZEB activities, most prominently the New Buildings Institute which leads a Getting to Zero campaign and maintains a database of ZEBs, and Architecture 2030, which has established a goal for all new buildings, developments, and major renovations to be carbon-neutral by 2030, and recently released the "ZERO CODE" that sets a path for new buildings to be designed as "zero net carbon."[4]

While all of these initiatives aim toward some variation on the term ZEB, in practice most have somewhat different definitions of the actual "zero" metric, along with different definitions and energy consumption and production boundaries, which make them hard to compare directly.

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2. http://www.worldgbc.org/advancing-net-zero

3. http://www.worldgbc.org/sites/default/files/GBC%20ANZ%20Snapshot_GBCA_FINAL2.pdf

4. Architecture 2030 ZERO CODE, April 2018; http://architecture2030.org/zero-code/

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Zero Energy Building Related Definitions

A variety of different terms have been used to characterize very low energy buildings, with the target of "**zero**" energy or emissions from buildings, whereby any energy consumed within the building is generated by renewable sources at the building site. They are usually high performing, highly efficient buildings that use, over the course of a year, renewable technology to produce as much energy as they consume from purchased commercial energy sources.

Most countries' policies are aimed at zero energy instead of zero carbon, as building regulators generally have more direct control over building energy consumption, while the overall carbon content of purchased energy such as electricity is regularly not as directly controllable by building owners, but often dependent on policies from other policymakers or regulators aimed toward decarbonizing the electricity supply. The difference between a zero energy and zero carbon approach can be significant in terms of the likely impact on emissions; indeed, the variation in the definitions for the ZEB concept means that understanding the quantitative impact of the difference between zero energy versus zero carbon will need to be conducted on a region or country specific basis, reflecting the detailed ZEB requirements and calculations in each jurisdiction. We will discuss this in more detail below.

Key terms and acronyms

ZEB: Zero Energy Building
nearly ZEB: Nearly Zero Energy Building
NZE: Net Zero Energy
ZC: Zero Carbon
ZE: Zero Energy
ZNC: Zero Net Carbon
ZNE: Zero Net Energy

The term "**net zero**" is often used to take into account that the building likely uses some energy for certain end uses, but that energy consumption is supplied by on site renewable energy such that over some period (generally over the course of a year) the "net" non-renewable energy use is zero. This same concept is sometimes also referred to as "**zero net energy**" or ZNE.

Instead of the technically correct accounting term of "net zero," there has recently been more of a move toward not including "net" and just using the term "**zero energy**" for simplicity and communication with non-technical audiences. Another term sometimes used is "**energy neutral**."

As noted above, the European EPBD uses the term "**nearly zero energy building**" ("nearly ZEB;" now generally referred to in Europe as "NZEB" but that acronym is not used in this report to avoid confusion with "net ZEB").

Some programs and policies go further than ZE, and target "**energy positive**" buildings (known in Germany as PlusEnergy, or "Plusenergiehaus," and in France as "Bâtiments à énergie positive"), where the building produces more energy than it consumes.

Because some policy makers have set targets for renewable energy to be able to offset any on-site energy use but found that renewable energy provided by solar

Josh Byrne & Associates & Acorn Photography

Josh's Zero Emissions House , Hilton (near Perth), Australia

photovoltaic (PV) systems was not yet cost-effective in some situations (or the regulatory rules for utility interconnection was not yet mature or economically viable), there has been increasing use of the term "**zero energy ready**" (or net zero ready). This refers to buildings that are built with low energy demand, and have adequate structural and electrical infrastructure capabilities, but the solar PV systems are not required to be installed at the time of construction.

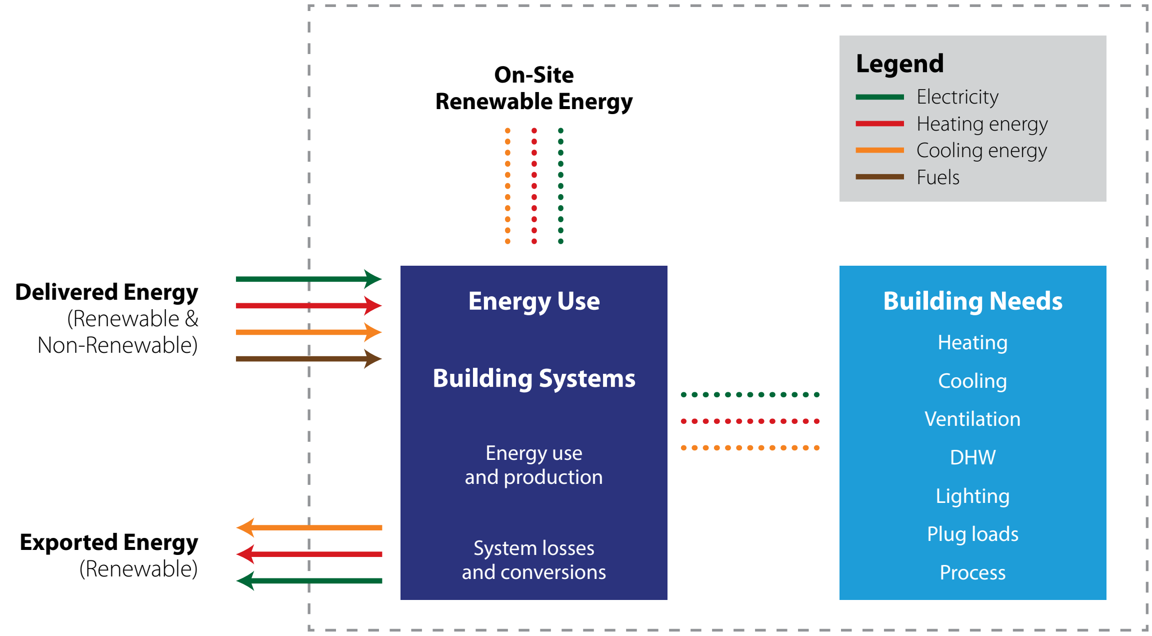
While not directly a "zero energy" path, "**Passive House**" standards and certification development have had tremendous impact in driving very low energy consumption buildings, easing the way for ZEB development.

Boundaries of energy use

To understand energy performance for a ZEB, it is important to carefully establish the "boundaries" of energy use or production included in any definition. A variety of national and international standards in recent years have included diagrams showing how to account for energy consumption in a building or site.

Many of the boundary diagrams developed for various technical standards were considered during the development of the US Department of Energy (DOE) Common Definition for Zero Energy Buildings (US DOE 2015). This common definition is one of the more comprehensive definitions, intended to simplify ZEB concepts to make them more easily understood by both technical audiences, as well as the general public. The "site boundary" diagram included as part of the US DOE ZEB definition is shown in Figure 1.

Figure 1. Site Boundary of Energy Transfer for Zero Energy Accounting (US DOE Zero Energy Buildings Definition)



Dotted lines represent energy transfer within the boundary. Solid lines represent energy transfer entering/leaving the boundary used for zero energy accounting.

Different standards sometimes vary in their definitions of "regulated energy," or what end uses are included/excluded in the energy consumed that must be counted, as represented by the 'Buildings Needs' box in Figure 1. For example, nearly all European standards and definitions exclude "plug loads" from the calculated building energy needs, as those loads are not permanent to the building structure. Other standards and energy accounting systems count all energy consumed within a building; this methodology is usually considered "whole building" energy consumption. As with the distinctions on definitions, understanding the nuances of what is in or out of scope for ZEB qualifications will also impact the magnitude of likely emissions reductions that might emerge from the initiative.

