Chapter 10
Zero Energy Homes

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Abstract In the last 50 years a fifth of the planet's inhabitants had a strong development that deeply changed their habits and their life quality. For this enhancement, the people of the developed areas paid a high price. A large use of energy, produced from non-renewable sources as fossil fuels, increased the carbon dioxide (CO_2) emissions into the atmosphere with several problems and a huge impact on the nature. As a consequence, there is a need to rethink the design of buildings, cities and their organizations. The challenge for the new sustainable cities is to grow according to the lifestyles of today and tomorrow, while implementing a better relation between the nature and the mankind and restoring the lost human contacts. An option for doing this is to design and develop Zero Energy Homes (ZEH) reducing to the minimum the impact of pollution and the exploitation of non-renewable sources. In particular, the following aspects should be considered: to use of renewable and recycled materials; to improve the energy efficiency of buildings; to introduce more efficient energy systems that use alternative and clean sources; and to introduce building automation systems

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(to optimize the energy consumption). In this lecture the following topics will be presented: definition of ZEH, including a review of definitions, parameters influencing the definition and examples, criteria to build or refurbish to a ZEH standard and some questions and examples related with the design, construction and operation of new Zero Carbon Homes.

10.1 Definition of the ZEH

10.1.1 Introduction—Holistic Approach and Definitions Review

Zero-energy buildings have gained more attention since the publication in 2010 by the European Union Council of the Energy Performance Building Directive (EPBD) recast (EPBD 2010). According to Directive, by 31 December 2020, all new buildings should meet higher levels of performance than before by exploring more the alternative energy supply systems available locally on a cost-efficiency basis and without compromising the comfort in order to ensure that they are nearly zero-energy buildings. A “nearly zero-energy building” refers to a high energy performance building of which annual primary energy consumption is covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby. Since the Directive does not specify minimum or maximum harmonized requirements as well as details of energy performance calculation framework, it is up to the Member States to define the exact meaning of “high energy performance” and “amount of energy from renewable sources” according to their own local conditions and strategic interests. Although the European Directive refers to “nearly” zero-energy building, the terminology used for this building performance can also be referred as “Zero-Energy Buildings”, “Net Zero-Energy Buildings”, “NZEB”, “NetZEB”, “nZEB”.

Zero-Energy Buildings have been the object of various studies in the recent years as various countries have set this performance as a long-term goal of their energy policies (Torcellini et al. 2006; Ayoub 2009; Aelenei et al. 2011; Sartori et al. 2012; Marszal et al. 2011).

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Zero energy housing falls into two categories: self-sustainable or net (Noguchi 2008). The former type is a standalone house whose operational energy relies solely on its own power generation and storage so that it is disconnected from a commercial grid or disuses the power from the outside sources. The latter is the one whose energy 'use' becomes net zero over a fixed period of time. In addition, a house whose energy 'bill' becomes net zero under the same conditions is termed net zero-energy-cost housing. The notion of zero carbon housing today is from time to time likened to that of the above-mentioned homes; perchance, the performance may entail the further steps to cover CO_2 emissions that derive from not only the operation but also the construction and demolition—i.e. over the house's full life cycle.

Regarding Net Zero Energy Buildings (NZEB) performance, four main types of NZEBs can be identified: Net Zero Site Energy, Net Zero Source Energy, Net Zero Energy Cost and Net Zero Energy Emissions (Marszal et al. 2011; Aelenei et al. 2013). Net Zero Site Energy means that the annual balance is based on the grid interaction at the boundary of the building site, i.e. the overall energy delivered to the building from the utility grid has to be offset by the overall energy feed into the grid. In the Net Zero Source Energy definition, which is the one that matches the currently used by EPBD recast in a nearly zero-energy context (EPBD 2010), the energy (delivered from and feed into the grid) has to take into account primary energy conversion factors. Net Zero Energy Cost buildings definition is based on an economic balance (the energy bills of a building are equivalent to the amount of money the utility pays the owner for renewable energy the building feeds into the grid) whereas in the Net Zero Energy Emissions case, buildings produce and export at least as much emissions-free renewable energy as they import and use from emission-producing sources on an annual basis (Torcellini et al. 2006). The same author identified the following main definitions of a Zero Energy Building (Torcellini et al. 2006): Net Zero Site Energy: a site ZEB produces at least as much energy as it uses in a year, when accounted for at the site; Net Zero Source Energy: a source ZEB produces at least as much energy as it uses in a year, when accounted for at the source. Source energy refers to the primary energy used to generate and deliver the energy to the site; Net Zero Energy Costs: in a cost ZEB, the amount of money the utility pays the building owner for the energy the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year; Net Zero Energy Emissions: a Net Zero Emissions Building (NZEB) produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources (in other words, a Zero Carbon Building).

Although there is no standard approach for designing and realizing a Net Zero Energy Building (there are many different possible combinations of building envelope, utility equipment and on-site energy production equipment able to achieve net-zero energy performance and also the balance boundary, which defines which consumers are included in the balance differs in known approaches) there is some consensus that zero energy buildings (ZEB) design should start from passive sustainable design as this level of performance is achieved as a result of executing two fundamental steps: (a) reduce building energy demand and (b) generating electricity

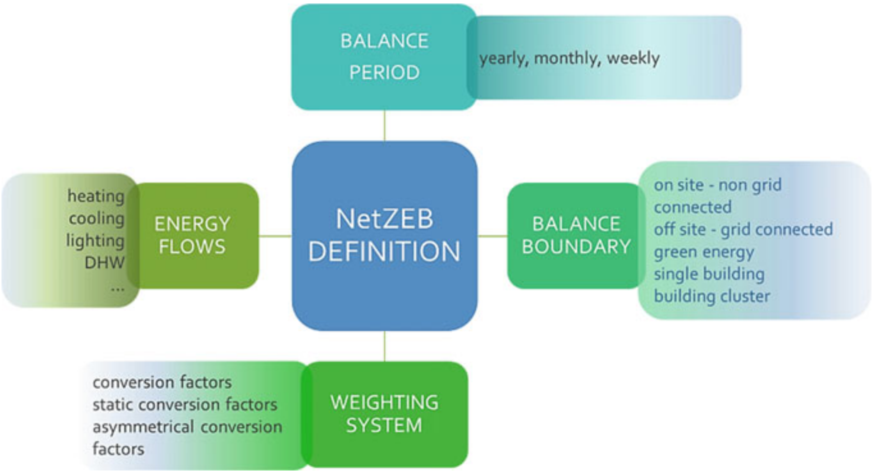

Fig. 10.1 ZEH parameters (Aelenei 2012)

or other energy sources to get enough off-sets to achieve the desired energy balance from renewable energy systems (RES). As one can easily imagine passive approaches play a crucial role in addressing NZEB design as they directly affect the heating, cooling, ventilation and lighting loads of the building's mechanical and electrical systems and, indirectly, the strive for renewable energy generation. The combination of design measures and strategies together with other energy balance parameters (Fig. 10.1) should be considered for a consistent zero energy balance definition.

10.1.2 ZEH Parameters Influencing Definition

10.1.2.1 Energy Balance and Boundary

If one draws an imaginary boundary in the nearby of a building (to account for renewable energy produced on-site and/or nearby), the energy balance may be schematically represented (Fig. 10.2). Accordingly, zero-energy buildings exchange energy with the grids (electricity, heating or cooling, gas or biomass) in the form of energy carriers that is converted from or on to primary sources using credits. Accordingly, the Energy Balance (EB), for different energy carriers, is, between the energy delivered (ED) to building and the energy exported (EE) into the public grids, writes:

$$EB = \sum_i EE_i \times f_{e,i} - ED_i \times f_{d,i} \tag{10.1}$$

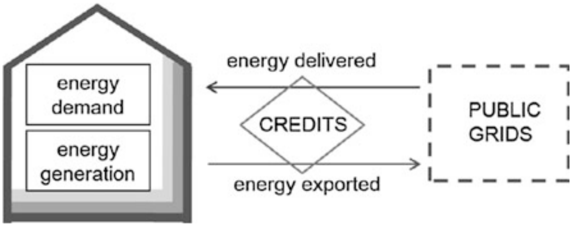

Fig. 10.2 Schematic representation of energy balance of zero energy buildings (Aelenei et al. 2013)

where f are factors which are used to convert the physical units into other metrics, such as primary energy or equivalent carbon emission.

In view of the abovementioned analysis model (Eq. 10.1), one can draw the conclusion that three different scenarios are possible, depending on the value of the energy balance. In the case of a neutral annual energy balance (i.e. the building use no more energy than it produce), the building is commonly referred as a Zero-Energy House. If the building falls short of the neutral balance then it can be referred to as a "nearly Zero Energy House". In the scenario where the balance is positive (when the building produces more energy than it consumes) the building is referred as a Plus Energy Building. The simple balance approach described so far becomes rapidly complex if one considers other features. For instance, if the boundary is drawn around a group of buildings instead (zero energy community), additional concerns regarding grids and conversion factors together with community-based infrastructure and industry need to be considered as well. In such cases, it is possible that plus-energy buildings may provide the additional amount of energy to nearly zero energy buildings from the same community and contribute in this way to the zero balance target of the entire community.

10.1.2.2 Weighting System

Primary energy indicator sums up all delivered and exported energy into a single indicator using primary energy factors. Therefore, the metric of the energy balance should allow comparison of different forms of energy (electricity, natural gas, biomass and solid fuels). Using primary energy as an indicator raises a question concerning the conversion factors that should be applied (Voss et al. 2011). The averaged conversion factors may be either derived from actual national statistics or from European similar figures and they are usually strategically determined in order to give priority to a particular category of energy fuel. A good example is the case of the asymmetrical weighting factors where the primary energy conversion factor for energy delivered by the grid is different from the factor for energy exported into the grid to encourage on-site generation. In cases where carbon dioxide is considered appropriate, conversion factors from primary energy to carbon dioxide can also be considered. This approach provides additional information about the consequences of energy use, in the terms of CO_2 emitted to the atmosphere. However, due to the fact that carbon cycle has a strong dynamic character, accounting for emissions in the same context can be a tricky business (Black et al. 2010).

