Chapter 3
Zero-Energy Buildings

A *zero-energy building*, also known as a zero net energy (ZNE) building, is a popular term to describe a buildings use with zero net energy consumption and zero carbon emissions annually.

Zero-energy buildings can be used autonomously from the energy grid supply—energy can be harvested on-site usually in combination with energy-producing technologies such as solar and wind while reducing the overall use of energy with extremely efficient HVAC and lighting technologies. The zero-energy design principle is becoming more practical in adopting due to the increasing costs of traditional fossil fuels and their negative impact on the planet's climate and ecological balance.

The zero net energy consumption principle is gaining considerable interest as renewable energy harvesting as a means to cut greenhouse gas emissions. Traditional building use consumes 40% of the total fossil energy in the US and European Union. In developing countries many people have to live in zero-energy buildings out of necessity. Many people live in huts, yurts, tents, and caves exposed to temperature extremes and without access to electricity. These conditions and the limited size of living quarters would be considered uncomfortable in the developed countries.

The development of modern zero-energy buildings became possible not only through the progress made in new construction technologies and techniques, but it has also been significantly improved by academic research on traditional and experimental buildings, which collected precise energy performance data. Today's advanced computer models can show the efficacy of engineering design decisions.

Energy use can be measured in different ways (relating to cost, energy, or carbon emissions) and, irrespective of the definition used, different views are taken on the relative importance of energy harvest and energy conservation to achieve a net energy balance. Although zero-energy buildings remain uncommon in developed countries, they are gaining importance and popularity. The zero net energy

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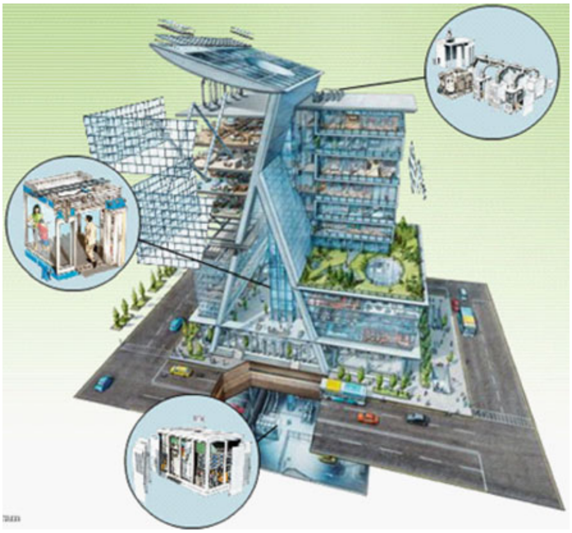

Fig. 3.1 Zero-energy building approach

approach has potential to reduce carbon emissions, and reduce dependence on fossil fuels.

A building approaching zero net energy use may be called a “near-zero energy building” or “ultra-low energy house”. Buildings that produce a surplus amount of energy during a portion of the year may be known as “energy-plus buildings” (Fig. 3.1).

If the building is located in an area that requires heating or cooling throughout parts of the year, it is easier to achieve zero net energy consumption when the available living space is kept small.

Advanced HVAC and lighting controls are the “brains” behind the intelligent operation of zero-energy buildings. Controls that improve the intelligent response of building systems include the following characteristics:

- Direct digital controls (DDCs) with electronic ancillary devices for both central equipment control and zone-level management
- Integration into one central BAS
- Interoperability achieved through an open protocol standard

The benefits of a ZEB usually are as follows:

- Isolation for building owners from future energy price increases
- Increased comfort due to more uniform interior temperatures
- Reduced requirement for energy austerity
- Reduced total cost of ownership due to improved energy efficiency
- Reduced total net monthly cost of living
- Improved reliability—photovoltaic systems have 25-year warranties—seldom fail during weather problems

- Extra cost is minimized for new construction compared to an afterthought retrofit
- Higher resale value as potential owners demand more ZEBs than available supply
- The value of a ZEB relative to similar conventional building should increase every time energy costs increase
- Future legislative restrictions, and carbon emission taxes/penalties may force expensive retrofits to inefficient buildings.