There can also be quite wide differences in what is considered "allowable" renewable energy to offset the building's energy consumption. An investigation of different EU member state regulations regarding the use of renewable energy systems in nearly ZEB calculations found that there are many different types of "renewable energy system (RES)" solutions that different countries allow as part of their energy performance calculations.[1] As shown in Table 1, a relatively small number of RES solutions are included in these calculations in all EU member states' calculations (solar thermal panels for domestic hot water [DHW] or heating support; PV for

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[1] New buildings and NEARLY ZEBs: Status in November 2016, for EU EPBD Concerted Action; see https://www.epbd-ca.eu/wp-content/uploads/2018/04/CA-EPBD-CT1-New-buildings-NEARLY ZEBs.pdf

Table 1. **Accountable Renewable Energy Solutions in EU Member States' Energy Performance Calculations**

Country Solution	BE-BR	BE-FL	BE-WA	BG	CY	DE	DK	EE	GR	ES	FI	FR	HR	HU	IT	LT	LV	MT	NL	NO	PL	PT	SE	SK	SL	UK
RES as part of district heating	Y	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N	Y	Y		Y	N	Y	Y	Y
RES as part of district cooling	N	N	N	Y	Y	Y	N	Y	Y	N	Y	Y		N	Y	N	N	N	Y	Y	N	Y	N	N	Y	N
Solar thermal panels for DHW	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Solar thermal panels for DHW	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
PV for self-use	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
PV for feed-in	Y	Y	Y	Y	Y	N	N	Y	Y	N	N	Y	Y	Y	N	Y	Y	Y	Y	Y	N	N	N	Y	Y	N
PV for heating (input to heat storage)	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
PV/T hybrid solar collectors for self-use	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
PV/T: PV for feed-in, T for self-use	Y	Y	Y	N	Y	Y	Y	Y	N	N	N	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	N
Micro wind-turbine for self-use	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
Micro wind-turbine for feed-in	N	N		Y	Y	N	Y	Y	Y	N	N		N	N	N	Y	Y	Y	Y	Y	N	N	N	Y	N	N
Local hydro for self-use	N	N	N	N	N	N	Y	Y	N	Y	Y	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
Local hydro for feed-in	N	N	N	N	N	N	N	Y		N	N	N	N	N	N	Y	Y	N	Y	Y	N	N	N	N	Y	N
Biomass boiler	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
Biomass CHP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y/N	Y/N	Y	Y	Y	Y/N	N	Y	Y	Y	Y		Y	N	Y	Y	Y
HP coupled to external or exhaust air	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
HP coupled to ground/ ground-water	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Direct geothermal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Direct ground water cooling	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Y	Y	Y	N	Y	Y	Y
RES electricity via grid (specific contract)	N	N	N	Y	N	N	N	N	N	N	N	Y	N	N	N	Y	N	N	N	Y	N	N	N	N	N	N
Alternative: higher insulation level	Y	Y	N	Y	N	Y	N	Y	Y/N	Y/N	N	N	N	N	Y	N	N	N	Y	Y	Y	N	Y/N	N	Y	N

From: New buildings and NZEBs: Status in November 2016, for EU EPBD Concerted Action; see https://www.epbd-ca.eu/wp-content/uploads/2018/04/CA-EPBD-CT1-New-buildings-NEARLY ZEBs.pdf

self-use; biomass boiler; and, some types of heat pumps), while there are other RES solutions that are only included by a much smaller number of the member states.

Beyond definitions and boundaries for energy consumption, for policies aiming toward zero carbon buildings, it is important to understand boundaries generally considered for carbon reporting, such as direct and indirect emissions (scopes 1, 2, and 3 emissions). A good primer on carbon accounting as applied to the building sector is contained in the Australian National Carbon Offset Standard for Buildings.[2]

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[2] http://www.environment.gov.au/climate-change/government/carbon-neutral/publications/ncos-buildings

Definitions of energy use and/or consumption

To further complicate matters, different expressions of energy use or consumption are also used among the various definitions, which can have a significant impact on the real stringency or difficulty in meeting the target. The most common of these expressions are described in Table 2.

While most ZEB definitions consider only the energy used and generated over the course of a year, in some regions there are growing concerns about the impact of the timing of when renewable energy is produced and injected into the electricity grid. In jurisdictions with large amounts of solar capacity, for example, there may be too much solar generation in the afternoon for the system to handle. To address this, some jurisdictions are incorporating the time of energy use and renewable generation as part of their ZEB standard.

In the US State of California, for example, the regulatory codes being developed to implement ZEB policies are considering the "time dependent valuation" of energy use and production[3] as part of the cost/benefit analysis for revising building energy codes. The time dependency recognizes that energy savings or production may be significantly more valuable during some time periods (such as the time of an electric system peak demand) than others. In a neighborhood or utility distribution network with a very high penetration of solar PV powered homes, there will be significant energy feeding into the grid at some hours, with exacerbated peak demand (and supply ramp) situations at other times, raising the costs for building and maintaining the electric grid network. This is currently a major issue in regions with rapidly growing ZEB markets including solar PV.

Nearly all ZEB definitions refer to the operational energy use[4] in the building (what is consumed while the building is operating and occupied), not the embodied energy that goes into construction materials used to construct the building, or any energy consumed during construction or demolition of a building. These other, non-operational energy uses, have traditionally been a small fraction of overall building life-cycle energy consumption, though in ZEB or very low energy consumption buildings, the embodied energy can be a larger portion that will require more attention in the future.

In some cases, the "zero" target is for emissions, usually carbon emissions. The exact definition of "carbon" for these definitions is often not specified, though in the cases where it is, it is generally CO_2 equivalent to account for any other relevant greenhouse gas emissions (often just called "carbon equivalent").

The UK national definition for nearly ZEBs was initially based on carbon. The UK government in 2008 established "a target for all new homes in England to be 'zero carbon' from 2016 and an ambition for all new non-domestic buildings in England

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[3] More information on Time Dependent Valuation for setting building energy regulations at: http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/general_cec_documents/Title24_2013_TDV_Methodology_Report_23Feb2011.pdf

[4] The energy consumed during the full period that the building is operated and occupied, even though this energy use may be calculated based on the prescribed calculation methodology expressing the building's energy needs.

Table 2. Common ZEB Expressions

Concept	Description
Zero Site (delivered) Energy	Addresses energy as consumed at the building site and measured by the consumption of all energy meters at the building, but not considering upstream losses from energy generation, transmission or distribution.
Zero Primary (Source) Energy	In addition to site energy, the energy needed for generation, transmission and distribution to the building site; gives extra benefit to on-site electricity generation exports, which offset the purchased electricity losses, and can help with offsetting any fossil fuel consumed at the site.
Zero Energy Costs	Selling enough energy back into the grid to offset the cost of all energy purchases —a different form of energy accounting.
Zero Emissions	Instead of energy as the measurement of consumption to be netted to zero, carbon emissions are measured and need to net to zero.

For more information see Zero Energy Buildings: A Critical Look at the Definition, https://www.nrel.gov/docs/fy06osti/39833.pdf

to be zero carbon from 2019 (2018 for new public-sector buildings)."[5] However, in 2015 the government cancelled this policy, and the replacement policy has not yet been finalized.[6]

Other large scale voluntary initiatives, including the World Green Building Council's "Thousands to Billions" campaign,[7] use net zero carbon as the metric.

ZEB definitions mostly do not allow the purchases of offsite renewable energy, or any sort of tradable renewable energy credits or energy/carbon offsets. In some cases, there are specific rules about the proximity of these offsite renewable sources, stipulating that any renewable credits or offsets must come from power plants within some specified distance from the building. Some voluntary schemes, for example, the World Green Buildings Council "Net Zero Carbon" principles allow for some portion of on-site energy use to be balanced with off-site renewable sources or purchased carbon offsets.

While not tied directly to ZEB definitions, **Passive House** standards and certification development over the past decade have had tremendous impact in driving very low energy consumption/ZEB construction. Passive House concepts and standards were initially developed as a result of an EU funded academic study to assess

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[5] UK National Plan for Increasing the Number of Nearly Zero Energy Buildings, September 2012. Available at https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings/nearly-zero-energy-buildings

[6] https://www.ukgbc.org/ukgbc-work/zero-carbon-non-domestic-buildings/ and http://www.energysavingtrust.org.uk/sites/default/files/reports/ERP4_The%20Clean%20Growth%20Plan_A%202050-ready%20new-build%20homes%20policy.pdf

[7] http://www.worldgbc.org/advancing-net-zero

how efficient buildings should be. It evolved into a building standard that, over the past 27 years, has been successfully implemented around the world, with millions of square meters of buildings being constructed in all climates, representing all building types. As an overall energy performance standard (combined with co-benefits of comfort and health), Passive House results have been verified by ongoing monitoring of completed projects. Passive House standards are not limited to any specific construction design but set very low energy consumption standards; for typical buildings there is a limit for the building heating or cooling load of 10 W/m^2 or an annual heating or cooling demand of 15 kWh/m^2/y.[8] Overall energy consumption is also strictly limited, with special use buildings (e.g., swimming pools, hospitals, supermarkets, etc.) permitted additional energy. The standard also includes EnerPHit, a comprehensive methodology addressing the retrofit of existing buildings.