10.1.2.3 Balance Period

The standard energy calculation procedure is annual due to the need of accounting the whole range of operating energy of a building typical for a complete meteorological cycle. Climate plays a dual role in ZEB (houses mainly) as it is a driver for space heating and cooling and a driver for supplying renewable energy resources at the same time. Using time intervals shorter than one year for calculus of the energy balance (seasonally, monthly or daily) is useful for the analysis of the interaction of the building with the electricity grid and other energy grids (Hermelink 2013). According to the same study, a yearly energy balance is not capable to provide the complete interaction with the grid as this procedure assumes the grid as an infinite storage. Buildings incorporating renewable energy systems are often characterized by a mismatch between the energy need and the energy generated on site. For instance, a seasonal calculus of the energy balance may result positive in summer (due to higher solar potential and lower energy needs) and negative in winter. As the consequences of mismatch are a matter under investigation, perhaps the best strategy to adopt in this respect is to reduce the absolute value of the potential mismatch between demand and local generation (Black et al. 2010). An effective way to reduce the mismatch is to reduce energy needs, a strategy which also provides advantages in terms of economic benefits (low energy buildings are significantly less prone to risks connected to volatility of costs/prices of conventional and renewable energy during their lifetime) and benefits associated to higher thermal comfort and user satisfaction (Hermelink 2013).

10.1.2.4 Balance Type/Energy Flows

The choice of a balance boundary and of which of the different energy end uses is to be included in the balance calculation has a major influence on the ZEB balance. For example, the inclusion or not of electrical plug loads or of central services can make a difference of 100 % in energy that must be generated to create the balance. In operation, to check that the so called energy import (delivered energy) and energy export (green line in Fig. 10.3) target is met requires sophisticated sub-metering. The difference between those two values is “self-consumption” (on the x-axis in Fig. 10.3), which represents the part of on-site generated energy which is instantaneously consumed in the building. It lowers the needed energy import and it is not fed into the grid.

During design analysis, energy use predictions for the balance calculation require three separate aspects of the energy flows to be simulated: the energy needed to maintain comfortable temperatures; the energy needed for appliances, hot water use and so on in the buildings; and the energy generated on site. Simulation

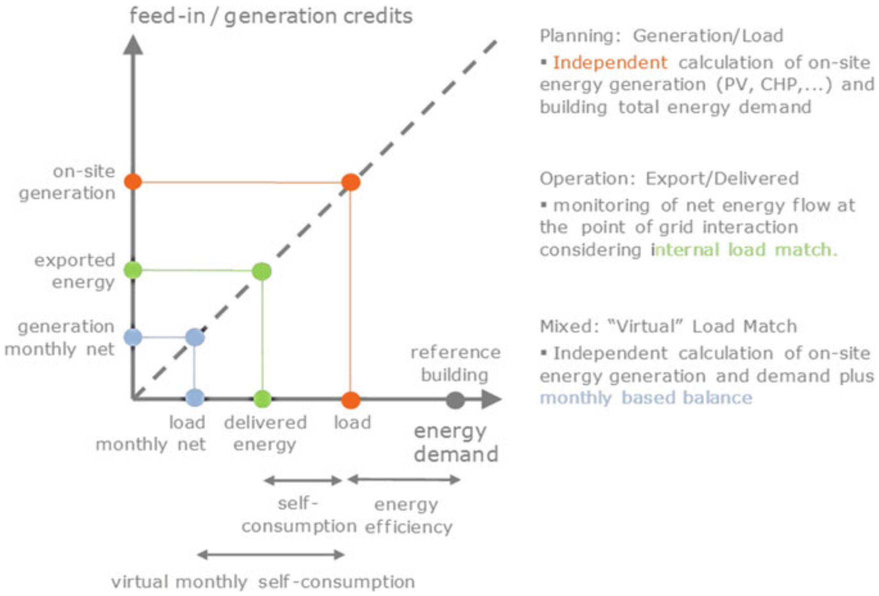

Fig. 10.3 Graphical representation of the three types of balance: import/export balance between weighted exported and delivered energy, load/generation balance between weighted generation and load, and monthly net balance between weighted monthly net values of generation and load (Voss et al. 2012)

of the first and the last of these energy flows is dependent on 'typical' climate data for the location. The variation from year to year of the climate from this typical value is rarely studied. Energy end uses are even more unpredictable being based upon predicting user behaviour. Data on end use patterns for appliances, hot water use, and so on with sufficient time resolution is required and is often unavailable. Because they are easier to predict with a degree of confidence, calculated on-site generation and energy demand are often balanced (load/generation balance, red line in Fig. 10.3), during the planning phase. These quantities do not cross the building system boundary. This approach at design time can often lead to subsequent pronouncements about a performance gap: the difference between the predicted performance and the actual performance (Voss et al. 2012). The standardized norms for people's behaviour and their use of equipment in a building used during design are proving to be about as accurate as the standardized norms for people's behaviour when driving a car that produce the manufacturers' fuel-efficiency comparisons. Put real people in the car (building) and the performance is very different.

In an effort to synthesize many of the issues covered in the previous sections, and to assess the advantages and disadvantages of different strategies and scenarios of NZEB definitions, an excel-based tool (NZEB evaluator tool) was developed by a group of experts from IEA SHC Task 40—ECBCS Annex 52 (International Energy Agency Solar Heating and Cooling Task 40 /ECBCS Annex 52 2008). The

Table 10.1 Net Zero Energy buildings definitions according to IEA

Definitions	Description
(IEA 2012)	**Net ZEB limited** Weighted energy use for heating, production of domestic hot water (DHW), cooling, ventilation, auxiliaries and built-in lighting (for non-residential buildings only) versus weighted energy supplied by on-site generation driven by on- or off-site sources. Static and symmetric primary energy factors are possible
	Net ZEB primary Weighted energy use for heating, DHW, cooling, ventilation, auxiliaries and lighting and every kind of plug loads (electrical car possibly included), versus weighted energy supplied by on-site generation driven by on- or off-site sources. Static and symmetric primary energy factors
	Net ZEB strategic Weighted energy use for heating, DHW, cooling, ventilation, auxiliaries, built-in lighting and every kind of plug loads versus weighted energy supplied by on- and off-site generation systems driven by on- or off-site sources. Weighting factors could be static and asymmetric, varying on the basis of the energy carrier, the technology used as energy supply system and its location
	Net ZEB emission Balance between building CO_2 equivalent emissions due to energy use for heating, DHW, cooling, ventilation, auxiliaries, built-in lighting, every kind of plug loads and the weighted energy supplied by on-site generation systems driven by on- or off-site sources. Static emission factors are used. They can be symmetric or asymmetric, depending on the energy carrier, technologies used as energy supply systems and their location

tool allows checking annual energy or emission balances as well as characterizing the load match and the grid interaction profile of a building by simplified indicators on the basis of four energy balance approaches (Table 10.1).

10.1.3 ZEH Best Practice/Examples

10.1.3.1 Plus Energy House

In the Plus Energy Houses, the supply energy systems installed in the building produce more energy than its owners actually need. In fact the energy balance is positive and exceed the performance of a ZEH or near ZEH, generating a surplus of clean energy (more often solar) into the house's power supply. Schlierberg Solar Settlement (Fig. 10.4) is a project developed by the architect Rolf Disch, a pioneer of solar buildings. The authors identified a full zero-fossil energy balance for the consumption of the 50 ground-based plus-energy terrace houses with heating and electricity on the demand side and solar electricity generation on the generation side.

This project had different goals, one of them being energy monitoring, a full balance of the consumption of the 50 ground based terrace houses with heating and electricity on the demand side and electricity generation on the generation side.

Fig. 10.4 Solarsiedlung am Schlierberg

Another goal was the special attention paid to the integrated urban planning. The orientation and housing density on the site were designed to take into account living quality, unobstructed solar radiation on the PV systems installed on the roof, sun shading for summer protection and sun exposure strategy for heating season (Heinze and Voss 2009).

The houses have a high energy performance as they were designed according to the passive house standards. Between the measures adopted: high insulation with a U-value for the building envelope of 0.28 W/m^{2}K, efficient ventilation system with heat recovery. Electricity saving appliances and appropriate user behaviour reduced the domestic energy consumption. Water savings tap fittings were installed.

Only a small remaining amount of energy is balanced by the PV yields installed on the roofs. This high energy efficiency on site reduces the consumption of the renewable energy and the requirements on transport and storage of energy in grids (Heinze and Voss 2009).

10.1.3.2 ÉcoTerra

A successful net zero-energy healthy house project is ÉcoTerra house, which won the Canadian federal government's EQuilibrium sustainable housing competition. The house was built in Eastman in the province of Quebec and it is currently open to the general public in order to sharpen the consumers' awareness of commercially available net zero-energy healthy housing today (Noguchi 2008). The house was constructed by making use of Alouette Homes' pre-engineered modular housing

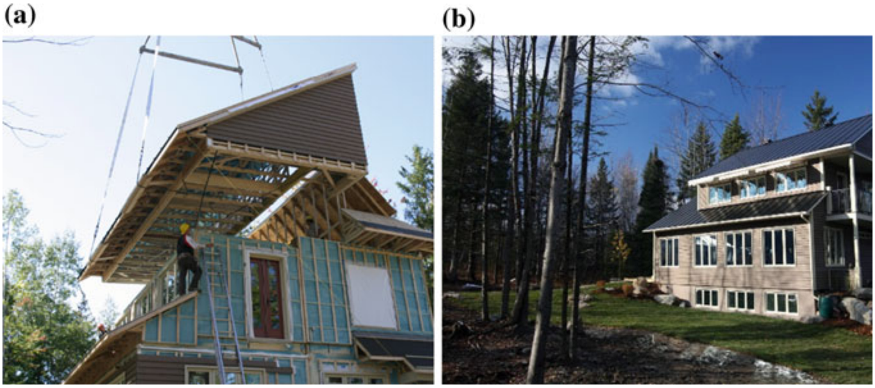

Fig. 10.5 ÉcoTerra house: **a** during the modular construction and **b** after the completion

system (Fig. 10.5) that helped eliminate or reduce on-site construction nuisances, such as bad weather, theft and vandalism.