The disadvantages of a ZEB will be as:

- Initial costs can be higher—effort required to understand, apply, and qualify for ZEB subsidies
- Very few designers or builders have the necessary skills or experience to build ZEBs
- Possible declines in future utility company renewable energy costs may lessen the value of capital invested in energy efficiency
- New photovoltaic solar cells equipment technology price has been falling at roughly 17% per year—it will lessen the value of capital invested in a solar electric generating system—current subsidies will be phased out as photovoltaic mass production lowers future price
- Challenge to recover higher initial costs on resale of building—appraisers are uninformed—their models do not consider energy
- Climate-specific design may limit future ability to respond to rising-or-falling ambient temperatures (global warming)
- While the individual house may use an average of net zero energy over a year, it may demand energy at the time when peak demand for the grid occurs. In such a case, the capacity of the grid must still provide electricity to all loads. Therefore, a ZEB may not reduce the required power plant capacity
- Without an optimized thermal envelope the embodied energy, heating and cooling energy and resource usage is higher than needed. ZEB by definition does not mandate a minimum heating and cooling performance level thus allowing oversized renewable energy systems to fill the energy gap
- Solar energy capture using the house envelope only works in locations unobstructed from the South. The solar energy capture cannot be optimized in south facing shade or wooded surroundings.

The most cost-effective steps toward a reduction in a building's energy consumption usually occurs during the design process. To achieve efficient energy use, zero-energy design departs significantly from conventional construction practice. For a successful zero energy building design we have to combine time-tested passive solar, or natural conditioning, principles that work with the on-site assets. Sunlight and solar heat, prevailing breezes, and the cool of the earth below a building, can provide day lighting and stable indoor temperatures with minimum mechanical means.

Fig. 3.2 Zero-energy dwellings

ZEBs are normally optimized to use passive solar heat gain and shading, combined with thermal mass to stabilize diurnal temperature variations throughout the day, and in most climates are super insulated.

All the technologies needed to create zero-energy buildings are available off-the-shelf today. A zero-energy building is capable of providing tenants with all of these desired building features (Fig. 3.2).

Advanced HVAC control systems enable greater tenant control of temperature, ensure more comfortable temperatures throughout the building, monitor indoor air quality, and give facilities managers the information and control they need to quickly respond to tenant complaints. Smart buildings are also designed to allow easy reconfiguration of suite layout (Fig. 3.3).

Sophisticated 3D computer simulation tools are available to model how a building will perform with a range of design variables such as building orientation (relative to the daily and seasonal position of the sun), window and door type and placement, overhang depth, insulation type and values of the building elements, air tightness (weatherization), the efficiency of heating, cooling, lighting, and other equipment, as well as local climate. These simulations help the designers predict how the building will perform before it is built, and enable them to model the economic and financial implications on building cost benefit analysis, or even more appropriate—life cycle assessment.

Zero-energy buildings are built with significant energy-saving features.

The heating and cooling loads are lowered by using high-efficiency equipment, added insulation, high-efficiency windows, natural ventilation, and other techniques. These features vary depending on climate zones in which the construction occurs. Water heating loads can be lowered by using water conservation fixtures, heat recovery units on waste water, and by using solar water heating, and high-efficiency water heating equipment.

In addition, day lighting with skylites or solartubes can provide 100% of daytime illumination within the home. Nighttime illumination is typically done with fluorescent and LED or high powered LED lighting that use one-third or less power than incandescent lights, without adding unwanted heat. And miscellaneous electric loads can be lessened by choosing efficient appliances and minimizing phantom loads or standby power.

Fig. 3.3 Zero energy house

Other techniques to reach net zero (dependent on climate) are Earth sheltered building principles, super insulation walls using straw-bale construction, Vitruvian built pre-fabricated building panels and roof elements plus exterior landscaping for seasonal shading.

Zero-energy buildings share a set of characteristics that set them apart from other buildings. These characteristics include:

- Advanced HVAC and lighting controls
- Smart metering capabilities, allowing central access to real-time utility data
- A structured cabling infrastructure with high bandwidth and connectivity
- Adaptability to changing technology and tenant needs

Zero-energy buildings are often designed to make dual use of energy including white goods; for example, using refrigerator exhaust to heat domestic water, ventilation air and shower drain heat exchangers, office machines and computer servers, and body heat to heat the building. These buildings make use of heat energy that conventional buildings may exhaust outside. They may use heat recovery ventilation, hot water heat recycling, combined heat and power, and absorption chiller units.

