Undergraduate Alternative Energy Resources Research Project: A Short Investigation of the Net-Zero Energy House

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Abstract

This paper is a part of alternative energy resources class which required students to conduct research on topics related to alternative/renewable energy resources to increase students' research, technical writing and presentation skills. A brief exploration which serves to unravel the concept, application, and understanding of the Net Zero Energy House is discussed. This paper considers various systems presently used in Net Zero Energy homes in order to gain appreciation for the application of theory. Additionally, the importance of design, preplanning, and modeling is covered.

1. Introduction

A net-zero energy house (NZEH) is described as a building that generates as much energy as it consumes. This energy is produced on location implementing various alternative energy resources[1]. The components of the NZEH will be explored in moderation in order to develop an introductory level understanding of the design and integration of the NZEH. Basic examples of each specific component will be considered so that an up-to-date application of each is realizable.

It is most important to note that a NZEH is a theoretical concept. These buildings are very complex because they take into consideration the most up to date energy-efficient building designs, technical systems, building materials, and equipment. This is done so to minimize the heating and electrical demand, sustainability, and mitigation of CO_2 emissions. A NZEH can be classified as a building having one or more of the following characteristics; energy generation on building footprint, on-site generation from on-site renewable sources with no source transportation, on-site generation from off-site renewable resources, off-site generation, or off-site supply[2].

2. Photovoltaic Panel Installation

It is observed that it is most suitable and favored to implement PV arrays as one of the forerunning electrical generation techniques in a NZEH. Solar radiation is always available and there is a plethora of free energy via the sun. There is very little, if any, maintenance on a PV system. This is mostly attributed to the absence of moving parts. The roof mounted PV system is also favored because it takes advantage of already unused space; the roof. Costs are reduced as PV panels replace roof shingles and house siding where applicable[1]. There are also software simulations available to see the effect of shading and temperature on the panels to predict their operational behavior such as maximum output power, voltage and current[3].

2.1. Array Design I: The Solar Decathlon is a biennial competition which poses the challenge to develop and construct a functioning NZEH to students and professors in the collegiate field. This competition yields intuitive solutions; one solution was proposed by a team from the University of Illinois at Urbana-Champaign.

The PV electrical system for which the team chose to implement was comprised of two separately distinct parts. The first being a roof-mounted array and the second being an array integrated into the canopy of the front egress, see Figure 1.

Figure 1: Canopy PV system[4]

The roof-mounted array consisted of various SunPower modules. The canopy implemented a Sanyo HIT PV array. The primary array had a dc rating of 5.52 kW and consisted of twenty-four 230 W monocrystalline modules connected in three parallel strings. These modules were connected to an ac rated 5 kW, grid-tied inverter. There were four rows of six panels. These panels were tilted at an angle of 37˚ to the horizontal. The canopy array's characteristics are as follows; dc rating of 1.17 kW with six 195W heterojunction with intrinsic HIT modules. These modules were connected to an ac rated 1.5 kW, grid-tied inverter. The HIT modules are bifacial, meaning sunlight can be collected from both sides of the PV panel. This application maximizes direct light captured, but also reflected light from the walls of the house.

Each inverter implements a maximum power point tracking algorithm so that adjustments can be made to the impedance presented to the photovoltaic modules in order to extract the maximum power[4].

2.2. Array Design II: Another team, two years prior to the aforementioned group from the same university, embarked upon the Solar Decathlon, too. This team implemented a singular PV system. It consisted of forty 225 W monocrystalline modules, see Figure 2. The dc induced by the PV panels was converted to ac power by the use of two 5 kW grid-tied inverters. These inverters, similar to those of the previous team, supplied schemes for protection against islanding. The PV array was south facing at an angle of 45˚ to the horizontal.

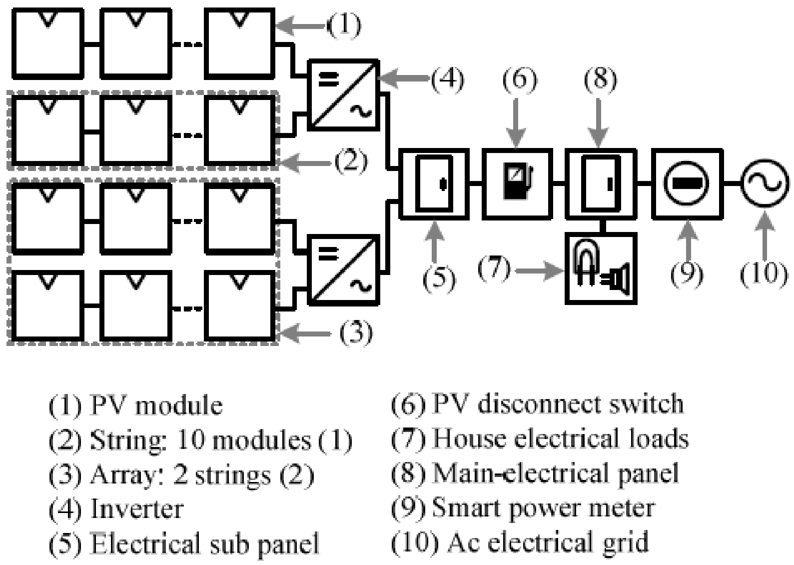

Figure 2: Block Diagram Depicting Electrical System[5]

This was done such that maximum solar energy could be captured throughout the entirety of a year. The inverters also have integrated dc disconnects. These disconnects make the design much simpler. An electrical sub panel is implemented to combine the output of the two inverters[5].

