NET-ZERO ENERGY BUILDINGS: DESIGNING TO NATURE'S BUDGET

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Summary

This paper will describe the concept of NZE buildings and how the result of migrating to their large scale deployment will force the built environment to live within the energy budget provided by nature. This has long been one of the "Holy Grails" of the strong sustainability movement. In addition this paper will provide information on the growth of the photovoltaic industry supporting the deployment of NZE buildings, and discuss the state of the art of current U.S. residential and commercial NZE buildings. Finally the barriers and problems with the NZE concept will be described to provide closure on this subject. The increasing cost of energy and international pressure to address climate change are forcing some major shifts in high performance building strategies in the U.S. and elsewhere around the world. Coupled with lower construction costs, tax breaks and other incentives, and more favorable pricing for renewable energy systems, particularly photovoltaics, the implementation of net-zero energy (NZE) strategies for commercial and residential construction is rapidly moving from concept to reality. Migrating to NZE buildings is being embedded in U.S. energy strategy and California has already mandated NZE residential buildings by 2020 and NZE commercial buildings by 2030 (Wendt 2008).

Keywords: net-zero energy, high performance buildings, renewable energy, photovoltaics

1 Overview

The built environment is a major consumer of resources, both in its construction and operation. Buildings consume about one-third of global energy, and the built environment continues to grow as population, affluence, and urbanization increase. In the U.S., buildings consume 40% of primary energy, while the industrial sector consumes 32% and transportation accounts for 28%. According to Torcellini, Pless, Deru and Crawley (2006), commercial and residential buildings use almost 40% of the primary energy and approximately 70% of the electricity in the United States. The power required to heat and cool buildings causes about 40% of greenhouse gas (GHG) emissions, and if current trends continue, buildings will be the major energy consumers by 2025, using as much energy as industry and transportation combined. The challenge is to develop radically new, holistic strategies that can reverse this trend and reduce both energy and GHG emissions. One of the hopeful new strategies is the development of net-zero energy (NZE) buildings which, over the course of a year, produce as much energy from renewable sources as they consume, the result being buildings that are energy self-sufficient. According to Madsen (2007), "the U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) in a June 2006 conference paper titled *Assessment of the Technical Potential for Achieving Zero-Energy Commercial Buildings*, 22 percent of buildings today have the potential to be ZEBs. Through advancements in technology, an estimated 64 percent of buildings could be ZEBs by 2025.” This statement embodies the ideal that although net zero energy building is not a brand new concept, it is still in its infancy. With the tremendous amount of money that the current U.S. presidential administration has allocated for research and development in the building sector, the idea of net zero energy building is growing in popularity and implementation.

As a side note, by way of a deal reached on 17 November 2009, the European Union is expected to enact laws to set energy efficiency standards for all public buildings by 2018 and thereafter all commercial buildings and homes. Converting existing buildings to near-zero energy standards was a major part of negotiations that took place between European Parliament and Council in hopes of using the public sector as an example for the rest of Europe’s buildings and homes. All new buildings built after 2020 must rely mostly on renewable energy under this plan. By mid-2011, EU Member States must identify financial and other incentives for the transition, such as technical assistance, subsidies, loan schemes and low interest loans.

2 The NZE Concept

In general it is assumed that the NZE building is connected to the grid and that energy flows to and from the grid over the course of a typical day. Rather than have an energy storage system on-site, the grid is used as the storage device. The following are several variants of the definition of NZE buildings by the U.S. National Renewable Energy Laboratory (Torcellini, Pless, Deru and Crawley 2006; Malin and Boehland 2005):

2.1 Zero-net-annual site energy

This is probably the most commonly understood definition for NZE buildings and the concept is that on an annual basis, an equal amount of energy is exported from the building footprint as is imported in the form of electricity and/or natural gas. The site generated energy is normally electricity and the accounting is done at the site boundary. Energy derived from wood on-site or methane generated onsite are not included in the accounting, only energy generated within the building footprint.

2.2 Zero-net-annual source energy

The total energy used off-site to generate the energy imported to the building must be matched by on-site generated energy. In the U.S. for electrical energy, each unit of energy generated requires a factor of 3 units of fuel energy. For natural gas 1.1 units of fuel energy are required to deliver each unit of natural gas energy to the building. This definition tends to favor the use of fossil fuels over electricity as an energy source.