The goal of green building and sustainable architecture is to use resources more efficiently and reduce a building's negative impact on the environment. Zero-energy buildings achieve one key green-building goal of completely or very significantly reducing energy use and greenhouse gas emissions for the life of the building. Zero-energy buildings may or may not be considered "green" in all areas, such as reducing waste and using recycled building materials, etc. However, zero-energy, or net-zero buildings do tend to have a much lower ecological impact over the life of the building compared with other 'green' buildings that require imported energy and/or fossil fuel to be habitable and meet the needs of occupants.

Because of the design challenges and sensitivity to a site that are required to efficiently meet the energy needs of a building and occupants with renewable energy (solar, wind, geothermal, etc.), designers must apply holistic design principles, and take advantage of the free naturally occurring assets available, such as passive solar orientation, natural ventilation, day lighting, thermal mass, and night time cooling.

The first consideration in a ZEB is to maximize efficiency in the building's energy demand or load. Designers should minimize the electricity load by utilizing integrated energy design strategies such as building envelope improvements, day

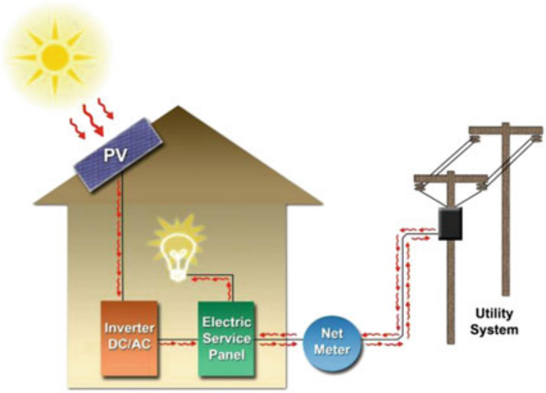

Fig. 3.4 Zero-energy house using PV system

lighting techniques, and natural ventilation applications (refer to various energy design resources design briefs).

Additionally, installing energy-efficient lighting and cooling equipment throughout a building minimizes energy loads. The goal is to minimize the building's energy needs and then supplement the remaining loads supplied by the local utility grid with PV-generated electricity. By minimizing the electricity needs and utilizing for example BIPV, the designer maximizes the potential energy cost savings (Fig. 3.4).

Just as a building should be designed to maximize energy efficiency, another system such as a BIPV system should be designed to optimize electrical output. It is important to note that the availability of solar radiation generally matches commercial building electric loads throughout the day and throughout the year. For example, typical energy use for office buildings peaks near midday and during the summer season, the time when there is the greatest solar potential. For maximum energy output, it is important to determine the orientation, tilt angle, size and location of the BIPV system in relation to the building site and design. Flexibility exists in the placement (tilt and orientation) of BIPV, so it is best to match the time of day, month, and season when peak solar generation occurs with the peak electrical needs of the building.

Generally, there is no simpler way to save energy than turning off equipment when it is not needed that means scheduling equipment operation and "locking out" equipment operation when conditions warrant.

Needless operation after hours and on weekends is one of the largest energy wasters in commercial buildings. HVAC and lighting systems can be scheduled at the zone level, so that systems in unoccupied areas can be shut down.

Optimum start produces energy savings by starting equipment only as early as required to bring the building to set point at the time it will be occupied and optimum stop strategy determines the earliest possible time to turn off equipment before unoccupied periods begin and still maintain occupant comfort.