Buildings meeting Passive House Standards, or other low energy consumption requirements, are sometimes referred to as "**very low energy buildings**" or "VLEBs." One of the widely recognized standards for VLEBs is the Swiss Minergie standard.[9]

Because of concerns about differences between predicted/calculated energy performance and actual/measured energy consumption (sometimes referred to as the "performance gap"), some groups have recently developed further definitions for "**ZE Verified**," where there has been some independent verification/validation of the actual energy performance, documenting that the expected ZE performance has been met. In some jurisdictions, there is currently work examining the potential for "outcome-based codes," where the energy code/regulation compliance is linked to the occupied building's energy performance. Beyond ZE Verified is a newer definition being considered in some jurisdictions, though not yet implemented anywhere, of "**ZE Certified**."

Common definitions

Among the most common definitions used are the following:

- US Department of Energy: 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.**" This same definition, if the word "building" is replaced in the expression an "energy-efficient building," can also be extended to a ZE portfolio, campus, district, or community. (US DOE 2015)
- European Union: Nearly Zero Energy Building (nearly ZEB): a building that "**has a very high energy performance with the nearly zero or very low amount of energy required covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.**" (EPBD 2010/31/EU).[10]

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[8] More information at www.passreg.eu

[9] https://www.kobelthaus.ch/en/extras/minergie.html

[10] In addition to this EPBD "framework definition," the Directive also delegates EU member states'

- In Japan, to support government ZEB policies, the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan (SHASE) defined ZEB as "**…a building that has high energy saving through load reduction, natural energy use and efficient appliances without decreasing the environmental quality both indoors and outdoors. With the introduction of on-site renewable energies, the on-site energy generated will be equal to or greater than the actual energy consumed within the building in the course of a year.**" (SHASE 2015)
- The World Green Building Council (WGBC) has defined a net zero carbon building as "**A highly energy-efficient building with all remaining operational energy use from renewable energy, preferably produced on site but also off-site production, to achieve net zero carbon emissions annually in operation.**" (WGBC 2017).

Overview of international ZEB definitions and parameters

While definitions in some jurisdictions are evolving, and in some cases more fluid, there are some opportunities to compare the key parameters that impact the ease or flexibility in meeting ZEB definitions. The key parameters for these definitions, and some of the boundary issues, can have a significant difference on how challenging it can be to meet the definition, and what the environmental impact of these policies will be.

A summary of the requirements in some of the key international ZEB parameters, including the metric chosen, system boundaries, and what sort of minimum requirements are specified, are shown in Table 3.

Some general findings about the range of definitions can be summarized as follows:

- The most common metric considered is primary (source) energy;[11]
- Energy efficiency is usually a core component of the definition, and a base level of energy efficiency is a common requirement;
- While European definitions nearly all include a minimum Renewable Energy (RE) component (largely because that was part of the overarching EU EPBD Directive), that is not common outside of Europe;
- Plug loads are generally not included in the European definitions, but are almost always part of US definitions; and

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authorities to develop their own specific definition for what is considered a Nearly Zero Energy Building in that country., reflecting the national, regional or local conditions, including a numerical indicator of primary energy use expressed in kWh/m^2 per year. A summary of the key requirements in IPEEC member EU country "nearly ZEB" requirements are shown in Annex 1.

[11] "Primary"/source energy includes all of the energy needed to generate, transmit and distribute the final, metered energy consumption as measured by building energy meters.

- Because the definitions mostly apply to new construction, most definitions use calculated energy performance, not actual/measured performance (with the US DOE definition a major exception).

Table 3. Key Parameters and Boundaries in Leading ZEB Definitions

Country/Region	Definition/Policy/Initiative	Metric			Plug loads included in energy consumption?	Calculated (C) vs Actual/ Measured (M) Energy Use	RE system boundary		Minimum requirements	
		Primary (Source) energy	Final (Site) energy	Carbon emissions			On-site	Off-site	EE*	RE* share
Australia	Carbon Neutral Certified Building			✓	✓	M		✓	✓	
California	ZNE	✓			✓	C	✓		✓	✓
EU	EPBD	✓				C or M	✓		✓	✓
France	EPBD Implementation	✓				C	✓	✓	✓	✓
Germany	EPBD Implementation	✓				C	✓	✓	✓	
Italy	EPBD Implementation	✓				C	✓		✓	✓
Japan	Zero Energy Building Definition	✓				C			✓	
Korea	Zero Energy Building Certification	✓				C			✓	
UK	Zero-carbon building			✓		C	✓		✓	
US	Zero Energy Building (DOE)	✓			✓	M	✓		✓	
US	Architecture 2030 ZERO CODE	✓			✓	C		✓	✓	
World	Passive House		✓		✓	C			✓	
World	World GBC Net Zero Carbon			✓	✓	C		✓		

4

Summary of Leading ZEB Policies and Initiatives

As noted earlier, there have been a growing number of ZEB policies and other initiatives established in recent years by IPEEC member countries, and other leading national and sub-national governments. A global review looking more broadly at ZEB activity around the world was conducted as part of an International Energy Agency (IEA) joint project between the Energy in Buildings and Communities Programme Annex 52, and the Solar Heating and Cooling Programme Task 40. The project[1] studied current net zero-, nearly zero- and very low-energy buildings, and how to develop a harmonized international definitions framework, tools, innovative solutions and industry guidelines.

Europe

In Europe, the recast Energy Performance of Buildings Directive (EPBD, 2010/31/EU) provides a framework definition for nearly ZEBs. The Directive's general framework for the calculation of energy performance of buildings states that nearly ZEBs are buildings that have a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby.

By the end of 2020, all new buildings in Europe must be nearly ZEBs (by the end of 2018 for buildings owned and occupied by public authorities), and member states must stimulate the transformation of existing buildings into nearly ZEBs through cost-effective renovation. The specific requirements of what constitutes a nearly ZEB must be developed by each of the EU Member States, and that set of standards must include a numerical indicator of the primary building energy use, expressed in kilowatt hours per square meter per year (kWh/m^2/y).

Furthermore, EU Member States shall draw up national plans for increasing the number of nearly ZEBs including information on the policies and financial or other measures adopted for the promotion of nearly ZEBs, and details of national requirements and measures concerning the use of energy from renewable sources in new buildings and existing buildings undergoing major renovation.

Nearly all EU Member States have already developed their nearly ZEB roadmaps. A study conducted in 2013 for the European Commission (Hermelink 2013), concluded that a very low level of energy for heating and cooling is a vital pre-condition for nearly zero primary energy buildings. In that respect, by 2021,

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[1] More information about this project is available at www.task40.iea-shc.org.

a cost-optimal, nearly ZEB could be defined as a building for which the energy need for heating and cooling is less than 30 kWh/m^2/y. In 2016, the European Commission released Commission Recommendation (EU) 2016/1318, on guidelines for the promotion of nearly ZEBs and best practices to ensure that, by 2020, all new buildings are nearly ZEBs.[2]

In October 2014, Ecofys prepared a report on the progress of member states in delivering on nearly ZEB targets by 2019 and 2021 for the European Commission.[3] The report indicated progress had been made in providing the necessary definitions and guidance, but that significant work remained. Since then nearly all EU Member States have finalized their definitions for nearly ZEB, and the required plans. In reality, as shown in Annex 1 summarizing nearly ZEB definitions in selected European countries, among the various Member States, the definitions allow energy consumption from 20 to 117 kWh/m^2/y for residential, and 25 to 110 kWh/m^2/y for non-residential buildings. As context, typical residential existing buildings in Europe have average primary energy intensity of approximately 180 to 280 kWh/m^2/y for residential, and 375 to 500 kWh/m^2/y for non-residential buildings.[4]

The European Commission's Energy department maintains a webpage with more information about the EU nearly ZEB policies, including updates on activities and links to Member State policies.[5]

EU Member States reported a wide range of policies and measures in support of the nearly ZEB objectives in their national plans. More than two thirds of the EU Member States have in place policies and measures in the categories of awareness raising and education, strengthening building regulation and energy performance certificates. Financial instruments and support measures, including incentive policies, loans with reduced interest rate, tax exemptions, energy bonuses for private individuals, grant schemes for installation of renewable energy, guidance and financing for at-risk populations and subsidised mortgage interest rates for highly energy performing houses are another focus to promote nearly ZEBs. Most of the policies and measures reported by the EU Member States also apply to public buildings.