One of the key healthy housing design features applied to the ÉcoTerra house is the thermal comfort maintained by the application of high thermal insulation materials (e.g. U-value of nearly 0.1 W/m^{2}K in external walls) and the air-tight construction. These features are further combined with the continuous, balanced mechanical ventilation. In this house, the air-tightness is maintained at 1 air change per hour (or 1 ACH) at 50 Pa.

For energy generation ÉcoTerra integrated Building Integrated Photovoltaic Thermal (BIPV/T) systems. These BIPV/T systems have a great advantage compared with stand-alone photovoltaic (PV) arrays or solar thermal collectors because they generate both thermal and electrical energy simultaneously (Chen et al. 2007). Therefore, a 3 kW BIPV/T based on a system concept developed at Concordia University was installed in the ÉcoTerra house, having the capacity to produce approximately 12 kW of heat at 14 m^3/min of air flow according to the engineering team's previous experiment (Liao et al. 2007).

10.1.3.3 Casa Zero Energy

The Casa Zero Energy located in Udine (Italy) is not only a simple ZEB, it is also a prototype, which represents a demonstration project for proving that it is possible to build a house able to respect the environment in terms of impacts reduction and improvement of the inhabitants lifestyle (Fig. 10.6). Indeed, the aim of the project was not only the construction of a low-impact and low-energy building, but the construction of a building in which the role and the wellbeing of the users have a relevant importance. For such reasons, the design of the building was oriented to ensure the contact with the nature, guaranteeing a new and better living dimension for the people (Frattari 2013).

Fig. 10.6 Casa Zero Energy

The Casa Zero Energy is the prototype of a building that does not use energy produced from fossil sources, but that produces the needed energy with alternative energy systems. It was designed according to the criteria of bioclimatic architecture and integrated with passive systems for getting advantage from the climatic site characteristics for the heating in winter, and for the inner cooling and ventilation, in summer.

The Casa Zero Energy designed by Arch. Arnaldo Savorelli and Prof. Antonio Frattari, was developed in the years between 2007 and 2010 by the company Gruppo Polo—Le Ville Plus of Cassacco (UD). Some of the main features of the building design are: strong natural and bioclimatic characterization, similarity to passive house concept, the use of natural, renewable and recycled materials for the building construction, a new and innovative anti-seismic timber frame system, a new and innovative envelope to save energy, low energy consumption, the integration with energy systems using alternative and clean sources, the integration with an intelligent system (home automation) (Fig. 10.7) able to optimize the indoor comfort, the energy consumption and safety.

Two interesting aspects can be identified: the house is built with natural, renewable, recycled and recyclable materials. For this reason it is classifiable as a “natural building” and secondly the house is automated, through smart solutions that have been implemented for testing and verifying the utility and the effective use of scenarios for the flexible utilization of automated passive solar systems, quantifying the contribution of automated control for the lighting, shading and conditioning systems, experimenting the possibility to guarantee both safety and security

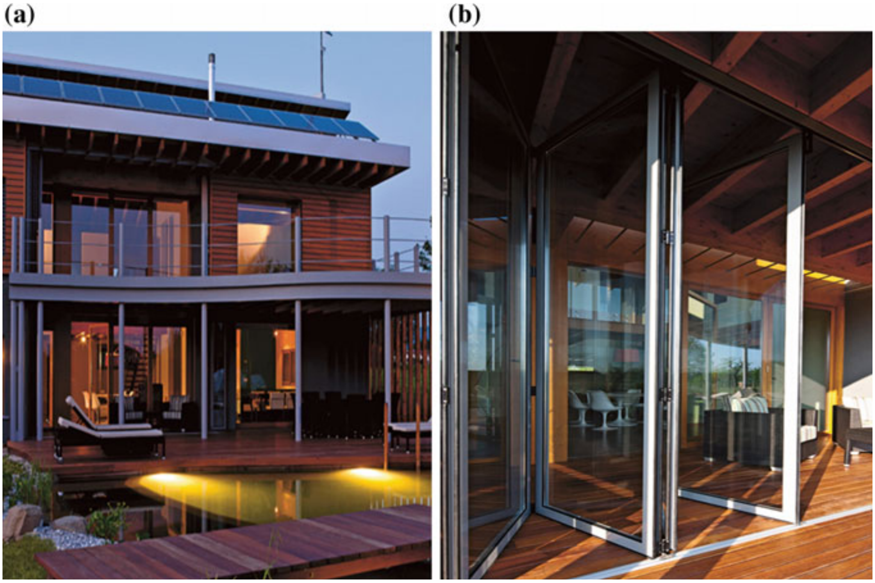

Fig. 10.7 Casa Zero Energy: **a** The sunspace closed in winter and **b** the sunspace opened in summer

to the house users. In the near future in the context of Smart City paradigm, the buildings need to be interactive/intelligent in order to satisfy the user need, the proper use of renewable energy and the interaction with the grid.

10.1.3.4 The Vermont House

ECOxIA is a French company in the green building industry, whose founders were very influenced by the experience of their Zero Energy Mass Custom Home (ZEMCH) Mission to Japan in 2007. It has been created with the corporate mission to democratize positive energy housing. The definition given back to 2010 was to build dwellings that are so sober in energy, it becomes easy, on a yearly basis, to produce more renewable energy on site than needed to operate the building. The challenge was not only to design a bioclimatic architecture with a very well insulated envelope but also a zero energy house. The company also wanted to develop a building solution that would be versatile (customization) and at an acceptable price premium (mass). The Smart Building Envelope (SBE) was the outcome of those specifications.

As a synthesis of best international practices, theory said that the SBE would have a low carbon footprint at the construction stage thanks to its all-wood structure and the off-site prefabrication; and at the use stage with a passive design (U-value below 0.125 W/m^{2}K in external walls and floors, and air-tightness below 0.6 air change per hour at 50 Pa). Comfort should be excellent with generous natural light (large window surface), good external sound proofing (design and air-tightness), an excellent indoor air-quality (high-end dual flow ventilation), and ideal indoor temperature and humidity levels in all seasons. Moreover, the architectural creativity should not be too much impaired by the concept of the SBE and the construction cost should remain under control, savings due to planning and off-site production counterbalancing, at least partially, the extra costs of features like triple-glazed windows, energy recovery ventilator or PV panels.

ECOxIA hence decided to build a prototype house to validate its SBE technology. However, more than an easy demo house, it had to be a guinea pig that would prove that the SBE can work in most situations. The house had hence to be single storey, with an elegant flat roof and rather small in size (about 100 m^2), which makes it more difficult from a cost and energy performance standpoint. Designed with American and French architects, the Vermont House was born.

The Vermont House (Fig. 10.8) was installed in Yerres, near Paris, France in November 2012.

The house it was prefabricated under 3D modules (Fig. 10.9a) at 200 km^2 from the location in Normandy with a high level of completeness (full envelope, partition walls, electricity, etc.). The three main modules and the elevated roof were installed on the low-impact foundation in one day. After finishing, the monitoring of the Vermont house in real life could start (Fig. 10.9b). It has been used as an office weekly by 3 employees and as a week-end house since April 2013.

The Smart Building Envelope is a true ZEMCH building solution. The life cycle analysis of the Vermont House measured 10 tons of carbon at the construction

Fig. 10.8 Vermont House by ECOxIA: positive energy Vermont House in Yerres, France

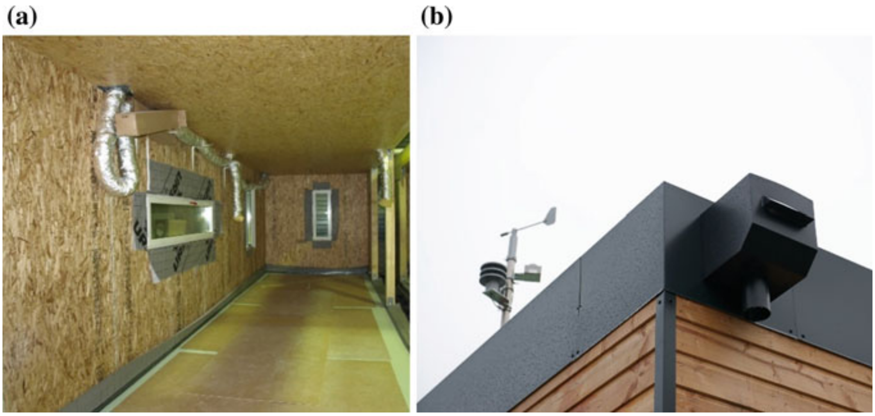

Fig. 10.9 Vermont House: **a** Modules under assembly in Normandy and **b** Weather mast on the roof

stage, and 6 tons of carbon sink. Its net building impact on the environment was 4 tons of carbon equivalent, which is very low.

From a usage standpoint, the purpose was to build a house at Net Zero Energy Cost. After 2 years of experience, the average total consumption for this all electric house is just under 4500 kWh per year, or 116 kWhPE/m^2. The 20 m^2 of PV panels installed on the roof (Fig. 10.10a), with a 3 kWp at a 0 % angle, produce about 2500 kWh per year. Consequently, the ECOxIA prototype yields an energy profit every year. Thanks to the advancement in PV and battery technologies, positive energy or even off-grid housing becomes possible.

From a mass customisation perspective, the Vermont house costed less than € 200,000 to build. Experts found it very cost effective, may be 50 % less than similar houses. However, it is still 20 % more than the new houses on the French market. More standard architecture and economy of scale would bring the premium to 10 %, which would lead to a very high cost performance ratio.

Unless you have a very high level of in-factory completeness and very flexible production units, 3D module prefabrication is not always panacea. As a feedback from the prototyping, the SBE is now delivered on site under flat packs (2D panels that comprise all the components to build passive). This means that the architecture is totally free, within the constraints of physics and bioclimatic principles (Fig. 10.10b).

The Vermont House is an interesting example of how zero energy cost project turned into a Zero Energy Mass Custom Home building solution.