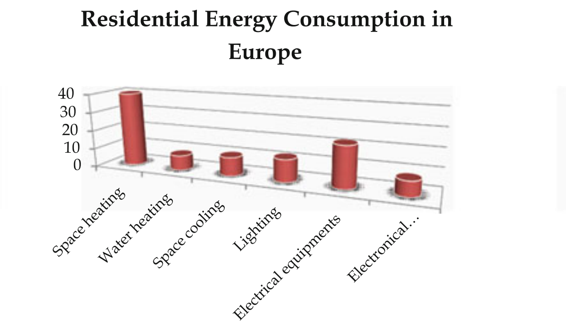

Fig. 3.5 Energy consumptions in European houses

Another technique is to bring the building to the desired temperature before occupancy after a night setup or setback with the least amount of energy, by closing outside air dampers.

In climates with a large nighttime temperature depression (dry climates), purging or flushing the building with cool outside air in the early morning hours can delay the need for cooling until later in the morning.

The boiler, the chiller, and associated pumps can be locked out above a set outside air temperature, by calendar date, or when building heating requirements are below a minimum.

In a ZEB it is needed to eliminate demand spikes by programing time delays between startup of major electrical load-generating equipment so that the startup peak loads stay below the peak demand later in the day. In general, there are two characteristics to reduce energy consumption and to make a ZEB:

- Clear and understandable using energy methods.
- Correct and describe a system that will actually perform its intended functions.

In an era of rising energy prices and increasing concerns about the adverse effects rising energy demand could have on the environment, there are tremendous opportunities in energy efficiency and conservation.

Efficiency and conservation represent vast and relatively untapped domestic energy resources capable of reducing the need for more costly production-side expansions in electricity generation. In transitioning to a new energy economy, the European Union can take the leading role by promoting energy efficiency to create even stronger economies, greener communities, and a healthier environment (Fig. 3.5).

Energy efficiency truly represents an undiscovered gold mine of energy and cost savings across Europe. If every country in Europe adopted energy efficiency best practices, the need for new generating facilities in the region could be reduced by as much as 75% over the next 15 years, the equivalent of 100 new large power-generating facilities. Project estimates a regional net economic gain of 37 billion euros, along with improved air quality, water savings, and reductions in regional greenhouse gas emissions.

Public and residential buildings offer energy-saving opportunities because they represent roughly one-third of all energy consumption in the EU. Homes and public buildings serve as foundations upon which the EU can begin to build an energy-efficient future.

Develop demand-side management tools, such as near-zero energy use in homes, energy efficiency improvements in older homes, energy-saving programs offered through utilities and smart infrastructure across the grid.

Public buildings must set a model example in energy-efficient and green building designs. Given the long, but often tight financing schedules for public buildings, there are tremendous opportunities to utilize performance-based financing mechanisms that fund and service buildings with long-term energy savings that accumulate throughout the lifetime of a building. They offer a win–win scenario: performance-based contracts pay for themselves and often achieve 25% or greater energy savings than conventional construction projects.
The greatest potential to generate energy efficiency gains:

- Improving energy efficiency education
- Strengthening code performance
- Rewards and incentives for energy-efficient practices
- Manage energy demand for efficiency results
- Decoupling and regulatory restructuring to remove utility impediments
- Innovative financing for public building projects.

Near-zero energy homes are built, operated, and maintained to achieve at least a 50% or greater improvement in energy performance over conventionally built homes through a combination of energy efficiency improvements and the use of on-site renewable energy systems, such as photovoltaic (PV) panels and solar thermal hot water systems to produce as much energy as the home consumes on an annual basis. They feature comfortable and traditional-looking home designs that perform well and require only standard maintenance.

Near-zero energy homes are growing in their potential to become more cost-effective for homeowners. PV panels often present a significantly higher initial cost by adding up to 20,000 euros to the price of a new home. However, near-zero homes have demonstrated energy savings that reduced homeowner utility bills by 60% or more, offsetting higher mortgage payments.

In many countries, tax credits and utility incentives are available to reduce the initial cost of efficiency features and renewable energy systems for builders and/or homeowners. To encourage greater investment and savings returns in near-zero homes, EU can offer compelling incentive options to stimulate investment in near-zero energy homebuilding.

Using smart infrastructure could be expanded to create a positive rate impact. In cases where utilities have the ability to charge time-of-use rates, many smart meters determine real-time price peaks, allowing residential customers to adjust their energy use to off-peak hours. An increasing number of utilities also offer voluntary “cycling” programs that deactivate electricity transmission to air-conditioning units by remote control as a way for customers to save energy during periods of peak energy demand without affecting home comfort. Time-of-use rate programs are encouraged to complement smart meter use.