There are interesting developments within certain EU countries. For example, France recently launched their Energy Positive/Carbon Negative (in French: "Bâtiment à Énergie Positive & Réduction Carbone",[6] or "E+C-") new building trial scheme, which includes technical specifications and subsidies of 20 million euro to support

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[2] Commission Recommendation (EU) 2016/1318, issued 29 July 2016: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016H1318&from=EN

[3] Groezinger, J. et al., 2014. Overview of Member States information on NEARLY ZEBs, Project number: BUIDE14975, Ecofys 2014 by order of: European Commission, October 2014. https://ec.europa.eu/energy/sites/ener/files/documents/nearly ZEB_full_report.pdf

[4] The European nearly ZEB definitions express allowable energy consumption in primary (source) energy, which includes losses from generation, transmission and distribution of energy carriers like electricity. The typical existing building intensity figures were derived from the 2015 IPEEC/IEA Building Energy Performance Metrics report (IEA and IPEEC 2015), converted from final energy intensities as reported in that document.

[5] https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings/nearly-zero-energy-buildings

[6] http://www.batiment-energiecarbone.fr/en/home/

the construction of 6,000 E+C- housing units.[7] Germany offers incentives for energy positive housing units as the "Efficiency House Plus" rating levels (in German: "Effizienzhaus Plus"), where guidelines provide specifications and other data about the performance level for the energy performance.[8]

In June 2018 the Energy Performance of Buildings Directive (EPBD) was revised. The revised EPBD among other ambitious amendments, creates a clear path "towards a highly energy efficient and decarbonised building stock by 2050, facilitating the cost-effective transformation of existing buildings into nearly zero-energy buildings" by requiring EU Member States to establish long-term renovation strategies to support the renovation of the national stock of residential and non-residential buildings, both public and private.[9]

North America

In the US, a variety of policy initiatives have been driving national ZEB activity. In 2007, the US Congress passed the Energy Independence and Security Act which requires that beginning in 2030, designs for new buildings or major renovations of Federal government buildings must be fossil fuel free, and essentially zero net energy. A number of Federal Executive Orders followed that provide more specific details about the requirements.

To define more clearly what is considered a zero energy building, in 2015 the United States Department of Energy (US DOE) issued a document "A Common Definition for Zero Energy Buildings,"[10] to establish a national definition to avoid the confusion entailed by the variety of interpretations of ZEBs.

As part of a new Canadian "Pan-Canadian Framework on Clean Growth and Climate Change," issued in December 2017, "Federal, provincial, and territorial governments will work to develop and adopt increasingly stringent model building codes, starting in 2020, with the goal that provinces and territories adopt a "net-zero energy ready" model building code by 2030. These building codes will take regional differences into account."[11]

Asia/Pacific

Japan, as part of their hosting of the G8 Summit in Hokkaido in 2008, facilitated adoption by the G8 of a variety of building energy efficiency policies, including "Passive Energy Houses and Zero Energy Buildings." Since then, the Ministry of Economy, Trade and Industry has also created guidelines and standards for net ZEBs.[12] The

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7. http://www.batiment-energiecarbone.fr/informer/faq/

8. https://www.forschungsinitiative.de/effizienzhaus-plus/

9. http://europa.eu/rapid/press-release_IP-18-3374_en.htm?pk_campaign=ENERNewsletter-May2018

10. US DOE 2015. A Common Definition for Zero Energy Buildings, September 2015: https://www.energy.gov/eere/buildings/downloads/common-definition-zero-energy-buildings

11. https://www.canada.ca/en/services/environment/weather/climatechange/pan-canadian-framework/complementary-actions-reduce-emissions.html#3_2

12. http://www.meti.go.jp/english/press/2015/1217_01.html

Japanese government has also committed up to 4 billion Japanese yen for financial subsidies for ZEBs (APEC 2014).

In 2016, the Korean government established a national goal of greenhouse gas reduction through the creation of a new market by adopting ZEBs. To support this, both the Ministry of Land, Infrastructure, and Transport, and the Ministry of Trade, Industry and Energy, in January 2017 established the ZEB Certification System which allows for market tracking and progress, as well as a variety of market development activities.[13]

The Australian Government in 2017 developed the voluntary "National Carbon Offset Standard for Buildings," which provides best-practice guidance on managing emissions and allows for buildings to be certified as carbon neutral through either the NABERS Energy or the Green Star Performance rating schemes.[14]

A group of countries have also been participating in recent years in an ongoing coordinated Asia-Pacific Economic Cooperation (APEC) Energy Working Group project on "Nearly (Net) Zero-Energy Buildings," led by the China Academy of Building Research as Secretariat but with significant input from—and review of the state of activity in—the United States, Japan and Korea. The project reports describe in more detail how policies in Japan, Korea and the United States have set up clear and aggressive goals for nearly ZEBs, and Japan and Korea have established financial and taxation policies to stimulate development. The findings also highlighted current obstacles and barriers to wider market penetration of nearly ZEBs.

Sub-national

There is also substantial activity happening at the state/provincial and local level. In the US, some states have led the way with more ambitious state level policies and targets.

In 2007, California adopted the goal that all new residential construction would be zero net energy by 2020 and all new commercial construction would be zero net energy by 2030. In 2008, the state's Public Utilities Commission adopted a Long-Term Energy Efficiency Strategic Plan, which reiterated this commitment. By 2015, the state launched its Zero Net Energy Action Plan to ensure that all new homes will be net zero energy by 2020.

In July 2016, the province of Ontario, Canada revised its five-year Climate Change Action Plan and included specific plans for net zero carbon homes, including rebates to individuals who purchase or build net zero homes.[15]

Cities are also taking a lead in implementing strategies to significantly reduce emissions within their jurisdictions. For example, the City of Vancouver, Canada will require all buildings constructed from 2020 onwards to be carbon neutral in operations.[16] Similarly, Melbourne, Australia, has committed to being a carbon neutral city

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[13] http://www.energy.or.kr/web/kem_home_new/energy_issue/mail_vol22/pdf/publish_05_201507.pdf

[14] http://www.environment.gov.au/climate-change/government/carbon-neutral/ncos/buildings

[15] Ontario, 'Climate Change Action Plan' https://www.ontario.ca/page/climate-change-action-plan#section-5

[16] http://vancouver.ca/green-vancouver/green-buildings.aspx

by 2020.[17] As of October 1, 2016, the Greater London Authority, United Kingdom, requires all new residential development to achieve a "zero carbon standard," though based on modelled data and not including plug loads. Housing Supplementary Planning Guidance explains that this standard must be achieved first through a 35% reduction in regulated carbon dioxide emissions, beyond Part L of Building Regulations. The remaining regulated carbon dioxide emissions are "to be off-set through a cash in lieu contribution to the relevant borough to be ring fenced to secure delivery of carbon dioxide savings elsewhere."[18] Additionally, a large number of US cities have recently committed to ZEB targets.[19]

The timeline, and some unique characteristics, of some of the more advanced ZEB policies are summarized in Table 4.

Table 4. Summary of Leading ZEB Dates and Characteristics

Country/ Region	Responsible Agency/ Organization	Year Initiated	Date for ZEB Target		Unique Characteristics
			New Public Buildings	All New Buildings	
EU EPBD	European Commission, Individual Member States	2010	2019	2021	Set EU wide framework definition for nearly ZEB, but delegates full definition and implementation to individual EU Member States
California	California Energy Commission, Public Utilities Commission	2007		2020 for residential buildings, 2030 for commercial	Initial goals for full ZNE compliance by these dates, and have scaled back specific requirements to phase in major market shift
Japan	METI	2014	2020	2030	Includes very significant funding for pilot projects

Large scale ZEB initiatives from leading NGOs

A variety of non-governmental organizations (NGOs) have been actively promoting and advocating for ZEBs for the past decade or more. Some of the largest scale initiatives are described in this section.