2.3 Zero-net-annual energy cost

For a zero-net-annual energy cost building, the amount of money collected by the building owner from the utility for exporting on-site generated electricity is equal to the electric and natural gas utility bills. Because natural gas is cheaper, less site generated electricity can be used to offset the same amount of natural gas energy.

2.4 Zero-net-annual emissions

This definition is based on offsetting the emissions of the energy source used to power the building and generally refers to greenhouse gas (GHG) emissions. As a result another name for a zero-net-annual emissions building is a *climate neutral building*. Offsets can be created by onsite generated PV electricity, or through the purchase of, for example Renewable Energy Certificates (RECs) or Green Tags that support the generation of off-site renewable energy.

Although NZE generally applies to individual buildings, it can also be applied to groups of buildings. For example a recently completed research report into the feasibility of using PV energy at large scale by the Florida Department of Transportation concluded that it was possible to make large turnpike plazas self-sufficient for meeting their energy needs (Kibert et al. 2010). A description of this project is included as a case study in this paper.

Occupant behavior is an important factor which must not be ignored in NZE building design. A factor of 3 difference in home energy use has been observed even in co-housing communities where environmental awareness is generally high. Being able and willing to shift to natural ventilation, for example, by opening doors and windows, makes achieving NZE performance achievable.

3 Energy Budget for NZE Buildings

Achieving NZE buildings is a challenging process because it is heavily dependent on several factors, all of which must be favorably addressed for a building to achieve this level of performance:

- The building must be designed to consume the minimum energy possible.
- The occupants must be willing to conserve energy in the operation of the building (system scheduling, setpoints, maintenance, recommissioning)
- A feedback and control system designed to inform occupants and assist in reducing energy consumption must be provided.
- Adequate site and building roof area must be available for installation of a renewable energy system, most often PV system.

These factors point to some significant constraints on PV powered NZE buildings. An average PV panel may generate about 110 Kwh/m^2 annually which represents a highly efficient commercial office building. A NREL study which monitored six relatively efficient office or academic buildings across the U.S. concluded that a single story office building could achieve NZE performance but that a two story building could not (Torcellini et al. 2004). If additional area is available over parking areas or other on-site locations, then there is potential for multi-story NZE buildings. If collecting wind energy is feasible, then much larger NZE building, even high-rise buildings may have potential.

Solar insolation worldwide varies from about 1000 Kwh/m2/year to a maximum of about 2500 Kwh/m2/year. Figure 1. indicates the annual solar insolation for the U.S., Spain, and Germany. For a NZE built environment based on PV technology, the location of the building, the energy footprint of the building, and the efficiency of the PV technology limit the number of floors in the building, assuming it were to be completely solar powered (See Figure 2.).