10.1.3.5 LIVINGBOX

LIVINGBOX is a prototype designed by Prof. Antonio Frattari and developed at the Laboratory of Building Design of the University of Trento. It has been designed (Figs. 10.11 and 10.12) as a Near Zero Energy Building to minimize the impact of

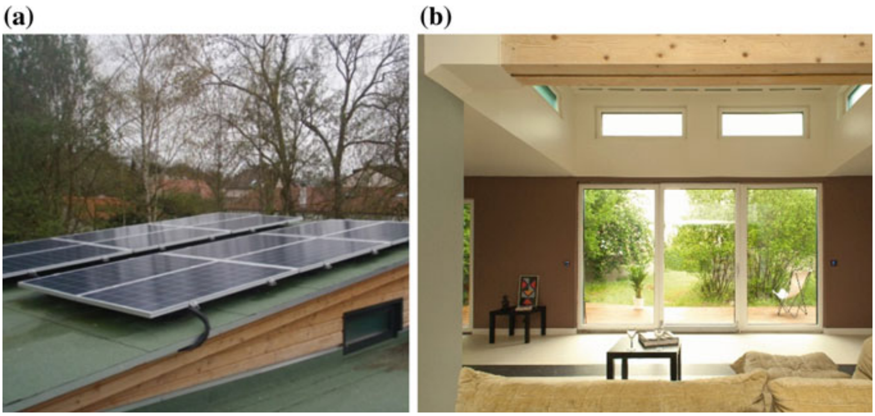

Fig. 10.10 Vermont House: **a** 3 kW PV panels on the elevated roof and **b** Windows facing South are the main radiators of the house

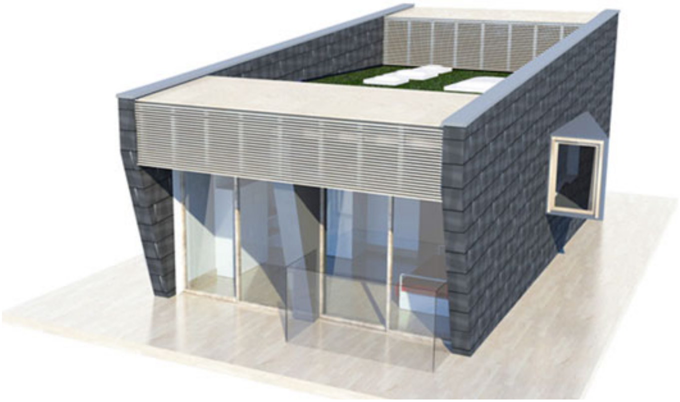

Fig. 10.11 LIVINGBOX 3D design

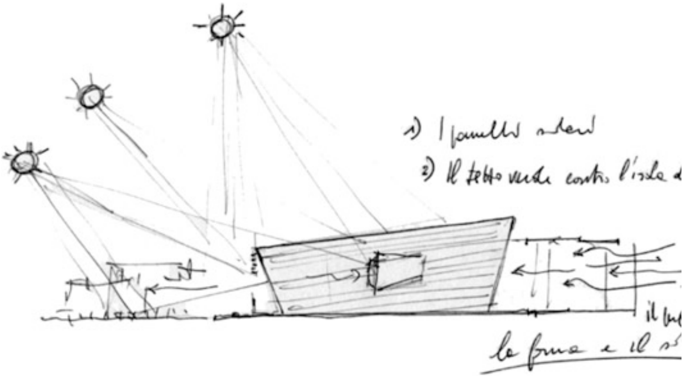

Fig. 10.12 Preparatory sketch for the bioclimatic design of the unit

the building on environmental matrixes: water, air, soil. To reach the target of NZEB it is equipped with systems for producing energy from renewable sources to minimize use of fossil energy. In addition, the unit is a low consumption building. A prototype at real scale has been built to verify the constructive feasibility.

The home is articulated in a large multi-purpose space that can be modified during the day and in a fixed kitchen-bath block. The unit can be expanded from 50 to 75 m^2 gross. In this last case, the kitchen and the bathroom block is bigger. The units can be put together to form terraced houses or block houses up to three storey. The living unit also can be organized functionally as hotel room. In this case the space is articulated in a room of about 15 m^2, in a multi-functional space (between the bedroom and the bathroom access, about 5 m^2), equipped with a wardrobe (length 2.40 m), and a bathroom, about 5 m^2. This unit can generate different types of hotels: blocks up to three storey or small settlements with the units spread over the territory. The living unit has been designed to minimize the impact of the building on environmental matrixes: water, air, soil. The used materials are natural, recyclable or recycled. It is characterized by extensive use of wood to limit CO_2 emission in the atmosphere and it was designed as a Near Zero Energy House.

It is built with load-bearing panels in massive laminated wood: Crosslam. The quantity of wood used embodies around 9.5 tons of CO_2 as a positive contribution to the greenhouse effect. Even the other used materials, mostly recycled, were chosen through a Life Cycle Assessment (LCA) including the aspects that minimize the CO_2 emitted in the atmosphere during the construction, maintenance and disposal. In addition, to further reduce the environment impact, have been studied architectonic and constructive solutions for maximising the free contributions offered from the surroundings in terms of solar and wind contributions to produce clean energy.

The design is based on bioclimatic solutions. A mini-greenhouse is on the south façade to improve winter heating and natural ventilation for summer cooling. LIVINGBOX is opened to the south, partly opened to the east with a screened window to minimize the negative sun in summer and it is totally closed, without any window, on the north front. The unit has been design to minimize the heat island effect through a green roof and, possibly, green walls. Roof and walls are ventilated to decrease use of insulating membranes and to ensure the natural breathability. The employed materials such as the paints are low-emissivity. For example, the water paint with acetic acid used for aging the larch of the interior fittings or of the battens wooden of the outer walls.

In addition, the low consumption of the living unit is enhanced by the envelope's stratigraphy that insures a transmittance value between 0.20–0.25 W/m^2K, and a thermal lag between 10–15 h. With these constructive solutions, the energy consumption is around 16 kW/m^2 for year. Particular attention has been paid to the prevention of thermal bridges realizing a continuous isolated envelope in rock wool. The thermal efficiency is approaching that of a "Passive Envelope" inspired by the "Passive Haus". To optimize the relationship between comfort and energy consumption LIVINGBOX is equipped with a modular home automation system. It allows managing with integrated modular packages the lighting and the heating, the daylighting, the shading and the natural or mechanical ventilation.

10.2 Criteria to Build or Refurbish to a ZEH Standard

As previously pointed out, there are different definitions and approaches to achieve Zero Energy House. The provisions of the Energy Performance of Building Directive (EPBD 2010) introduced in Article 9, "nearly Zero-Energy Buildings" (nZEB): "by 31 December 2020, all new buildings are nearly zero-energy buildings; and after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings" will be the starting point of the project. Anyway, despite the EPBD Recast focuses on new buildings, the energy and CO_2 emissions associated to the existing buildings refurbishment towards nZEB is worth investigating because of the huge potentialities of energy savings.

Figure 10.13 shows a typical retrofit process contrasted with a deep retrofit process. On the right, in green, the deep retrofit process is shown. The blue steps on the right indicate the additional considerations that need to be taken in a net zero energy project process.

The process of taking an existing building to net zero energy is similar to that of a deep energy retrofit (RMI 2015) with some additional considerations. A deep energy retrofit involves a whole-building analysis process that delivers much larger energy cost savings, i.e. sometimes more than 50 % reduction, and fundamentally

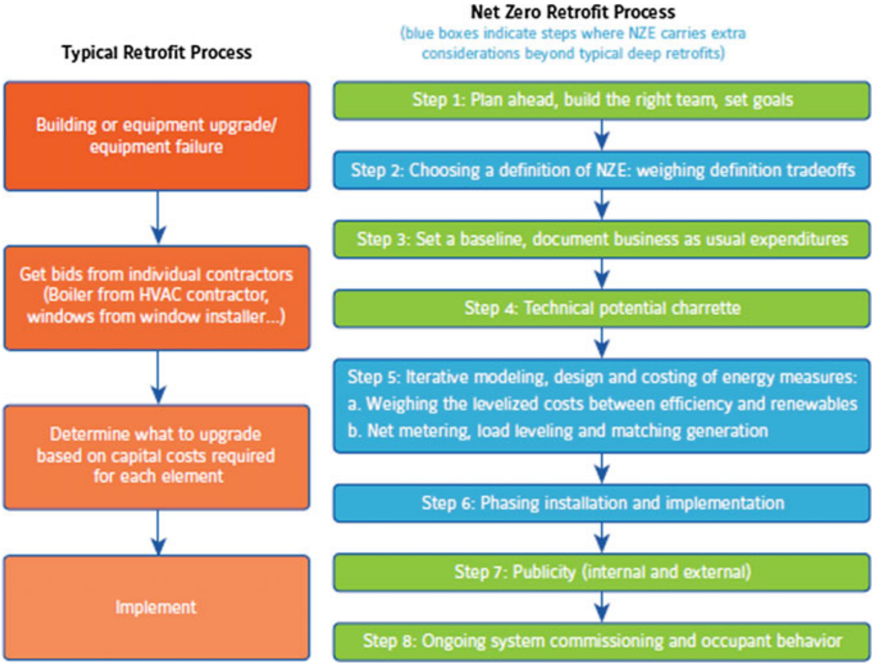

Fig. 10.13 Typical retrofit, deep retrofit and net zero retrofit process considerations (Carmichael and Managan 2013)

enhances the building value. The following analysis describes the process of completing a net zero retrofit (NZR), which was put together by the Institute for Building Efficiency—Johnson Controls, Inc. (Carmichael and Managan 2013).

Step 1 Plan Ahead, Build the Right Team, and Set goals. The need for a retrofit can be a sudden and not-so-subtle milestone in a building's life, often preceded by the degradation or failure of a key piece of equipment. When equipment fails, it is useful to analyse the life-cycle cost of replacing that equipment, along with complimentary retrofit measures. This can result in a better long-term outcome for the building.

Planning for equipment replacement and starting with the replacement of load reduction measures over time, such as upgrading windows, reducing plug loads, and improving lighting controls, enables better decision-making when equipment fails. Good planning can also help avoid common pitfalls, such as following rules of thumb on sizing and equipment selection based on obsolete data and assumptions that were relevant a generation ago.