The following tools and actions could encourage building occupants to capture greater energy savings from demand-side management programs:

- Employ greater use of smart infrastructure and metering to shape consumer awareness of electricity consumption.
- Expand smart infrastructure to serve as the price driver, charging time-of-use or off-peak pricing and installing new meters to have a rate impact.
- Allow demand-side management to be utilized to the fullest extent possible by including it in the rate base.
- Meet long-term demand needs by including DSM considerations as an integral component of energy portfolios.
- Encourage utilities to write comprehensive energy efficiency plans.
- Create a report card of utility EE best practices to determine what programs are working and collaboratively develop a matrix for effective program delivery and evaluation.
- Formulate a simple, efficient, and consistent method of tracking energy efficiency, such as quantifying DSM efforts in KWH per unit over time.
- Encourage utilities to put more energy efficiency information on utility bills to serve as important educational tools by including suggestions for reducing customer demand or statistics comparing electricity consumption to neighboring homes or normalized use.
- Include state energy efficiency goals as part of state renewable portfolio standards (RPS).
- Develop pilot programs within local governments that initiate and showcase construction efforts for near-zero homebuilding.

Construction of a ZEH involves many of the same materials and technologies familiar to the building trades and homeowners. Opportunities to reduce energy use exist in all areas of the home. The first opportunity to save energy is to reduce space heating and cooling and water heating loads.

This often means that more insulation is required, along with attention to other important features such as air infiltration moisture barriers, and ventilation. Major equipment in the home should also be of the highest efficiency that is affordable, and be sized and installed correctly. This includes the furnace, air-conditioner, and water heater as well as the duct and piping systems that deliver air and water to the outlets.

The next opportunity to reduce energy loads is to use higher efficiency lighting and appliances. The final opportunity is to be aware of energy use on a daily basis and turn off lights and appliances when not in use. Once the home's energy use requirements are reduced, a photovoltaic (PV) system is installed to provide the electricity used in the home and offset electricity supplied by the utility when averaged over the course of 1 year.

The means to achieving a successful ZEH are not the same for all homes. There are new building systems that can be used to increase the insulation of the walls and the roof, including structural insulated panels (SIPS), insulated concrete forms (ICF), and typical frame wall systems which can be used with new types of insulation.

Research into energy-efficient construction techniques will prove fruitful in designing and constructing the most energy efficient home for the least amount of money.

Some smart solutions to make a zero-energy building are:

1. *Decrease the energy requirements for space heating, cooling, and water heating:*
   - Orient the home with smaller walls facing west and include overhangs and porches
   - Increase foundation, wall, and ceiling insulation
   - Use low U-value, low-E windows in all climates and low solar heat gain (low SHGC) windows in cooling climates
   - Seal all holes, cracks, and penetrations through the floor, walls, and ceiling to unconditioned spaces
   - Install adequate ventilation, especially from kitchens and baths
2. *Increase the efficiency of the furnace (or heat pump), and the air-conditioner:*
   - Buy as high-efficiency equipment as affordable for the climate
   - Design the supply and return duct system appropriately and seal tightly using approved tapes or mastic
   - Consider ground-source heat pump technology where space and cost conditions permit
   - Where climate-appropriate consider alternative cooling systems such as ventilation only or evaporative coolers
3. *Install a solar hot water preheat system, an efficient backup water heater, and an efficient distribution system:*
   - Consider a parallel, small diameter piping system for the hot water outlets
   - Install low-flow fixtures
   - Choose water heating equipment with a high energy factor
   - Look for a knowledgeable solar hot water installation company
   - Evaluate solar systems
4. *Install efficient lighting fixtures:*
   - Consider permanent fluorescent fixtures in as many locations as possible
   - Look for the ENERGY STAR® label
5. *Install efficient appliances:*
   - Include the refrigerator, dishwasher, and laundry appliances
   - Look for the ENERGY STAR label
   - Compare appliance efficiencies