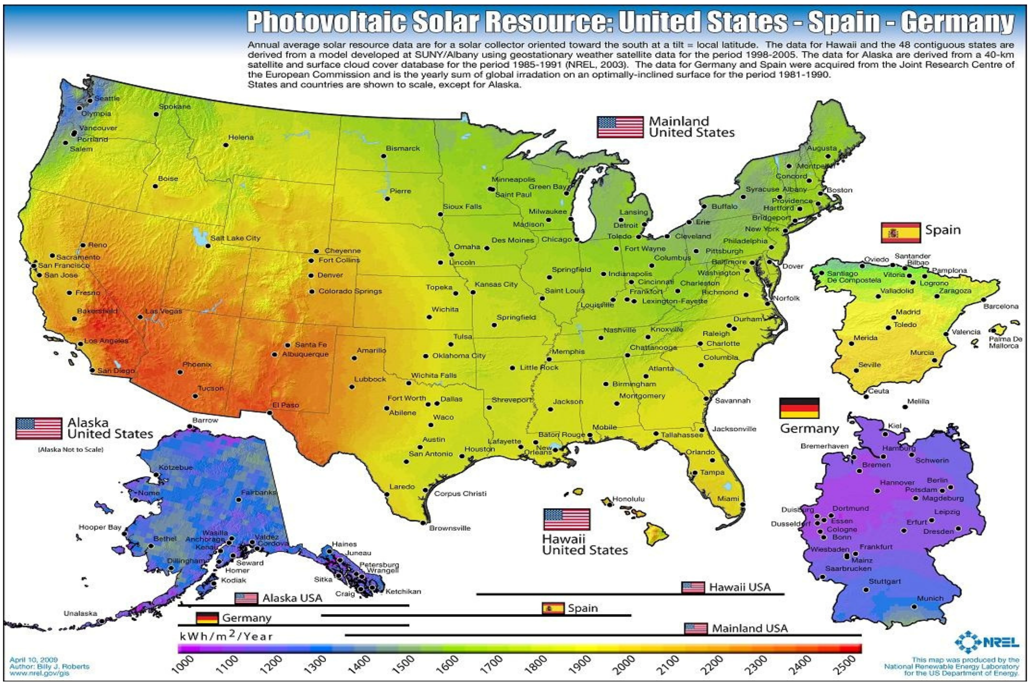

Fig. 1 Annual solar insolation in the U.S. far exceeds that of Germany and is comparable to the solar energy experienced in Spain and North Africa (Source: National Renewable Energy Laboratory)

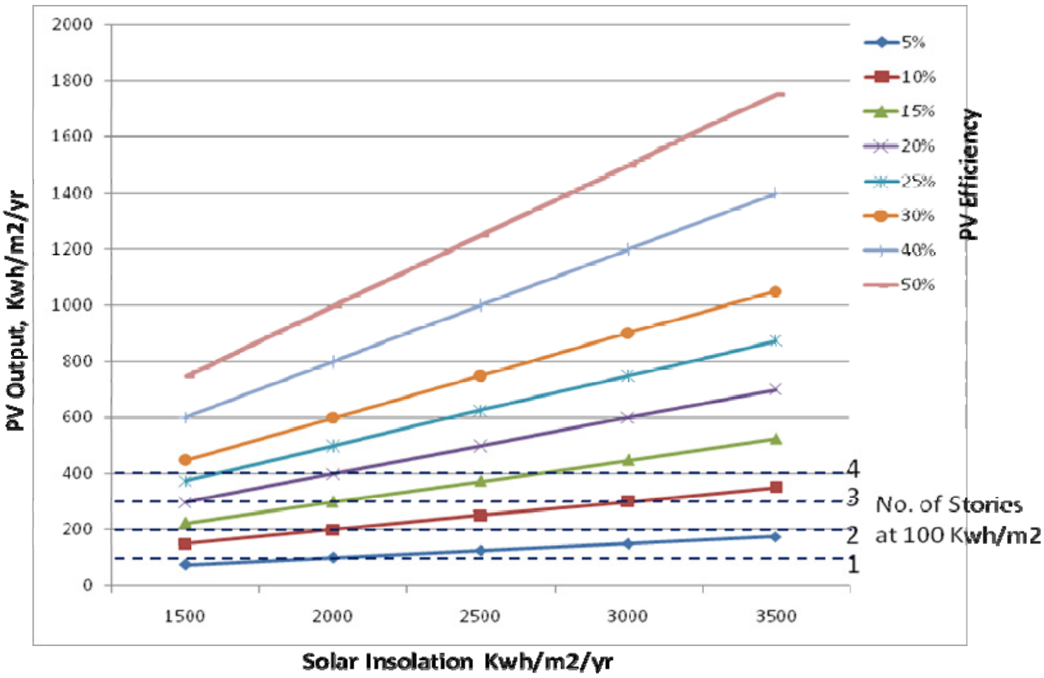

Fig. 2 The number of building stories feasible for a NZE building will be a function of its energy footprint, its location, and the type of technology being employed.

4 Status of U.S. Photovoltaic Industry and Photovoltaic Installations

The demand for solar PV is growing rapidly as indicated in Figure 3. which shows data for world PV market growth in 2008, the last full year for which data is available. Figure 2. indicates present and future forecasted growth in the global PV market. U.S. demand for PV in 2008 was just 6% of world demand but the economic downturn, a new administration favorable to renewable energy investments, a growing public demand for significant utility investment in renewable, may change this scenario.