Assembling the right execution team helps as well. The team should include designers and engineers who can design across systems and understand whole building benefits, as well as building maintenance personnel, and building operators and/or users more importantly. The right team will also be able to identify and mitigate risks that may arise during the project. The team should gather the energy use and cost data, upgrade history, equipment performance and life expectancy data, capital expenditure forecasts, lease structures, and major lease rollovers (for investor—owned buildings, mainly commercial buildings). Working together, the owner and design team can put forth goals that can include achieving net zero energy. The team should start planning early and keep all key stakeholders engaged throughout the process.

Step 2 Choose a Definition of NZE and Weigh Defined Trade-offs. All net zero energy buildings share a goal of maximising energy efficiency and then meeting remaining power needs with renewable energy. The key difference between types of net zero energy buildings is how and where the renewable energy is generated. Taking as example the definition proposed by NREL (Torcellini et al. 2006), (Table 10.2), all four definitions account for annual operations, even if there are surpluses and deficits on any single day or night. Net zero site energy is the most commonly used definition, and most in line with the spirit and intentions of achieving net zero. Each of the definitions has trade-offs regarding cost and tracking metrics, and different types of renewable energy can be used to meet each definition.

Step 3 Set a Baseline and Document Business-as-usual Expenditures. At the onset of a project, the project team should clearly document the energy use, costs, and how the building is performing today, and then lay out the anticipated future costs or the business-as-usual scenario without any net zero energy investments. Under business-as-usual, there will be costs involved in operations, maintenance, repair and replacement that should be documented. The business-as-usual case should include estimates for anticipated end-of-life capital investment needs in addition to anticipated future energy costs. Knowing future costs under the business-as-usual scenario is critical for comparison with the future costs of

Table 10.2 Summary of definitions and tradeoffs for Net Zero Energy (Torcellini et al. 2006)

Definition	Summary	Metric	Pros	Cons
Net zero site energy	Renewable energy must be generated on the building or site.	Site kBtu	Simple accounting low external fluctuations (i.e., not dependent on energy prices)	Annual energy bills may not be $0. Assumes electricity exported from the site can be used to offset natural gas needs on site. May emphasize an all—electric strategy if PV is the primary renewable energy system
Net zero source energy	Energy use is accounted for at the source, including the energy used for extraction, generation and distribution	Source kBtu	More accurate depiction of total environmental impact	Annual energy bills may not be $0 more complex accounting (acquiring site-to-source conversion multipliers, source energy technology changes)
Net zero cost energy	The amount the owner pays the utility for the energy is less than or equal to the amount of money the utility pays the building owner for the renewable energy the building exports to the grid	dollars	Energy costs are $0 simple accounting	
Net zero emissions energy	The building offsets all of the greenhouse gas emissions produced from the energy it uses through renewable energy production and carbon offsets (for up to 50 % of net energy consumption)	Co_2e	Uses greenhouse gas metric that aligns with carbon disclosure efforts and climate change	Annual energy bills may not be $0 challenging to track. Questions/concerns regarding carbon offsets

operating and maintaining a net zero energy building. The project team can then build a comprehensive and compelling business case in which investments in energy efficiency can reduce loads to the point where mechanical equipment can be downsized or eliminated, reducing capital and operating expenses.

Step 4 Organise a Technical Design Charrette. Every net zero energy project should start with a team charrette or brainstorming session to identify the technical potential for the building—the lowest possible energy use that could be provided by efficiency using available technology and best practices. This approach pushes both architects and engineers to focus on major, whole-systems improvements, fundamentally changing the design question from "We can't do this because …" to "We could do this if…" it gets participants to think outside the box about options for maximizing the efficiency of each building system, about the types of on-site generation options that may be available, and about the ways different strategies interact to form an integrated design.

Step 5 Conduct Iterative Modelling, Design, and Costing of measures. An energy model of the building is critical to selecting a compatible bundle of energy measures. Since many retrofit projects occur over multiple years, if the model is set up early, it can be calibrated based on actual building energy meters and updated on an ongoing basis. Each individual energy measure, as well as different combinations of measures, can be modelled to see how they affect load throughout the day, season, and year. The energy model should also be used to analyse the cost-effectiveness of different measures because in that event, investments in complementary measures can be analysed together.

10.3 Design, Construction and Operation of New Zero Carbon Homes

The design and construction criteria of new Zero Energy/Carbon Homes (ZEH) are explained in this section. The UK construction practices, regulations and standards in general and the Code for Sustainable Homes (CSH) in particular are being explored to describe the design and construction stages as well as operational energy requirements of ZEH.[1]

10.3.1 Code for Sustainable Homes

Housing industry is one of the major sectors that should contribute towards the UK Government's objectives to reduce carbon emissions by 80 % by 2050 (DECC 2009). Domestic sector stands for around 29 % of all the CO_2 emissions of the UK 66 % of which is related to space heating, 17 % to hot water, 15 % to lighting and appliances, and 3 % to cooking (DECC 2011). In 2006, the UK government announced its ambition to make new homes carbon neutral by 2016 (EST 2009; DCLG 2008a) through gradual amendments in building regulations based on the Code for Sustainable Homes (CSH) standards (McManus et al. 2010; Osmani and

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[1] Some parts of this chapter are adapted excerpts from 'Code for Sustainable Homes: opportunities or threats for offsite manufacturing and mass-customization' (Hashemi and Hadjri 2013).

Table 10.3 Gradual improvements to building regulations based on CSH standards (DCLG 2007a)

Year	2010	2013	2016
Energy/carbon improvements over building regulations part L (2006)	25 %	44 %	Zero carbon
Code for sustainable homes level	Code level 3	Code level 4	Code level 6

O'Reilly 2009). However, in July 2015, in an unexpected statement, the Conservative government announced that:

The government does not intend to proceed with the zero carbon Allowable Solutions carbon offsetting scheme, or the proposed 2016 increase in on-site energy efficiency standards (HM Treasury 2015). Although CSH has been scraped, its design approaches and strategies are still considered as one of the best example for achieving ZEH. This section therefore concentrates on CSH to explain design and construction stages of zero carbon homes defined by the Code for Sustainable Homes. Introduced in 2007 (DCLG 2009), CSH classified houses under six levels where Code Level 6 was the most sustainable and achieved zero carbon emissions (DCLG 2008b). The energy saving/improvement figures over the UK's Building Regulations, Approved Document L (2006) for Code Level 1 to Code Level 6 were estimated as 10, 18, 25, 44, 100 %, and finally, zero carbon for Code Level 6 (DCLG 2006). Code Level 6 was supposed to be implemented through the building regulations in 2016 when zero carbon homes would become mandatory (Table 10.3) (DCLG 2007a).

According to the Department for Communities and Local Government (DCLG 2007a) a house could be considered as zero carbon if it genuinely produces a net annual zero carbon for the consumed energy for heating, cooling, washing, cooking, lighting, ventilation, hot water and electric equipment. This house could be described as Code Level 6 in the Code for Sustainable Homes (EST 2009). Three requirements must be met for a home to be considered as a zero carbon home (Zero Carbon Hub 2013):

1. Complying with "Fabric Energy Efficiency Standard" (FEES) in terms of U-values, airtightness, etc. for the building envelope. The FEES is the maximum energy required for space heating and cooling;
2. Complying with the established "Carbon Compliance" limits (Table 10.4), established for zero carbon homes. Carbon Compliance is the maximum permitted CO_2 emissions from heating, cooling, hot water, lighting and ventilation;
3. Reducing any remaining carbon emissions to zero after considering items 1 and 2.

The third requirement can be met by intentional over-performance of the first and second requirements (by using, for example, photovoltaic panels, solar hot water, etc.) or can be achieved by investing in "Allowable Solutions" (Zero Carbon Hub 2013). CSH was originally very ambitious requiring all regulated (heating, cooling, hot water, ventilation, auxiliary services and lighting) and unregulated

Table 10.4 Fabric energy efficiency and carbon compliance requirements set by CSH standards (Zero Carbon Hub 2013)

Building type	Fabric energy efficiency standard (FEES) (kWh/m^2/year)	Carbon compliance (kgCO$_2$/m^2/year)
Detached house	46	10
Semi-detached house	46	11
End of terrace house	46	11
Mid terrace house	39	11
Apartment house	39	14

energies (home appliances) to be zero carbon (DCLG 2007a). The Allowable Solutions was proposed in 2008 to provide some flexibility due to the difficulties, such as high costs and feasibility issues, of delivering zero carbon homes based on entirely "on-site" strategies (Zero Carbon Hub 2011). The idea was that developers could pay to an Allowable Solution, which could be a small, medium or large offsite carbon saving project, to offset the remaining on-site carbon (Zero Carbon Hub 2011).

Design and Construction Approaches. Following are three design and construction approaches, which may lead to achieve a zero carbon home (Zero Carbon Hub 2013):

1. Balanced
2. Extreme Fabric
3. Extreme Low Carbon Strategies

The Balanced approach can be achieved by meeting the FEES requirements and considering reasonable onsite low carbon technologies. The remaining carbon emissions (e.g. 11 kg CO$_2$/m^2/year) will be eliminated by the Allowable Solution. In the Extreme Fabric approach, a very high performance fabric, significantly in excess of FEES, is considered to achieve a high standard building envelop comparable to Passivhaus (e.g. U-value 0.1–0.15 W/m^2/K; Air Permeability 1 m^3/h/m^2 @50 Pa; Thermal Bridge (y-value) 0.02 W/m^2/K; Space heating/cooling demand 25–30 kWh/m^2/year). Very little or no on-site low carbon energy technologies is used in this method. Similar to Balanced approach, Extreme Fabric approach fully complies with the requirements once the remaining carbon emissions are reduced to zero using Allowable Solutions. In the third approach, Extreme Low Carbon Strategies, on-site low carbon technologies along with high performance fabric (e.g. Passivhaus standards) are considered to considerably reduce the emissions beyond Carbon Compliance requirements for regulated emissions to zero (Code Level 5 in CSH). There is therefore no need for using Allowable Solutions to reduce emissions to zero (Zero Carbon Hub 2013). It should be noted that to achieve a fully on-site zero carbon home, both regulated (space heating, hot water, lighting and ventilation) and unregulated (e.g. appliances and cooking) energy/emissions should reduce to zero. This can be defined as Code Level 6 of CSH.