The World Green Building Council (WorldGBC)

The World Green Building Council (WorldGBC) has a mission to expand the deployment of green buildings to help combat climate change, as well as achieve numerous other wider social, economic, environmental and health benefits. In 2017

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[17] http://www.melbourne.vic.gov.au/about-council/vision-goals/eco-city/Pages/zero-net-emissions-strategy.aspx

[18] Greater London Authority, 'Energy Planning—GLA Guidance on preparing energy assessments' https://www.london.gov.uk/what-we-do/planning/planning-applications-and-decisions/pre-planning-application-meeting-service-0

[19] https://zeroenergyproject.org/advocate/cities-on-a-path-to-zero/


Fraunhofer ISE

Seoul Energy Dream Center, Sangam-dong, Seoul, Republic of Korea

the WorldGBC introduced their net zero vision of a world in which the ambitions set out by the Paris Agreement are achieved and every building emits no carbon emissions as it operates.

Beyond the WorldGBC, there are many affiliated national Green Building Councils (GBCs) in different parts of the world. As noted earlier, some of these are working closely with governments to stimulate ZEB policies and activities. Some of the most active in the Zero Carbon Building space are the GBCs in France, Canada, Brazil, Australia, and South Africa.[20]

Architecture 2030

Architecture 2030 is a U.S.-based think tank dedicated to transforming the global building sector to zero carbon by 2050. It has set a path for all new buildings to be designed Zero Net Carbon by 2030. Currently it supports cities in reaching their carbon reduction commitments by collaborating with relevant government and private sector stakeholders. It has pioneered carbon emissions reductions in the building sector and collaborated with both Chinese and international design and planning communities to drive the current shift to ZNC in the built environment.

International Living Future Institute (ILFI)

The ILFI is an international nonprofit focused on creating a healthier world without fossil fuels. Through its core Living Building Challenge program, the organization has been certifying zero energy performance for over a decade. The ILFI also has

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[20] http://www.worldgbc.org/news-media/new-worldgbc-snapshots-detail-net-zero-carbon-standards-developed-green-building-councils

standalone Zero Energy Building and Zero Energy Community Certifications, as well as a building energy performance label, "Reveal." In addition, ILFI also provides industry education, conferences, targeted advocacy, and consulting.

C40 Cities Climate Leadership Group (C40)

C40 connects over 90 of the world's greatest cities, representing 600 million people and one quarter of the global economy, with the aim of progressing urgent climate action. Reducing emissions from energy and buildings is a vital part of C40's work, consisting of several city networks and a technical assistance program covering building codes and standards, reporting building energy performance data, energy efficiency/retrofit measures, and clean energy generation. C40 also runs the "Climate Positive Development Program" supporting the creation of large-scale urban communities that seek to meet a "climate positive" target of net-negative operational greenhouse gas emissions. The program is currently working with 19 projects globally. Once completed, buildings in those communities will be carbon positive and will impact nearly one million people. Over 40 C40 member cities have developed climate action plans with firm carbon targets, and to date over 2,000 buildings sector climate actions have been reported by over 60 C40 cities.

New Buildings Institute

The New Buildings Institute (NBI) is a non-profit organization that drives better energy performance in buildings by working collaboratively to promote advanced design practices, innovative technologies, public policies and programs that improve energy efficiency. NBI's work is grounded in the study of leading edge practices and technology applications and translating them into innovative and practical solutions for the energy efficiency and commercial building industries. NBI has been supporting the zero-energy market for a decade with policy development, early adopter networking, training and education, and the tracking of growth and trends for the zero energy buildings market. NBI has developed a number of relevant resources, guidelines, case studies, on demand webinars, and hosts a regular "Getting to Zero" National Forum that gathers leading policy makers and ZEB practitioners to exchange lessons learned and network.

Net Zero Energy Coalition

Comprised of like-minded stakeholders, the Net Zero Energy Coalition's (NZEC's) mission is to accelerate the market adoption of zero energy and zero carbon buildings and communities across North America. The Coalition is dedicated to supporting the ZE community in tackling these major tasks through collaborative projects, including an annual inventory of ZE residential buildings in the North America.

5

Lessons Learned to Date in Policy Implementation

It is somewhat challenging to understand lessons learned, in that most policies and targets for widescale ZEB adoption are just now taking effect, and much more will be known about their impacts and issues confronted in a few years, after they have been in implementation for several years. Despite that, there are some findings that can be gleaned from the experience to date.

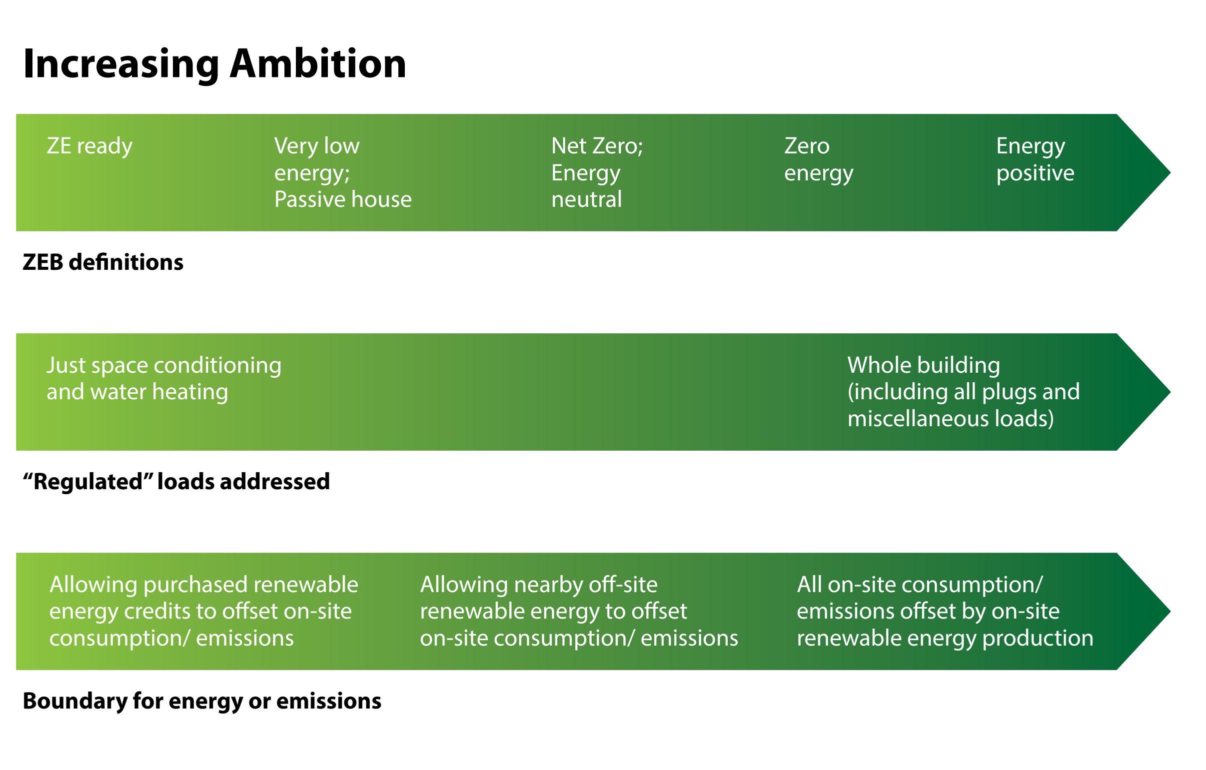
Achieving ZEBs not including plug and process loads is technically quite easily attainable in low-rise construction, especially in climate zones where the annual heating and cooling loads are relatively moderate, and where the biggest loads are plug loads (often referred to in many energy data tracking and forecasting systems as "miscellaneous loads").

Achieving levels of efficiency to bring energy consumption down to where it can be offset by on-site renewable energy supply (most often PV) energy production is not overly complex and can have reasonably attractive life-cycle cost economics in the right circumstances. The use of on-site renewable energy systems to reduce the demand of a building should be encouraged, but this should always be in conjunction with seeking energy savings from the building envelope and its technical building systems. In the regions with the most active policies, such as California, France and Germany, when combined with financial incentives to help transform markets, there is much progress.