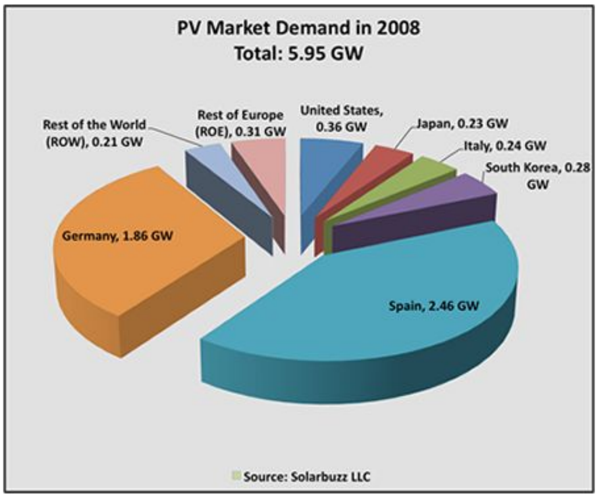

Fig. 3 Figure 3. Solar PV market demand for 2008 reached 5.95 GW. (Source: solarbuzz.com 2010)

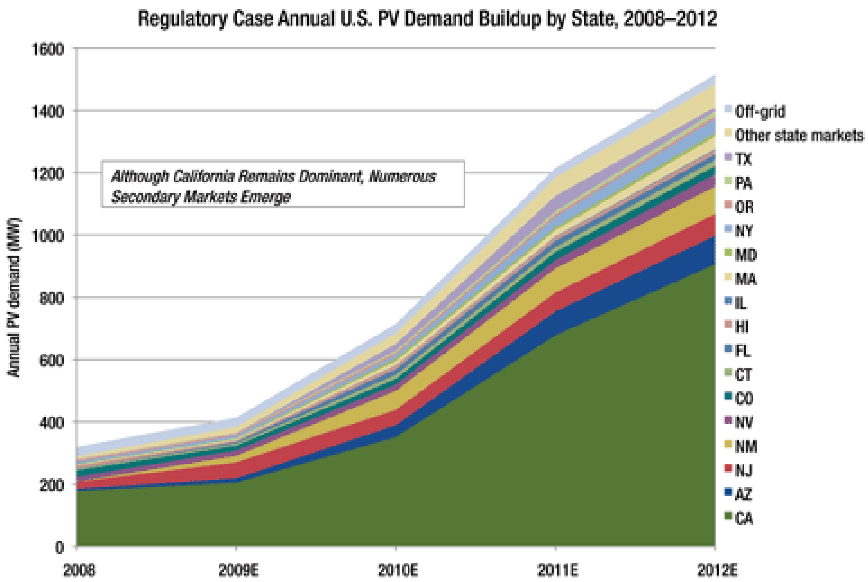

Fig. 4 Annual buildup of demand by U.S. State 2008-2012 in MW of annual installation (Greentech Media 2010)

In spite of the lagging U.S. market compared to Spain, Germany, and Japan over the next four years, the U.S. may well experience the most rapid demand growth of any major PV market. Base case U.S. PV demand indicates growth to 1,515 MW in 2012, with annual growth from 2008 to 2012 averaging 48 percent. The upside scenario sees demand reaching 2,022 MW in 2012. During this period, the U.S. surpasses Spain, and potentially Germany, to become the leading global PV market. Although California's market share remains relatively steady at around 50 percent of national capacity second-tier markets gain increasing value as their absolute size increases. The U.S. market is unique in the world because it is actually comprised of 50 state markets with various programs and incentives inducing PV installations (See Figure 4.). Renewable Portfolio Standards (RPS) in which a state requires its utilities to generate a minimum level of electricity via renewables is one of several forces causing the growth of solar PV in the U.S. By 2012, combined base case demand from leading secondary states Arizona, New Jersey, New Mexico, New York, Nevada and Massachusetts reaches 376 MW. A recent December 2009 forecast by Greentech Media Inc. indicates that the cost of PV generation and grid electricity is rapidly converging (Greentech Media 2010). In their report,Greentech Media modeled 16 states to determine when post-incentive PV generation costs and grid electricity will converge. Each state offers an incentive package that favors some market segments over others. Price convergence in these markets is heavily sector-dependent. States with high levels of demand, such as New Jersey and California, have already experienced price convergence in particular market segments, while others stand on the precipice. By 2012, 11 of 16 states will have surpassed price convergence in the commercial sector, and ten will have done so in the residential sector. The active engagement of solar developers offering Purchase Power Agreements (PPA), assisted by substantial finance and tax incentives, is obviating the need for capital investment by residential and commercial customers.