Code for Sustainable Homes is effectively a sustainability pointing/rating system in which buildings receive scores based on their design, construction, energy performance and implementation of sustainability strategies. There are minimum standard requirements for categories such as energy, CO_2 emissions, surface water, daily water consumption, waste and use of sustainable materials for roof, walls, floors, windows and doors. There are also some categories with no minimum standards such as pollution, health and wellbeing, management and ecology. A home must comply with the minimum standards as well as gain additional points on other categories in order to achieve a code level. For example, 60.1 and 64.9 additional points are required to achieve Code Level 5 and Code Level 6 respectively. Implementation of sustainable design strategies, such as Lifetime Homes (Goodman 2011) (up to 4 points), appropriate daylighting (up to 4 points), outside private space accessible by disabled people (1 point), cycle storage (1.2 points) and home office (1.2 points), are some of the design strategies which would count towards achieving higher points and levels of standard (DCLG 2006).

Barriers and Drivers for Delivering ZEH. The key drivers for delivering ZEH are legislations and regulations. Limited knowledge and skills in the construction industry (Heffernan et al. 2012) as well as considerable extra costs (DCLG 2011) are also the major barriers towards delivering ZEH. Achieving high standards for ZEH is not only difficult but is also expensive. Dwellings built based on Code Level 6 in 2016 could have been up to 50 % more expensive compared to 2010 regulations. According to the Department for Communities and Local Government, the total costs for achieving zero carbon homes is around £34 billion with an economic return of around up to £22 billion (DCLG 2007b). It has been estimated that Code Level 3 and Level 4 households can, respectively, save around £25–105 and £25–146 per annum. Code Level 6 households may save up to £359 per annum based on the entirely on-site solutions (DCLG 2007a). This is while another study by DCLG in 2011 indicates that the extra costs for a three-bed semi-detached house may vary between £16,407 and £29.326 for Code Level 5 and between £31.127 and £36,191 for Code Level 6 (Heinze and Voss 2009). A major portion of costs for achieving zero carbon homes is related to energy efficiency, which is achieved through fabric improvements (insulation, airtightness). For example, up to 79 % of the "extra over costs" for a semi-detached three bed house is related to improvements on the energy efficiency while it accounts only for around 36 % of the weight for the allocated points towards zero carbon homes (DCLG 2011).

Moreover, although zero carbon homes can be achieved by traditional methods of construction (DCLG 2013), considering uncertainties in the quality and construction period of traditional methods it is becoming more and more difficult and expensive to meet the requirements using traditional methods of construction (Miles and Whitehouse 2013). Traditional methods and practices have increasingly become less productive while their costs have increased significantly (Buildoffsite 2012). It has been suggested that offsite/prefabricated methods of construction can help to achieve zero carbon homes (DCLG 2007a) thanks to their higher quality

(Burwood and Jess 2005) compared to traditional methods of construction. However, a major barrier towards broader application of these methods is their extra immediate costs (Miles and Whitehouse 2013) compared to traditional methods of construction. In fact, cost is the key factor, which should be considered to increase the share of ZEH in the construction industry.

10.3.2 Examples

A permanent exhibition, known as Building Research Establishment (BRE) Innovation Park, has been established since 2005 by the UK's Building Research Establishment in Watford, near London, with the purpose of introducing Modern Methods of Construction, zero carbon homes and other innovative technologies (BRE 2013). The following are some examples of houses built in the Innovation Park. Kingspan Lighthouse is the first home certified to Code Level 6 in the UK and Barratt Green House is the first zero carbon home built by a major UK housebuilder. The BRE Innovation Park provides builders with an opportunity to test and showcase their construction technologies and capabilities. It is also a great opportunity for designers, experts, and the public to see the innovations and emerging technologies and approached towards achieving a sustainable construction industry (BRE 2013).

Kingspan Lighthouse. Kingspan Lighthouse was constructed in 2007 in the Innovation Park. The Lighthouse is a CSH Code Level 6, two and a half storey, two-bedroom detached house with an area of 93 m^2 (Fig. 10.14). The annual heating cost for the house (including water and space) is about £30, which means around 94 % saving on fuel costs. The energy bills of a similar house with the same size and shape built based on the 2006 Building Regulations would cost around £500 (Kingspan 2009). Kingspan's TEK Building System, which is an offsite SIP (Structural Insulated Panel) system, has been used in the Lighthouse. Heat-losses through the building envelop, compared to a standard house, have decreased to around one third thanks to the very low U-value of the walls, roof and floor (0.11 W/m^2K) along with the airtightness of less than 1 $m^3/hr/m^2$@50pa. Triple glazed windows (0.7 W/m^2K), low energy lighting, photovoltaic (4.7 kW, 46 m^2), wood pellet boiler (10 kW), rainwater harvesting, and the 88 % heat recovery mechanical ventilation, in addition to A++ rated white goods (Kingspan 2009) make Kingspan's Lighthouse considerably energy efficient. Moreover, proper use of thermal mass, passive ventilation, and solar shading helps to reduce energy consumption as well as maintain the indoor air quality. The rather low average daylight factor of 1.5 to 2 % is however an area where improvements could have been made to make Lighthouse even more environmentally friendly. As the first house certified to Code Level 6 standards, Kingspan's Lighthouse was a proper example for the UK's housebuilders and manufacturers during its rather short life from 2007 to 2012. The house was dismounted adopting a sustainable "zero-waste-to-landfill" approach in 2012 (BRE 2013).

Fig. 10.14 Kingspan Lighthouse

Barratt Green House. The Barratt Green House is a three-storey, three-bedroom family home built to Code Level 6 Standards (Barratt 2013) (Fig. 10.15). Barratt Green House was constructed in 2008 in the Innovation Park (BRE 2013). It is the first home built by a major UK housebuilder, which meets the requirements to achieve zero carbon emission. The Barratt house is constructed from wall with aircrete masonry blocks with thin-joint mortar, concrete floor slabs, Structurally Insulated Panels (SIP) roof and low U-value triple glazing. Similar to the Kingspan's Lighthouse, Barratt Green House can achieve very low energy bills thanks to its high levels of insulations (180 mm = 0.11 W/m^2K), airtightness (1 $m^3/hr/m^2$@50 Pa), use of PV panels, rainwater harvesting, solar shades, heat recover mechanical ventilation, and highly efficient appliances. Application of triple glazed windows with a low U-value of 0.68 W/m^2K has also helped to achieve a good glazing to floor area ratio of 25 % providing sufficient natural lighting while maintaining low heat-losses through the window (Barratt Developments PLC).

Fig. 10.15 Barratt Green House

10.4 Application of the ZEH Construction Criteria to the Refurbishment Phases of the Existing Buildings

The reduction of buildings' environmental impacts is an internationally agreed agenda. Energy conservation and carbon emission reduction drove the quest to design, build and operate high performing and zero energy buildings in order to meet national carbon reduction target agendas. However, existing buildings will continue to offset any new construction savings if not addressed. In fact, existing buildings finds it increasingly difficult to compete with the high performing new construction. Hence, retrofitting of existing building stocks offers significant opportunities for reducing global energy consumption and greenhouse gas emissions.

Contextual data from developed and developing countries all comfort the need to consider the retrofitting of the existing building stock, with the residential sector leading the way as a dominant building type. In Europe, the residential sector represents 75 % of the built environment and in many of these countries the housing stock is over 50 years old. The UK, for example has the oldest stock with around 27 million existing housing units, while only around 120,000 new housing units are build every year. In many developing countries the residential building stock is often newer, but has been developed under the pressure of fast mass production, lacking any building energy efficiency measures, resulting on uncomfortable living homes and energy intensive building operation. Establishing common global standards for high performance retrofitting is difficult as building conditions vary greatly from one country to another. However, initiatives to address existing building retrofitting are fast developing. Examples of retrofitting initiatives, cases, standards and tools as well as challenges and key drivers are addressed in this section.

10.4.1 ZEH Retrofitting Standards and Tools

Producing Net Zero Energy buildings by the target 2030 date (Architecture 2030 2015) drove numerous initiatives including revisiting building codes and standards, development of building rating systems, design and development of design and assessment tools aiming at producing or retrofitting buildings. This section presents some of the efforts, relevant related standards and tools applicable to energy efficient and Zero energy buildings' retrofitting.

The recently published ANSI/ASHRAE/IES Standard 100-2015 addressing the Energy Efficiency in Existing Buildings, derives from an extensive revision of the 2006 version, is intended to be a code-enforceable standard for adoption by local authorities (ASHRAE 2015). The standard provides comprehensive and detailed descriptions of the processes and procedures for the retrofit of existing residential and commercial buildings in order to achieve greater measured energy efficiency. It provides the minimum requirements for energy efficient design and operation of existing buildings. Included in the revised standards are criteria for energy use surveys, auditing and requirements related to implementation and verification. Additionally, life-cycle cost analysis procedures as well as identification of potential energy conservation measures are included in appendices. The standard structure is based on setting a single upper limit on site energy use (kBtu/sqft/year) for each of 48 commercial and institutional building types and 5 residential building types in 17 climate zones. Energy use calculation includes all fuel, steam, hot water, chilled water and electricity crossing the building site boundary, net of energy exported from the building (including excess production of electricity and thermal energy).

ASHRAE's Vision 2020 on the other hand is an ad hoc committee that sets to develop guidance and strategy for the development of energy-related products, research in renewable energy systems, and the sequencing of the various identified activities that will produce net zero energy usage for all types of facilities by 2020. It targets a building community, including those who design, build and operate buildings, that will create or retrofit market-viable net zero energy buildings by the year 2030 (ASHRAE 2020 Vision 2008).