However, in buildings over four to six floors in height, and in buildings with substantial plug and process loads (if they are included in the ZEB definition), it is much harder to get enough on-site generation to cover all of the energy use in even a high performing, very efficient low energy building. This is particularly true in dense urban environments where there is very little open area or parking structures where additional PV generation can be added beyond what is integrated into the building design. While there are a relatively small number of demonstration projects that have shown ZEB technical feasibility with large, high(er) rise buildings, much more work is needed to show how ZEB can be technically and economically feasible in taller structures without importing renewable energy from neighboring buildings.

The jurisdictions with the most success seem to result from a mix of ambitious regional (e.g., EU scale), or national/state/provincial policy leadership combined with grassroots local policy activity supported by ZEB and environmental advocates as well as industry leaders. This leads to a virtuous circle of ZE policy where the interaction of leading policies can drive continuous increases in ambition. A mix of policy instruments should be carefully designed to provide the required long-term stability to investors in high performing buildings, including deep and nearly ZEB renovations.

Figure 2. Range of Ambition from Different Definitions, Regulated Loads Included/Addressed, and Boundaries



Definitions that appear quite similar can have very different impacts

On the surface, definitions that seem to be based on "ZEB" or some relatively small variations on that term appear to be quite similar. However, there are a variety of key issues with the different definitions, such as the energy uses in a building that are regulated (or not) through the definition or policy, whether all fuels are included in the definition, whether off site energy production is allowed to offset some or all of the on-site energy consumption, and whether the definition is based on energy or carbon/emissions. These differences have major impacts on the relative stringency of an initiative and the resulting policy outcomes. The range of ambition among these differences is shown in Figure 2.

Similarly, on the surface, whether a building is "zero energy" or "zero carbon" seems like they should be nearly equivalent, but there are very different specific issues between the two metrics. Time dependency of the energy use and production becomes more significant when measuring carbon, and the need for storage to minimize higher carbon generating sources can be critical. A true zero carbon buildings policy will require near elimination of any fossil fuel consumption in the building, a major shift from current practice, particularly in regions with substantial space heating loads, where fossil fuel-based heating systems are generally a lower operating cost alternative. Having zero carbon as the metric will likely cause different design and construction choices than might be the case for net or nearly zero energy.

Determining the boundary for offsite renewable generation, and whether renewable credits can be purchased to offset on-site energy use, are also key issues for both zero energy or carbon.

Issues and barriers identified through early implementation

Measuring progress toward the ambitious ZEB goals is difficult when these goals have somewhat soft or evolving definitions, and the construction markets are changing rapidly to much lower energy consumption construction and standards in the past decade. Measuring progress and barriers to full uptake or compliance with targets is challenging.

There is widespread movement to much lower energy consumption residential buildings, though most of the tangible program activity has been in the "near zero" or "zero ready" buildings as opposed to true ZEBs. For example, the recently published 2017 Zero Energy Residential Buildings Study[1] prepared by the Net Zero Energy Coalition found that in the US and Canada, the number of identified ZEBs grew from 3,339 buildings containing 6,177 housing units in 2015 to 6,059 buildings containing 13,906 housing units in 2017—a dramatic growth rate of over 80% for the number of buildings, and over 120% for the number of housing units. However, this was still a tiny fraction of the 1.47 million "housing starts" as reported by government statistics. Additionally, of the residential housing units identified for 2017, nearly 74% of the units were "ZE ready," compared with 22% considered ZE, and 4% net energy producers.

When looking just at the leading jurisdictions where ZEB policies are most robust, the statistics are more favorable. As an example, in California, which had 5,279 ZE housing units constructed in 2017 according to the Net Zero Energy Coalition (about 38% of the North American total), that number was nearly 5% of the 111,800 total housing starts in California in 2017.

In Europe, the European Commission funded ZEBRA2020 Project[2] was established to monitor the market uptake of nearly ZEBs across Europe and provide data and knowledge on how to reach the nearly ZEB standard. Information was collected from 2014 through 2016, and was structured and analyzed to derive recommendations. ZEBRA2020 covers 17 European countries and almost 90% of the EU/European Economic Area building stock and population.

The project included a number of online data tools intended to provide unique information regarding nearly ZEB market development and nearly ZEB characteristics. New approaches were developed in order to allow for a better comparability of national data. However, the absence or difficult access to key data (in particular

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[1] NZEC 2017 Zero Energy Residential Buildings Study: http://netzeroenergycoalition.com/zero-energy-inventory/

[2] http://zebra2020.eu/

for non-residential and existing buildings as well as for renovations) remains an important obstacle.

The project's online nearly ZEB tracker, based on a set of criteria, assesses the nearly ZEB market maturity. At the EU-level, the tracker shows a substantial gap of market maturity that still has to be closed by 2019/2021. A set of barriers and related recommendations were identified both at the national and EU level:

- *"The implementation of a common, shared long-term vision for the building stock is crucial.*
- *A quantitative comparison of national nearly ZEB definitions is complex due to different system boundaries, calculation methodologies, applied factors etc. However, our analysis indicates that a significant share of nearly ZEB definitions does not meet the intention of the EU directive on energy efficient buildings (EPBD) that the energy consumption should be "nearly zero or very low amount" and the remaining part "should be covered to a very significant extent by energy from renewable sources." Thus, the new EPBD requires clear definitions of these terms and thresholds. Further, it is important to distinguish between new buildings and renovations—despite a common nearly ZEB definition for both cases.*
- *The nearly ZEB compliance monitoring and sanctions regimes need improvement. Only about half of the covered Member States monitor the compliance of new buildings with energy performance requirements.*
- *In many Member States, the reliability and credibility of Energy Performance Certificates (EPC) is often questioned by actors on the real estate market. Transforming EPCs into Building Certificates ("Passes") for the whole lifetime of a building may increase credibility and serve as a key measure to foster building renovation towards an nearly ZEB standard. Storage of building data in an electronically accessible national database may contribute to better data availability."* (ZEBRA 2020 2016)

As a practical matter, some jurisdictions have made allowances to phase in ZEB standards over a longer period than initially expected. As an example, the US State of California, which had the stated goal of all new residential construction to be ZNE by 2020, recognized some serious electric grid integration issues (as well as cost-effectiveness challenges based on the underlying energy code statutory language) with pushing full ZNE requirements into the California energy code (known as "Title 24") by 2020. As a result, they have excluded the energy used for space heating, domestic hot water, and cooking in a mixed fuel home from what must be offset by on-site renewable power. All other end-uses must be zero net energy, but the full ZNE requirements in the code have been postponed to future code upgrade cycles. In May 2018, the California Energy Commission adopted a new building standard requiring solar systems to be installed on all new homes in the state, the first such requirement in the US.[3]

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[3] http://www.energy.ca.gov/releases/2018_releases/2018-05-09_building_standards_adopted_nr.html


Taisei Corporation

Taisei ZEB Demonstration Building, Yokohama, Japan

As the traditional heating, cooling and water heating loads are reduced in ZEBs, the plug and miscellaneous loads become a much larger portion of overall energy consumption, sometimes representing as much as 50% of total on-site energy use.[4] This demonstrates the importance of understanding what energy loads are included as part of ZEB definitions—in most cases the European nearly ZEB definitions exclude plug loads, which can become the majority of energy use when space conditioning loads are minimized in high performing buildings. With the percentage of building energy consumption growing from lighting and plug loads, complementary policies such as regularly updating minimum energy performance standards can help minimize these loads.

There will need to be further examination of the "boundaries" for building consumption as there will likely be growing energy consumption from electric vehicles and other advanced electric plug-loads. Electric vehicle charging equipment (charge-points) within both residential and non-residential buildings are projected to grow dramatically in the coming decades in response to a variety of government clean transport policies.[5]

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4. See for example Impacts of Office Plug Load Reduction Strategies, October 2016, https://www.cards.commerce.state.mn.us/CARDS/security/search.do?method=showPoup&documentId=%7b5A402E71-6933-4A8A-BFC4-D9BE445B4FD7%7d&documentTitle=358673&documentType=6

5. See for example the UK Office of Low Emission Vehicles "Road to Zero Strategy" that includes consideration of "introducing a requirement for chargepoint infrastructure for new dwellings in England, where appropriate"; pp 14–15 in "The Road to Zero, " https://www.gov.uk/government/publications/reducing-emissions-from-road-transport-road-to-zero-strategy

With this much usage from plug loads, behavioral issues and diligence become much more important—reducing the hours that these loads are operating is critical to keep energy use low enough to be offset by the on-site renewable energy. The human element of building occupant and operator controls and regular decisions is much more important in ZEBs than in a typical building, as is the efficiency of plug load appliances and equipment added to the building's load.