The U.S. has enormous potential for renewable energy for both solar and wind applications. Solar insolation ranges from about 8 KWh/m^2/day in some areas of the southwest to 6 in Hawaii to about 5.5 in Florida, 4 in the northeast, 3.5 KWh/m^2/day in portions of the Pacific northwest, and to 3 KWh/m^2/day or less in Alaska. On the average it is in the 4 to 6 KWh/m^2/day range over most of the U.S. (See Figure 5.) By some estimates virtually all of the energy needs of the U.S. could be met by solar thermal or solar electric energy systems. At present the total grid connected solar PV is about 800 MW out of a total 1,000 GW of generating capacity in the U.S., about 0.1% of generating capacity. This compares to wind energy which now comprises 35,000 MW of generating capacity, a factor of more than 40 greater than solar PV.

5 Net Zero Energy Commercial Buildings

Research and development of NZE commercial buildings became national policy in the U.S. by virtue of the Energy Security and Independence Act of 2007 (ESIA 2007) which established the Net-Zero Energy Commercial Buildings Initiative. The stated goal of this initiative is: To develop and disseminate technologies, practices, and policies for the development and establishment of net-zero energy commercial buildings for: (1) Any commercial building newly constructed in the U.S. by 2030; (2) 50 percent of the commercial building stock of the U.S. by 2040; and (3) All commercial buildings in the U.S. by 2050 (NSTC 2008 and Butcher 2009). In addition to national and state policy drivers behind the move to produce NZE commercial buildings, the recent launch of the Building Energy Quotient (Building EQ) program by the American Society of Heating, Refrigeration and Airconditioning Engineers (ASHRAE) in December 2009 poses NZE buildings as the highest achievement level for a commercial buildings (See Figure 6.) (ASHRAE 2009).

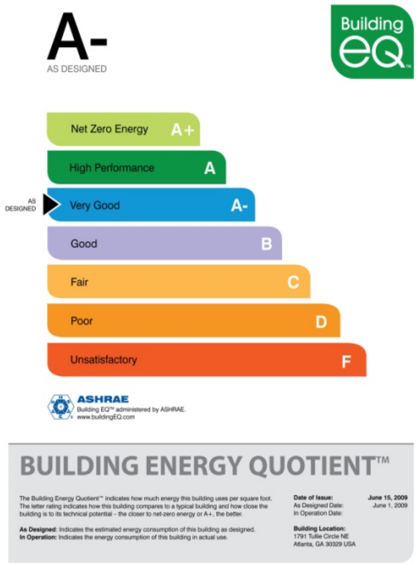

Fig. 5 The ASRAE Building EQ label reserves the highest level of building energy performance, an A+, for NZE buildings (ASHRAE 2009).

In fact at present there are just eight few non-residential buildings in the U.S. Zero Energy Buildings Database and most of these are relatively small buildings (See Table 1.)

Tab. 1 List of non-residential NZE buildings in the U.S. (USDOE 2010)

Name	**Location**	**Building Type**	**Floor area, m^2**
Aldo Leopold Center	Wisconsin	Commercial office	1,190
Audubon Center at Debs Park	California	Recreation center	502
Challengers Tennis Club	California	Recreation building	350
Environmental Technology Center	California	Higher education/laboratory	220
Hawaii Gateway Energy Center	Hawaii	Commercial office	360
IDeAs Z2 Design Facility	California	Commercial office	656
Oberlin College Lewis Center	Ohio	Higher education/library	1,360
Science House	Minnesota	Museum/interpretive center	153

6 Net Zero Energy Homes (NZEH)

Of particular importance in reducing U.S. energy consumption are residential buildings, especially single family homes. Table 2. indicates the characteristics of housing in the U.S. from the latest version of “American Housing Survey for the United States” for the year 2007. Although most housing is comprised of the existing housing stock, an enormous number of new homes, estimated at 34 million, were forecast to be constructed between 2005 and 2030 (McKinsey Company 2007). Consequently rapidly raising the bar for new residential construction is crucial to reducing U.S. energy consumption and shifting to renewable energy resources.