Energy efficient home retrofitting has spurred numerous guideline programs, aiming to assess viability and guide the retrofitting process. In this category, the European Retrofit Advisor developed an online decision tool (E2Rebuild) to assess the viability of retrofitting strategies. The vision of E2ReBuild is to transform the retrofitting construction sector from the current craft and resource based construction towards an innovative, high-tech, energy efficient industrialised sector (E2Rebuild 2015). In the US, the Regreen program was developed through a partnership of the American Society of Interior Designers and the U.S. Green Building Council (USGBC) (Regreen 2008). It guides a green home retrofit and addresses the major elements of a green retrofit, including site consideration, energy and atmosphere, material and resources and indoor environmental quality. It provides product selection, building system integration and technologies into integrated green strategies (Regreen 2008). Similarly, the E-Retrofit-Kit or the passive house retrofit Concept kit is a European initiative to provide a tool kit that guides an energy efficient home retrofit. Social housing companies in 14 mainly northern European countries were given the chance to benefit from a tool kit designed to help them carry out retrofitting in such a way as to considerably reduce primary energy consumption (by up to 120 kWh/m^2 a year). The tool kit includes best practices, “Passivhaus” standards and a methodology that guides the retrofitting process (E-Retrofit-Kit 2015a, b).

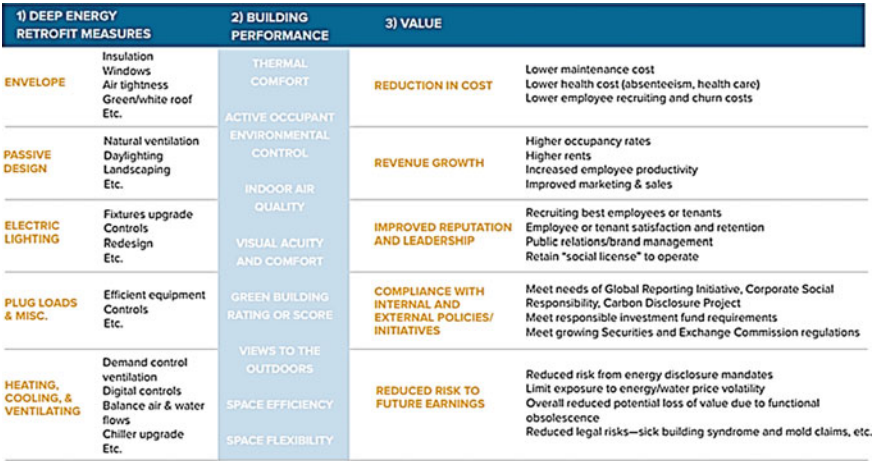
10.4.2 Process, Barriers and Drivers to ZEH Retrofitting

The challenges of a ZEH retrofitting are similar in nature to new ZEH construction. Challenges lie both within the decision-making process as well as within the retrofitting process itself. Lack of knowledge of the decision makers for retrofitting in general and limited awareness of owners are the initial barrier. Additional obstacles are of financial (investment costs) and social nature (building architectural and cultural value, structure of ownership). Further, the existing building structure and technical system may limit retrofitting potential. Direct actions that will benefit the existing housing retrofitting include review of policies, codes and standards processes, innovative financial scenarios and business models, awareness campaigns, training and industrial collaboration to standardize the process (Sutherland 1991; Dowson et al. 2012; Yudelson 2010; Building Technologies Program 2010; ZenN 2013; Anderson and Roberts 2008).

The key drivers to greening existing buildings, beyond concerns over energy use and carbon emission, are anticipated to lay in the following (Yudelson 2010)

- Return on investment
- Building occupants, tenants and stakeholders pressure
- Responsible property investing and future market competitiveness
- Corporate sustainability associated with leadership position
- Concern over energy prices and future volatility

Deep energy retrofit includes measures that not only increase energy efficiency but also improve other performance factors such as indoor air quality, thermal and



1) DEEP ENERGY RETROFIT MEASURES

ENVELOPE	Insulation Windows Air tightness Green/white roof Etc.
PASSIVE DESIGN	Natural ventilation Daylighting Landscaping Etc.
ELECTRIC LIGHTING	Fixtures upgrade Controls Redesign Etc.
PLUG LOADS & MISC.	Efficient equipment Controls Etc.
HEATING, COOLING, & VENTILATING	Demand control ventilation Digital controls Balance air & water flows Chiller upgrade Etc.

2) BUILDING PERFORMANCE

THERMAL COMFORT
ACTIVE OCCUPANT ENVIRONMENTAL CONTROL
INDOOR AIR QUALITY
VISUAL ACUITY AND COMFORT
GREEN BUILDING RATING OR SCORE
VIEWS TO THE OUTDOORS
SPACE EFFICIENCY
SPACE FLEXIBILITY

3) VALUE

REDUCTION IN COST	Lower maintenance cost Lower health cost (absenteeism, health care) Lower employee recruiting and churn costs
REVENUE GROWTH	Higher occupancy rates Higher rents Increased employee productivity Improved marketing & sales
IMPROVED REPUTATION AND LEADERSHIP	Recruiting best employees or tenants Employee or tenant satisfaction and retention Public relations/brand management Retain "social license" to operate
COMPLIANCE WITH INTERNAL AND EXTERNAL POLICIES/ INITIATIVES	Meet needs of Global Reporting Initiative, Corporate Social Responsibility, Carbon Disclosure Project Meet responsible investment fund requirements Meet growing Securities and Exchange Commission regulations
REDUCED RISK TO FUTURE EARNINGS	Reduced risk from energy disclosure mandates Limit exposure to energy/water price volatility Overall reduced potential loss of value due to functional obsolescence Reduced legal risks—sick building syndrome and mold claims, etc.

Fig. 10.16 Deep energy retrofitting measures, building performance and overall impacts (RetroFit Depot 2012)

visual comfort, which in turn create a benefit such as improved occupant health, organizational reputation and property value (Fig. 10.16).

10.4.3 Examples; Zero Energy Mass Housing Retrofitting

High performing residential retrofit cases are readily available and documented (Baeli 2014). Technologies to retrofit a house to net-zero energy consumption are now within the realm of possibility, but while it is possible, large-scale housing retrofits remain limited. Examples of ZEH individual retrofitting cases do exist, although not as numerous as new construction. Mission Zero House in Ann Arbor, MI, is one example of a Net Zero Energy Home retrofit, certified under the Living Building Challenge (Living Building Challenge 2015). The project initiated by the owners is a historic rehabilitation with the dual challenge to upgrade the house to the highest energy efficiency standards achievable today while preserving its mandated historic heritage. The strategies included insulation and sealing the building through an upgrade of the single pane window glass to low-e storm windows, wall, basement and attic insulation and photovoltaic panels covering a whole side of the roof (Fig. 10.17).

The above is an example of a deep-green renovation that can be achieved in the existing housing stock. However, it remains of limited value when it comes to mass housing retrofitting, especially with the financial and social restrictions it usually carries.

In this regard, the Dutch government driven initiative referred to as is seen as an achievement venture of zero energy social housing retrofitting (Energiesprong 2015a). Energiesprong is considered as one successful result of the Dutch

Fig. 10.17 Mission Zero House—Ann Arbor, MI (Mattgrocoff 2010)

Government funded Platform 31 program, an innovative program that brings together different actors for out-of-the-box thinking and approaches to complex problems. The result is a renovation program that commits to refurbish existing buildings (mainly social housing) to net zero energy, within a week, at zero cost to the tenant, a 30-year builder's guarantee and no subsidies. So far, 800 units have been retrofitted in the Netherlands and 100,000 are planned to undergo the same. The program calls for mass demand for deep refurbishments and is based on aims to meet the following criteria:

1. Quality and energy performance guarantee; by implementing quality standards, manufacturing and delivery methods, inspection and verification that enable a long-term performance warranty to be offered. The net zero energy refurbishment package needs to come with a long year (i.e. 30) energy performance warranty on the house, backed usually by an insurer.
2. Affordability; assured performance, coupled with mass-customized industrialization and delivery process efficiencies, will reduce costs and allow for the refinancing of the upfront investment. This will be achieved through guaranteed

energy cost savings (energy performance contracting), generation of on-site renewables and real estate value improvements and will thus make the solution affordable, independent of public grant. The ability to finance an investment requires a business case and in this case, the net present value of the energy cost savings over the lifetime of the package sets the price target.

3. Desirability: low disruption, fast process, improved aesthetics and comfort levels, increased asset value of individual dwellings plus neighborhood renewal and social impact of mass implementation (hassle-free solution) (Energiesprong UK 2015b). Quick delivery and least occupants interference (one week in this case); The instalment of the packaged does not require more than one week and allow occupants to continue living in the house for the greater part of the works.

Success ingredients overcoming a set of traditional barriers have been jointly considered in the Energiesprong venture and resulted so far in a growing experience that is being extended to the United Kingdom and France. The main idea behind this program is a transition of the building sector from project to product. The refurbishment drives the construction to innovate and start developing and producing integrated solutions that are industrialized instead of project based. The second idea resides in the financial trade off, i.e. cost versus performance, while fostering new industry collaborations (Fig. 10.18).

The result is an improved energy performance of the existing housing with added real estate and aesthetic value (Fig. 10.19).

Fig. 10.18 Prefabricated elements designed for a fast renovation of social housing, Energiesprong or the Dutch experience (Energiesprong 2015a, b)

Fig. 10.19 Examples of mass housing retrofitting in the Netherlands (Energiesprong 2015a, b)

10.5 Conclusions

Zero Energy Homes (ZEHs) have been receiving an increased attention in recent years as a result of constant concerns for energy supply constraints, decreasing energy resources, increasing energy costs and rising negative impacts of greenhouse gases on global climate. Among different strategies for decreasing the energy consumption in the building sector, ZEHs have the promising potential to significantly reduce or eliminate the total energy use, as well as to increase the overall share of renewable energy use. There are many different possible combinations of passive design energy-efficiency measures, utility equipment and on-site energy generation technologies able to achieve the net zero energy performance; thus, there is no common standard approach to designing a zero energy building. Nonetheless, this chapter attempted to define ZEHs with parameters that help demonstrate the cases. It also extended to identifying criteria applied to the design, construction and operation of new and refurbished zero carbon homes. The examples presented in this chapter led to clarify the possibility of calibrating net zero operational energy performance in housing where a passive design approach that helps reduce the energy demands can be considered a base for the progression and active technologies such as PV systems are supplied with the aim to cover or exceed the remainder of energy use in most cases.