The construction and real estate markets are traditionally very conservative industries that change slowly, and the audacious targets seem to make the most progress when broad goals can be supported by financial incentives to move markets at a quicker pace. An example of a country where financial incentives have been very successful in moving toward ZEB (or more specifically nearly ZEB and ZNE) progress is Germany, where very low energy buildings will receive significant subsidies through the KfW Development Bank if they demonstrate that they achieve the German nearly ZEB levels, or even greater incentives if they demonstrate that they achieve the established "Effizienzhaus," or "Efficiency House Plus," levels.

Similarly, in California, very substantial incentives from utility funding programs have supported both individual building design and construction, and a wide variety of market development activities.[6] In Oregon, the Energy Trust of Oregon runs the Path to Net Zero, which is a comprehensive incentive program for ZEB.[7]

Risks, opportunities, and non-energy benefits of ZEB

While performance simulations may show potential for ZE energy use, in practice, actual building operation may result in higher energy consumption than expected, or lower than expected renewable energy generation. This issue was identified in the ZEBRA 2020 project where the reliability and credibility of Energy Performance Certificates, based on energy performance simulation instead of measured performance, is often questioned by actors on the real estate market.

Careful monitoring of the performance to validate the ZE measurement is critical to avoid the "performance gap" between calculated/estimated and actual performance as noted above. It was found, for example, with the large US National Renewable Energy Laboratory's ZE Research Support Facility (RSF) that there was a need for strong vigilance in monitoring plug loads throughout the building, and operational details are critically important.

The proliferation of low energy buildings combined with on-site generation leads to new and complex demands on the local electric grid. There is often a mismatch of too much energy generation in a relatively small number of hours in a day feeding into the electric grid, often not coincident with the highest energy demand in the building. This is leading to load shifting challenges, with significant solar PV generation capacity (both from on-site ZEBs as well as utility scale PV) feeding into the grid at times when it may not be needed in the local/regional electrical

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[6] More information about subsidy programs and market progress in California can be found at https://www.capath2zne.org and http://www.cpuc.ca.gov/ZNE/

[7] https://www.energytrust.org/commercial/new-buildings-path-to-net-zero/

distribution network. "Net metering" policies, where on-site generation is netted out over the course of a month (or other billing period), are intended to make it more cost-effective for encouraging on-site PV generation, but in some cases are forcing excess power into the grid, at times causing other renewable energy to be scaled back.

The most research on this is happening in California, where the Public Utilities Commission (PUC) has been leading studies on grid integration costs, which can be quite significant.[8] Time dependent value (TDV) pricing, where savings or generation is valued differently depending on when they occur, to reflect the actual costs of energy to consumer, utilities and society, can help address this situation.

Recent modeling in California, where ZNE new neighborhoods are being developed by leading builders, which shows that the differences in load shapes and peak demand from individual buildings or neighborhoods can be quite dramatic. Figure 3 shows the modeled impacts on daily load shapes and kW peak for a residence meeting ZNE codes compared with older California energy code requirements.

Similar issues have been identified in the Australian state of South Australia which, as of 2016, had over 90% of the state's electricity generation coming from variable renewable sources (with 38% of wind power and 17.8% from rooftop solar).[9] Significant attention needs to be paid to grid balancing and security issues as the penetrations of renewables grows with on-site generation interacting with the grid.

As part of the drive to deepen carbon reductions, many jurisdictions are starting to consider policies that limit or prevent fossil fuel consumption in buildings, favoring electricity usage over traditional heating fuels with the cleaning or decarbonization of electricity grids and production. This can have the effect of reduced emissions, though there will be substantial grid strengthening and improvement costs that are just now beginning to be quantified and may increase the prices for purchased electricity as these costs are integrated into electric rates and pricing. However, with the significant energy savings from ultra-efficient and ZEBs the effect on rate payers may be low or even negligible.

While there are some added costs to achieve ZEB status, these extra costs can be added to building loans, and with reduced energy costs, in many cases result in a lower overall cost of ownership.

ZEBs have the potential to provide great resilience benefits, especially if solar PV systems are combined with batteries and enabled to operate independently of the grid, with the ability to operate when the power grid or other energy infrastructure may be down or compromised due to natural disasters or other reasons. This resiliency benefit has been difficult to quantify to date but has the potential for great added value.

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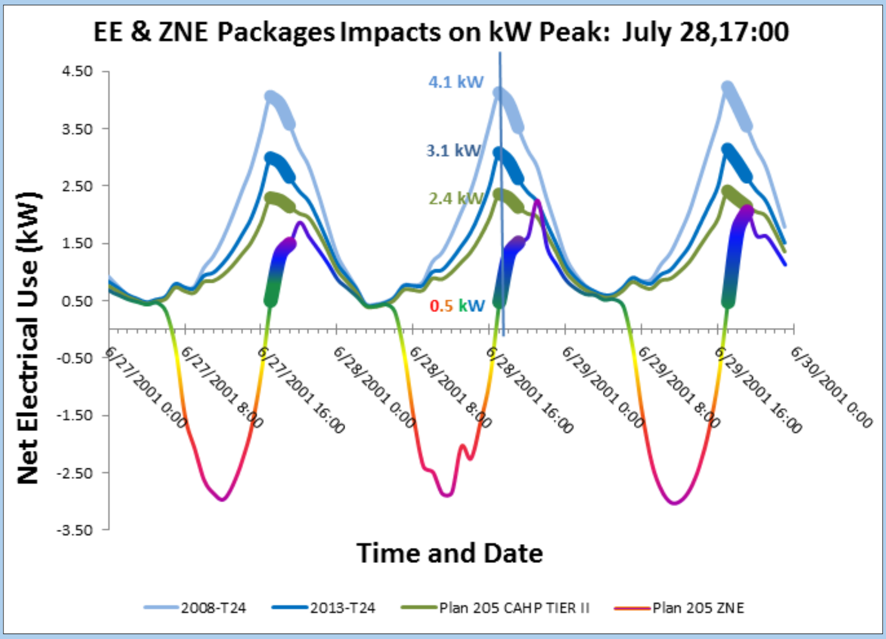
8. See more information at: http://www.cpuc.ca.gov/ZNE/

9. International Energy Agency "Energy Policies of IEA Countries: Australia 2018 Review": http://www.iea.org/publications/freepublications/publication/EnergyPoliciesofIEACountriesAustralia2018Review.pdf

Figure 3. Modeled Impact of Level of Efficiency on Load Shapes



Key: **T24**=Title 24, the California Energy Code; **Plan 205** represents different potential new ZNE codes. From Narayanamurthy 2016. Grid Integration of Zero Net Energy Communities.

Some ZEB advocates also highlight the potential for improved indoor air quality, increases in occupant comfort, and a variety of other benefits to ZEB owners and occupants. Evaluation over time will provide more confirmation of these potential benefits.

Tracking progress

A variety of tools have been established in recent years for the purpose of tracking ZEB market progress. Several of the most significant of these tools are highlighted below.

As part of ZEBRA 2020, a set of criteria was developed to measure the status of the market maturity for nearly ZEBs in the European Union. The nearly ZEB tracker[10] focuses on dynamic market aspects and uses data derived during the project and from national sources to create nearly ZEB-tracking graphs for each country and the EU as a whole.

A broader set of data on energy performance and characteristics of European buildings is contained in the European Commission funded EU Building Stock Observatory[11]. The Observatory, among others, includes data on the energy consumption limits for residential and non-residential buildings as contained in the specific nearly ZEB definitions for each country, and the number of nearly ZEB buildings constructed each year. The objective of the EU Building Stock Observatory is to monitor the improvement of the energy performance of buildings across Europe through:

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[10] http://zebra2020.ecofys.com

[11] EU Buildings Database: https://ec.europa.eu/energy/en/eu-buildings-database

- A methodological framework for the monitoring of Europe's building stock in the context of building energy efficiency policies; including a set of quantitative indicators and a methodology for data collection and verification;
- A snapshot of the current status of the European building stock energy performance, based on the results of a data collection exercise across EU Member States; and,
- A publicly available portal integrated in DG Energy's website which contains a database, a data-mapper and factsheets.