Tab. 2 Characteristics of Residential Buildings in the United States (AHS 2008)

Total Housing Units (millions)	Single-Family Houses (millions)	Multifamily Housing (millions)	Manufactured Housing (millions)
128.2	87.5	31.9	8.7

Some jurisdictions are already making policy changes that would require NZEH and other buildings in the not too distant future. Every two years, the California Energy Commission (CEC) releases an Integrated Energy Policy Report in which it makes recommendations for energy policy in the state, including changes to Title 24, the energy efficiency portion of the building codes (Pfannenstiel and Geesman 2007). In its 2007 report, CEC recommended adjusting Title 24 to require net-zero-energy performance in residential buildings by 2020 and in commercial buildings by 2030. The CEC believes that new legislation to incorporate these goals is not needed and is already moving to put them in place. The goals set in California were inspired by the 2030 Challenge goals, in which the nonprofit organization, Architecture 2030, called for no fossil fuel use by buildings by 2030. California's goals are focused on net-zero-energy performance instead of fossil fuel use. CEC based its definition of net-zero-energy performance, and many of its recommendations, on a report by the California Public Utility Commission (CPUC), which states that a goal of "no net purchases from the electricity or gas grid" may be met with energy-efficient design and "onsite clean distributed generation."

On September 5. 2007 the City Council of Austin, Texas passed a resolution to establish the Zero Energy Capable Homes (ZECH) program which requires new single-family homes to be ZNE capable by 2015 (Austin 2007). These homes will be 65% more efficient than homes built to the Austin Energy Code in 2006, and it will be cost-effective to install renewable on-site generation and become zero energy homes. The program will be implemented in phases. The first of four planned local amendments to the International Energy Conservation Code (IECC) was approved by the City Council in October, 2007. Austin's program demonstrates that increasing energy efficiency and decreasing greenhouse gas emissions can both be cost-effective. When the increased cost of building the home is rolled into a 30-year mortgage, reduced energy costs are greater than increased mortgage payments. Historically, the main obstacle to adopting effective energy codes has been resistance from the home building industry and affordable housing advocates, due to cost concerns. Austin overcame this resistance by forming a task force that included representatives from these groups as well as industry trade associations, energy efficiency advocates, the Electric Utility Commission, Texas Gas Service, and City Staff. A positive and productive task force addressed the needs of stakeholder groups, increased buy-in from the community, enhanced participation in the program, and will help insure the long-term success of the project. These program's initial amendments increased the overall efficiency of homes by 11% and electric energy efficiency by 19%. For 2008, based on average annual construction of 6,400 new homes, this translates into an annual reduction of 9,367 metric tons of CO2. The first amendments also reduced annual household energy consumption by 2515 kWh and 4 therms of gas. This decreases household energy costs by $227.68 per year, with an estimated payback of 5.2 years. And finally, the changes will reduce SO_2 emissions by 3.9 tons and NO_x by 19.8 tons.

On July 14, 2009 General Electric unveiled plans for a "Net Zero Energy Home" project which combines GE's most efficient appliances and lighting, the company's new energy management systems, and GE power generating and storing technologies in new home construction (LaMonica 2009). When applied together, the system would enable a homeowner to achieve net zero energy costs by 2015. The Net Zero Energy Home project – and new smart grid consumer poll data from the U.S. and the U.K. – were introduced at GE's smart grid symposium at its Global Research Center in upstate New York. As part of the company's Ecomagination strategy, the GE Net Zero Energy Home offerings will be comprised of three major groups within the product portfolio: energy efficient products including appliance and lighting products that will reduce energy consumption in the home; energy management products that will enable consumers to manage their costs and energy consumption; and energy generation/storage products like solar PV, advanced energy storage and next generation thin film solar that will play an integral part in the net zero energy home. In 2010 GE will introduce the *Home Energy Manager*, their version of a central nervous system for the Net Zero Energy Home that will work in conjunction with all the other enabling technologies in the home to help homeowners optimize how they consume energy. GE will also introduce a line of smart thermostats in 2010 that, together with the Home Energy Manager, will inform consumers on their energy use and empower them to make smarter decisions on their energy

Key to the NZEH strategy are radical improvements in the energy performance of homes, with reductions in typical home energy consumption on the order of 60% to 70% needed to bring NZEH to reality. This improvement in performance, coupled with advanced control technology and an optimized feedback system, and on-site generation of electricity from solar photovoltaic systems, provides a realistic and achievable pathway to NZEH's. Although NZEH's are rapidly becoming a reality, there are several gaps in technology that make the transition difficult. The advent of the smart grid will help close some of the key gaps needed to make the overall building stock shift to a NZE status. A smart grid uses digital technology to improve reliability, security, and efficiency (both economic and energy) of the electric system from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources (DOE/OEDER 2008a). The information networks that are transforming our economy in other areas are also being applied to applications for dynamic optimization of electric system operations, maintenance, and planning. Resources and services that were separately managed are now being integrated and rebundled as society addresses traditional problems in new ways, adapts the system to tackle new challenges, and discovers new benefits that have transformational potential.