References

Aelenei L (2012) Design issues for Net Zero-Energy Buildings. Oral presentation at the ZEMCH 2012 Conference, Glasgow, 20–22 Aug 2012

Aelenei L, Lollini R, Gonçalves H, Aelenei D, Noguchi M, Donn M, Garde F (2011) Passive cooling approaches in Net-Zero Energy Solar Buildings: lessons learned from demonstration buildings. In: CISBAT2011 Conference, Lausanne, 2011

Aelenei L, Aelenei D, Gonçalves H, Lollini R, Musall E, Scognamiglio A, Cubi E, Noguchi M (2013) Design issues for Net Zero-Energy Buildings. Open House Int Zero Energy Mass Custom Home Res Paradigms 38:7–14

Aelenei L, Gonçalves, H, Aelenei D (2013) The nZEBs in the near Future Overview of definitions and guidelines towards existing plans for increasing nZEBs. Paper presented at the Portugal SB13, Guimarães, 30 Oct 2013–1 Nov 2013

Anderson R, Roberts D (2008) Maximizing residential energy savings: net zero energy home technology pathways. Technical report NREL/TP 550-44547. National Renewable Energy laboratory, Golden

Architecture 2030 (2015) The 2030 challenge. http://www.architecture2030.org/2030_challenge/the_2030_challenge. Accessed 23 Nov 2015

ASHRAE (2015) Standard 100-2015, energy efficiency in existing buildings (ANSI Approved/IES Co-sponsored). I.P edition. The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA

ASHRAE 2020 Vision (2008) Producing Net Zero Energy Buildings. https://www.ashrae.org/file%20library/doclib/public/20080226_ashraevision2020.pdf. Accessed 28 Nov 2015

Ayoub J (2009) Factsheet towards Net Zero Energy Solar Buildings. Task40/Annex 52, Solar Heating and Cooling, Quebec

Baeli M (2014) Residential retrofit: twenty case studies. Edition RIBA Publishing, London

Barratt (2013) The Barratt House. Barratt Developments PLC. http://www.bre.co.uk/filelibrary/Innovation_Park/Barratts_Green_HouseBrochure.pdf. Accessed 29 Nov 2015

Black C, Ooteghem KV, Boake TM (2010) Carbon neutral steel building systems research project—a case study investigating the relationship of operational energy and embodied energy in achieving a holistic carbon neutral retail building. In: Proceedings of american solar energy society, national solar conference 2010, Phoenix, 2010

BRE (2013) Building research establishment. www.bre.co.uk/innovationpark. Accessed 02 Aug 2013

Building Technologies Program (2010) Summary of gaps and barriers for implementing residential building energy efficiency strategies. Building America, Building Technologies Program, U.S. Department of Energy, http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/49162.pdf. Accessed 29 Nov 2015

Buildoffsite (2012) Buildoffsite Review 2012: The business case for offsite. Buildoffsite, London

Burwood S, Jess P (2005) Modern methods of construction: evolution or revolution. BURA Steering and Development Forum, London

Carmichael C, Managan K (2013) Reinventing existing buildings 8 steps to net zero energy. Institute for Building Efficiency, Johnson Controls Inc, Milwaukee

Chen Y, Athienitis AK, Galal KE, Poissant Y (2007) Design and simulation for a solar house with building integrated photovoltaic-thermal system and thermal storage. ISES Solar World Congress, Beijing, vol 1. Springer, Heidelberg, p 327, 18–21 Sept 2007

DCLG (2006) Code for sustainable homes: a step-change in sustainable home building practice. Department for Communities and Local Government, London

DCLG (2007a) Building a greener future: policy statement. Department for Communities and Local Government, London

DCLG (2007b) Final regulatory impact, assessment building a greener future. Department for Communities and Local Government, London

DCLG (2008a) Definition of zero carbon homes and non-domestic buildings. Department for Communities and Local Government, London

DCLG (2008b) The code for sustainable homes setting the Standard in Sustainability for New Homes. Department for Communities and Local Government, London

DCLG (2009) Code for sustainable homes, impact assessment. Department for Communities and Local Government, London

DCLG (2011) Cost of building to the code for sustainable homes updated cost review. Department for Communities and Local Government, London

DCLG (2013) Annual Report and Accounts 2013–14. Department for Communities and Local Government

DECC (2009) Climate act impact 2008 assessment. Department of Energy and Climate Change, London

DECC (2011) Energy consumption in the UK: 2013. Department for Energy and Climate Change, London

Dowson M, Poole A, Harrison D, Susman G (2012) Domestic UK retrofit challenge: drivers, barriers and incentives leading into the Green Deal. Energy Policy 50:294–305

Energiesprong (2015a) Transition zero http://energiesprong.nl/wp-content/uploads/2014/06/Transition_zero.pdf. Accessed 28 Nov 2015

Energiesprong UK (2015b) Transition zero. http://www.energiesprong.eu/. Accessed 28 Nov 2015

EPBD (2010) The Directive 2010/31/EU of the European Parliament on the Energy Performance of Buildings Directive (EPBD recast). Official Journal of the European Union, 53

E-Retrofit-Kit (2015a) European retrofit advisor. http://www.e2rebuild.eu/en/events/workplan/pd/retrofitadvisor/Sidor/default.aspx. Accessed 28 Nov 2015

E-Retrofit-Kit (2015b) Tool-kit for “Passive House Retrofit”—Intelligent Energy Europe. http://retrofit.energieinstitut.at/. Accessed 28 Nov 2015

EST (2009) Low carbon futures: zero carbon case studies: CE310. Energy Saving Trust, London

Frattari A (2013) CasaZeroEnergy: an Italian prototype of zero energy building. Open House Int 2013(38):277–286

Goodman C (2011) Lifetime homes design guide. HIS BRE Press for Habinteg Housing Association, London UK

Hashemi A, Hadjri K (2013) Code for Sustainable Homes: opportunities or threats for offsite manufacturing and mass-customization? In: Proceedings of ZEMCH 2013 international conference: the visibility of zero-energy housing, University of Miami, Miami, USA, 30 October 2013–1 November 2013

Heffernan E, Pan W, Liang X (2012) Delivering zero carbon homes in the UK. In: Smith SD (ed) Proceedings 28th annual ARCOM conference, Edinburgh, Association of Researchers in Construction Management, pp 1445–1454, 3–5 Sept 2012

Heinze M, Voss K (2009) Goal: ZERO ENERGY BUILDING Exemplary experience based on the solar state solarsiedlung Freiburg am Schielrberg, Germany. J Green Build 4(4):93–100

Hermelink A (2013) Towards nearly zero-energy buildings: definition of common principles under the EPBD. Ecofys, London

HM Treasury (2015) Fixing the foundations: creating a more prosperous nation. Presented to Parliament by the Chancellor of the Exchequer by Command of Her Majesty, London

International Energy Agency Solar Heating and Cooling Task 40 / ECBCS Annex 52 (2012) Towards Net Zero Energy Solar Buildings (NZEBs). http://task40.iea-shc.org/publications. Accessed 28 Nov 2015

Kingspan (2009) Level 6 net-zero carbon house, fact file, lighthouse, Kingspan. www.kingspanlighthouse.com/pdf/lighthouse.pdf. Accessed 01 Aug 2013

Liao L, Athienitis AK, Candanedo L, Park KW, Poissant Y, Collins M (2007) Numerical and experimental study of heat transfer in a BIPV-thermal system. J SolEnergy Eng 129:423–430

Living Building Challenge (2015) Mission Zero House, http://living-future.org/case-study/missionzero. Accessed 28 Nov 2015

Marszal AJ, Heiselberg P, Bourelle JS, Musall E, Voss K, Sartori I, Napolitano A (2011) Zero energy building—a review of definitions and calculation methodologies. Energy Building 43:971–979

Mattgrocoff (2010) Ann Arbor, MI—Mission Zero House—Own work. Licensed under CC BY-SA 3.0 via Wikimedia Commons. https://commons.wikimedia.org/wiki/File:America%27s_Oldest_Net_Zero_Energy_Home_color_corrected_Grocoff.jpg. Accessed 28 Nov 2015

McManus A, Gaterell MR, Coates LE (2010) The potential for the Code for Sustainable Homes to deliver genuine 'sustainable energy' in the UK social housing sector. Energy Policy 38 (4):2013–2019

Miles J, Whitehouse N (2013) Offsite housing review. Construction Industry Council, London

Noguchi M (2008) Net Zero-energy home design strategies learned from Canadian experience. Open House Int 33(3):88–95

Osmani M, O'Reilly A (2009) Feasibility of zero carbon homes in England by 2016: a house builder's perspective. Build Environ 44(9):1917–1924

Regreen (2008) Residential remodeling program. http://www.regreenprogram.org. Accessed 28 Nov 2015

Retrofit Depot (2012) Guide for building the case for deep energy retrofits. RMI—Rocky Mountain Institute, Boulder

RMI (2015) Energy retrofits. RMI—Rocky Mountain Institute, Boulder

Sartori I, Napolitano A, Voss K (2012) Net Zero Energy Buildings: a consistent definition framework. Energy Build 48:220–232

Sutherland RJ (1991) Market barriers to energy-efficiency investments. Energy J 12(3):15–34

Torcellini P, Pless S, Deru M (2006) Zero Energy Buildings: a critical look at the definition. Paper presented at the ACEEE Summer Study Pacific Grove, National Renewable Energy Laboratory D. Crawley U.S. Department of Energy, California, 14–18 Aug 2006

Voss K, Musall E, Lichtmeß M (2011) From low energy to Net Zero-Energy Buildings: status and perspectives. J Green Build 6:46–57

Voss K, Sartori I, Lollini R (2012) Nearly-zero, Net zero and plus energy buildings—how definitions & regulations affect the solutions. REHVA HVAC J 06:23–27

Yudelson J (2010) Greening existing buildings, McGraw-Hill's Greensource Series. McGraw-Hill Education, London

ZenN (2013) Common barriers and challenges in current nZEB practice in Europe. ZenN—Nearly Zero energy Neighborhoods, IVL Swedish Environmental Research Institute, Stockholm

Zero Carbon Hub (2011) Allowable solutions for tomorrow's new home: towards a workable framework. Zero Carbon Hub, London

Zero Carbon Hub (2013) Zero carbon strategies for tomorrow's new homes. Zero Carbon Hub, London