Some EU Member States have also developed their own databases of nearly ZEBs or other low energy buildings (in many cases these EU Member State databases contribute to the wider EU Buildings Stock Observatory for the information on nearly ZEB progress). One of the more comprehensive datasets has been developed and regularly updated in Germany by the Deutsche Energie-Agentur ("dena"): the "Effizienzhaus database,"[12] which provides specific data about the energy performance of buildings in the database.

In addition, the Passive House Institute maintains a fairly comprehensive database of Passive House Certified buildings.[13]

The New Buildings Institute (NBI) developed and maintains a Getting to Zero Building Tracker which represents the most comprehensive data set of ZE verified, emerging and ultra-low energy buildings in the United States and Canada. Information about verified ZE buildings as well as ultra-low energy buildings can be found in the "Getting to Zero Database,"[14] based on a platform developed the US Department of Energy. NBI collects projects through a ZE buildings registry. Information from these projects is validated and documented by NBI staff who reviews the project information and determines a status. If the project is verified zero net energy or ultra-low energy, it is included on their annual Getting to Zero Buildings List and the Getting to Zero Buildings Database. Verified projects are also considered for case studies. Emerging projects are included on the Getting to Zero Buildings List only. Once verified, current emerging projects can move to the Buildings Database.

As noted earlier, the Net Zero Energy Coalition conducts an annual inventory of ZE residential buildings in the US.[15] This inventory, all on residential housing units instead of the focus of the NBI Getting to Zero tracking that aims to track larger, mostly non-residential buildings, is tracking market activity by North American state/provincial level, and also tracks projects by builder/developer and highlights the clear leadership from a relatively small number of residential builders that are doing a large portion of the ZNE projects.

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[12] https://effizienzhaus.zukunft-haus.info/effizienzhaeuser/informationen-effizienzhaus-datenbank/

[13] https://passivhausprojekte.de/index.php?lang=en and http://www.phius.org/phius-certification-for-buildings-products/certified-projects-database

[14] https://newbuildings.org/resource/getting-to-zero-database/

[15] NZEC Inventory Studies: http://netzeroenergycoalition.com/zero-energy-inventory/

As part of the IEA Solar Heating & Cooling Annex 40 project noted earlier, a global project map of "NZE Buildings Worldwide" was created. Since that project was completed in late 2013, the project map has not been updated, but an archived version of the map still provides a very interesting snapshot of the progress toward reported NZE Buildings as of December 2013.[16]

As the number of ZEBs around the world continues to grow, there will likely be additional tracking and database initiatives to document and demonstrate the concept and feasibility. Access to such data is very helpful in showing strong market progress.

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[16] https://batchgeo.com/map/net-zero-energy-buildings

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Conclusions, Areas for Further Study

There are a variety of different definitions for ZEBs around the world (and even within some regions/countries) that make it challenging to understand what is really being characterized as a ZEB, and the resulting progress toward dramatically reducing building energy consumption. There seems to be some harmonization happening as a few major economies, like the US, have developed standard definitions, though there seems to be a divide about whether "zero energy" or "zero carbon" is the better metric. Among advocacy groups there seems to be some consensus emerging that ZEBs are a means of making progress towards zero carbon homes and communities, though the majority of government policies have aimed toward ZEBs, and generally not yet focused on zero carbon buildings.

Definitions that appear quite similar can actually have very different impacts, and policy ramifications. There are a variety of key issues among the definitions, including which energy uses are regulated, the boundaries of energy consumption and production, and whether off-site renewable energy purchases can be counted; the choices among these issues can be quite significant.

Many ZEB policies begin with a quite ambitious target several years away, to allow time for capacity building and experience in understanding what is needed to get the major energy reductions. In most of the early cases where these targets had been set for 2020 or earlier, it is not clear whether the established goals will be met (most experts are very skeptical about all new buildings meeting established goals) but having aspirational targets has made a very significant difference in accelerating the penetration of ZE or very low energy buildings, relative to other regions or jurisdictions without such ambitious policies. Having these targets in place has proved to set a 'future-proof' vision for the sector and mobilize stakeholders accordingly.

Concerns have been raised about a performance gap, where buildings are designed to be ZEB, but in actual operation, consume significantly more than had been predicted. The performance gap issue is not unique to ZEBs, but needs careful attention to ensure that the ZEB expectations are met.

Definitions will continue to evolve, and realistic comparisons of progress between different regions will be challenging. Perhaps there is a role for IPEEC, IEA, or the Global Alliance on Buildings and Construction, or an industry association or regional group, to help align these definitions.

The policies and incentives supporting ZEBs matter. Most of the growth and progress have been seen in areas where there is strong supranational, national, state/provincial or local support, including access to financing; understanding how the progress continues in these leading areas will be important in the coming years.

China Academy of Building Research

China Academy of Building Research Nearly Zero Energy Building, Beijing, China

ZEB targets for tall buildings in dense urban settings continues to be a challenge—realistically, are there physical limits to true ZEBs? Is there actually a physical solution or is ZEB just not suited to this segment? Part of the answer to this question is where the boundaries are established: it may be impossible for individual building to reach ZEB targets, but when part of a larger low energy/carbon community, taller buildings might be able to access renewable energy from other net positive buildings in a community/region.

There seems to an emerging trend to use zero carbon instead of zero energy as the metric, and as noted earlier, there can be subtle issues between the two metrics that are significant. As zero carbon grows in uptake, additional research and quantitative analysis will be required to understand the differing impacts of the two standards, interactions between energy and carbon as the metric, and how existing policies may need to be adjusted.

In the coming years, it will be important to prove the ZEB concept after large numbers of buildings have been occupied for a period of time—and to communicate that effectively to industry associations, governments and the public—to enable future growth and progress.

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Annex: National Nearly Zero Energy Buildings (Nearly ZEB) Definitions in Select European Countries

Country	Year of Enforcement		Maximum primary energy for new buildings (kWh/m^2y)		nZE Limits Placed On	Renewable energy requirements	Detailed Definition Source
	Public	Non-public	Res.	Non-Res.			
Austria	1/2019	1/2021	160	170	Heat demand, total energy efficiency factor, final energy, CO_2 emissions	Min. share of final energy dependent on implemented RES technology	EPBD text in OIB 6 of 03/2015; detailed def. In national plan of 03/2014
Denmark	1/2019	1/2021	20	25	Primary energy (20 kWh/m^2 for dwellings, 25 kWh/m^2 for other buildings)	Indirect, examples of solar panel sizes to cover deficiencies	Included in BR10, currently voluntary, to be adjusted
France	10/2011	1/2013	40-65	70; 110 if has air-con	Energy for heating, refrigeration, domestic hot water, lighting and ancillary system elements	Direct, 5-12 kWh/m^2-yr for single- and multi-family houses	Included in RT 2012
Germany	1/2019	1/2021	40% PE		Probably to be mean U-value of the building envelope and primary energy	Direct requirements included in current minimum energy performance requirements	EPBD text implemented in energy saving act, detailed definition is being developed
Ireland	1/2019	1/2021	45	50-60% improvement	Primary energy/ carbon performance coefficient	Direct, RES contribution of 10 kWh/m^2-yr (thermal) or 4 kWh/m^2-yr (electrical)	Draft in national nearly ZEB plan
Italy	1/2019	1/2021	Class A1		Primary energy for heating and cooling; total primary energy	Planned for nearly ZEB is 50% of primary energy (requirements in current MEPS)	EBPD text in Decree Law no. 63/90 of 2013
Romania			93-117	50-102	Primary energy, CO_2 emissions	Direct, at least 10% of primary energy	Included in updated national plan of July 2014
UK (England)	1/2018	1/2019	~44	Not set	Final energy demand, CO_2 emissions	Indirect	National plan, no nearly ZEB definition but target of zero carbon for new buildings through incremental changes to building regulations

Primary sources (which include more specific details): Nearly Zero Energy Building Definitions Across Europe, BPIE 2015; Erhorn & Erhorn-Kluttig, Nearly Zero-Energy Buildings: overview and outcomes, EPBD Concerted Action, August 2015; and European Commission JRC Synthesis Report on the National Plans for Nearly Zero Energy Buildings, 2016.

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