Although the smart grid provides some level of data that a homeowner can access to understand and respond to reduce their energy consumption, it does not provide adequate feedback for a NZEH owner to be immediately aware of the home's energy consumption profile and patterns. Additionally the owner must log into a utility website to view data that is not real time and not adequately fine-grained for response. Ultimately the control of a NZEH and the integration of feedback loops will be key to the successful implementation of this concept. An Advanced Controls System for Net Zero Energy Homes (AFCS-NZEH) will have two major components: (1) an automatic control system that minimizes energy consumption based on inputs by the owner to the controller, and (2) a real-time feedback system that provides the homeowner with information on energy generation, consumption, and costs, and allows the NZEH owner to change strategies based on their response to the feedback.

The automatic control system will be connected, either via hard-wiring or wireless connection, to the major energy consuming devices in the home: air-conditioning, hot water heater, refrigerator, range, clothes dryer, lighting system, and plug loads. It will also be connected to the renewable energy system powering the home to optimize its performance based on conditions. For example it could be used to help a photovoltaic (PV) system track the sun to maximize electricity production and could provide information about the performance of the system to indicate any unexpected degradation of performance. The control system would similarly monitor all major appliances to assess their performance and indicate when performance is degraded. For an air-conditioning system this could occur due to dirty filters, leaking coolant, corroded and condenser or evaporator coils. The control system could, for example, close windows or indicate windows are open when the air-conditioning system is operating. It could also indicate when outside conditions are such that leaving the windows open during cooler periods would minimize energy consumption. Indoor air quality (IAQ) will be also be monitored with ventilation air controlled via the automatic control system.

The feedback component of the AFCS-NZEH will provide the owner with real-time information about the energy performance of the home including instantaneous power consumption , daily energy consumption and costs, monthly and billing period energy consumption and costs, renewable energy generation and energy value, and net energy for the month and billing period. It could also provide other information such as trends in consumption, energy generation, net energy, and performance of major systems. As important, the feedback system would allow the owner to alter the current strategy of the home by changing setpoints and schedules and providing them the opportunity to change their behavior. For example, if energy consumption was trending to exceed energy production, the owner could raise the setpoint of the air-conditioning system from 24^{o}C to26^{o}C. The owner could opt to hang clothes out to dry instead of using electrical energy for this purpose or they could opt to purchase a clothes dryer that relies on much higher spin rates to remove moisture from clothes. They would be informed that perhaps plug – loads are trending high and also be informed of the levels of so-called *vampire loads*. Vampire loads are energy consumption caused by computers, printers, chargers for cell phones, ipods, home video games, microwaves, laptops, and high definition televisions, the sum of which can add 10% to 20% to the energy consumption of an average home. By using smart switches connected to the feedback component that turns off devices that cause vampire loads, significant reductions in energy consumption can be experienced.

7 Summary and Conclusions

Strategies and technologies to create NZE buildings are a response to rapidly rising energy prices and the imperative to take action regarding climate change. National, state, and local jurisdictions throughout the U.S. are embracing the NZE approach as one that can successfully address these challenges and provide building owners with a degree of control and energy independence. The development of several technologies that are critical to the support of NZE buildings is rapidly advancing, namely PV panel efficiency, appliance efficiency, feedback and control systems, and increased lighting efficiency. The NZE concept can be applied not only to individual buildings but also to groups of buildings served by a renewable energy system. One limitation of the NZE concept is that, at present energy consumption levels, it is very difficult to apply to single story buildings, and virtually impossible to a multi-story building, unless substantial site area is available for PV systems. In spite of the difficulties in implementation, it appears that NZE marks a major shift in high-performance green buildings, one that combines extreme energy conservation and efficiency with renewable energy systems to produce buildings that are energy self-sufficient.

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