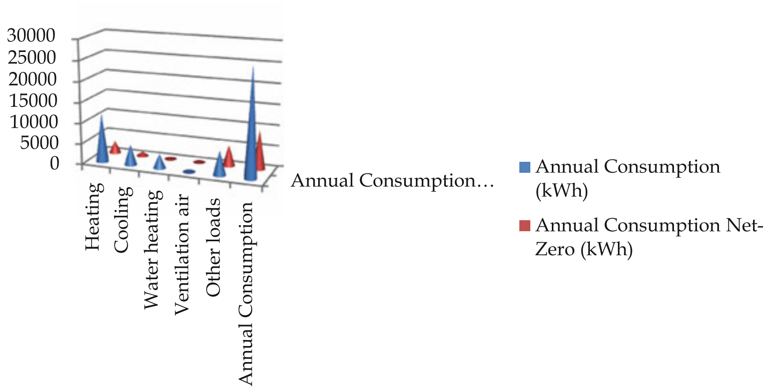

Fig. 3.6 Comparison of a zero-energy building and a typical construction one

6. *Install a properly sized photovoltaic system:*

- Look for a knowledgeable solar PV installation company
- Evaluate tax and other incentives
- Use PVWATTS for a quick estimate of PV output
- Find a certified solar PV installer

7. *Turn off lights, computers, and appliances when not in use*

The successful zero-energy home (ZEH) doesnot end with the designer and builder. The homeowner plays an extremely important role as they do with any well-maintained home. Throughout the life of the home, the homeowner has the most significant impact on the actual performance of the ZEH. Therefore, the ZEH homebuyer must be conscious of daily habits and patterns that affect energy use in the home as well as proper maintenance of equipment and appliances (Fig. 3.6).

For instance, understanding the way certain energy efficiency features of the home work such as programmable thermostats or photo-sensitive outdoor light fixtures are essential.

Simple things such as turning off lights when leaving a room or closing doors when performing even quick tasks outdoors can eliminate “wasted” energy. Paying careful attention to actual energy needs and avoiding unnecessary energy use are the first steps in ensuring that the ZEH performs as it was designed and built.

Secondly, as with any valued property, equipment in the home and the structure itself must be carefully maintained. Changing furnace filters, having heating and cooling systems cleaned regularly, periodically checking the operation of solar systems, and maintaining exterior caulking and painting are only a few examples of ways in which a homeowner can assure a long-lived, high-performance, and zero-energy home.

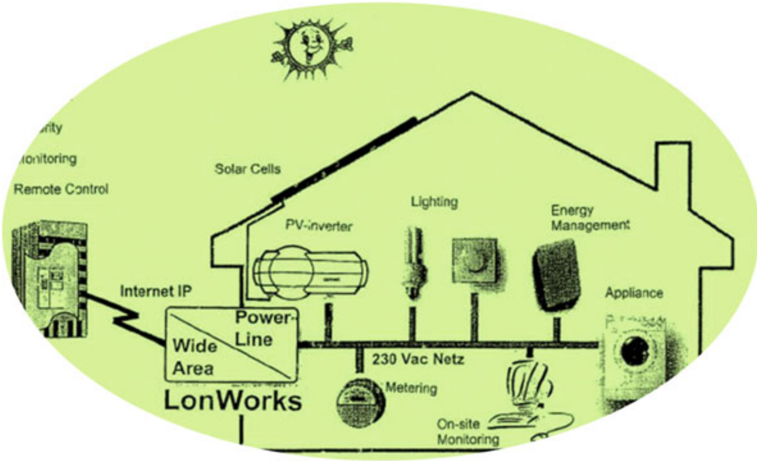

Fig. 3.7 Zero-energy smart house

A zero-energy home combines high levels of energy efficiency with renewable energy systems to annually return as much energy to the utility as it takes from the utility—resulting in a net-zero energy consumption for the home (Fig. 3.7).

Questions

1. What is a zero-energy building?
2. Give some simple solutions to make a zero-energy building?
3. Give some advantages and disadvantages of a ZEB?
4. How could encourage the homeowners to get a zero-energy house?
5. What are the characteristics of a zero-energy building?