3. Heating

3.1. Passive Solar: When implementing passive solar energy it is important to consider the location and climate of the region. In climates where heating takes precedence over cooling, the building should be designed such that its long side is facing the sun. This provides more opportunity for the sun's radiation to heat the home. In climates where cooling is most desired, the long axis of the home should be perpendicular to the south. This will provide less area for the solar radiation to affect[6].

It is best practice to have the most area of windows facing south to enhance heat capture. This is most beneficial in the winter months. Door heights, window sill heights, overhangs, and window header heights should be designed and placed to optimize the use of the solar energy. For example, height and width of roof overhangs will depend on specific solar exposure and climate. These are factors are most important upon determination of passive solar heating feasibility. Design focus should be to optimize heat gain in winter and avoidance of excessive heat gain in the summer[6].

3.2. Space Heating System: Heating, being a substantial source of cost, must be considered in order to minimize costs associated with the NZEH. It is possible in implement the following as reasonable sources of heat; active solar thermal with radiant floor, baseboard heating, or coil heating from the energy recovery ventilation (ERV) supply. Additionally, electric resistance heating, ground-coupled heat pump, and point-source natural gas furnaces can be used, yet are least favorable. See Figure 3 for a diagram of a home equipped with a energy recovery ventilation system[7]. Using Figure 3, Energy Recovery Ventilation System, it is well depicted how fresh air is drawn in, sent through the heat exchanger, then distributed throughout the entirety of the NZEH. Then, the exhaust is drawn from each room and sent back to the heat exchanger, then to the outside. This is a simple, yet effective, form of heating the home.

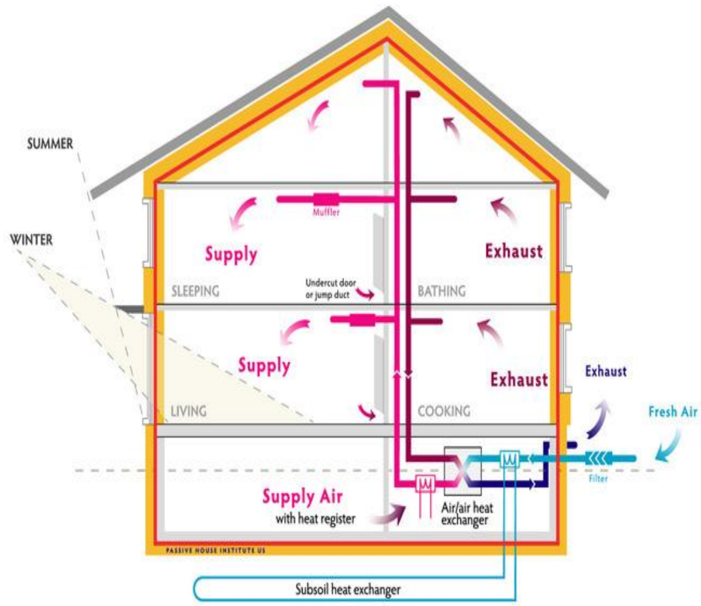

Figure 3: Energy Recovery Ventilation System[8]

An active solar thermal system with a large collector array and a large, well-insulated water tank for thermal storage is an excellent application for the NZEH, especially for colder climates. During the summer and at certain times during the fall and spring seasons, when the house is heated using the passive solar system, there is no need for the active solar thermal system. Therefore, colder climates would benefit from the active solar system for means of space heating[7].

Radiant floor heating is an alternative to active solar heating. The supply of air from the Energy Recovery Ventilation system is used to distribute heat. The hot water collected in the solar tank can be circulated through coils of piping sent to the Energy Recovery Ventilation supply fan[7]. This heat energy can be distributed throughout the home.

Potentially, heating via natural gas could be implemented in a NZEH. This is typically controversial such that NZEHs are known for only using the energy that they produce. Although, since the focus of the NZEH is concerned with net, using natural gas could be accepted and this cost could made up in other facets of the building design and implementation. Since owners of PV systems typically sell excess energy back to the electric utility company, this deficit is minimized. Natural gas can be used for various application including heating and cooking[7]. Another useful application of natural gas could be for backup generation. An external generator could be in place should all other forms of electric generation be rendered inactive. This is not ideal, but worth consideration for all possible design extremes.

4. Construction Methods

4.1. Design: A crucial part of developing a cost effective NZEH is the design. The architect should be familiar with the necessary steps involved in embarking upon a complete and successful build. An architect will consider the most cost-efficient technologies available with respect to the budget. As previously stated, the design should take advantage of the suns energy. The wall, floor, and ceiling systems should use advanced framing techniques. The insulation R-values should be considered. The air tightness along with thermal bridging considerations, window types, door types, energy efficient appliances, roof size, pitch, and orientation are all important factors the architect must realize to develop a successful NZEH[6]. There must be a well defined relationship between the designer and the contracting company. This working relationship will ensure the quality of the NZEH. Additionally, the home owner's wishes and expectations will be met. All three parties; owner, designer, and contractor play equally important roles for a successful final product.

4.2. Modeling: It is best practice to run simulations to ensure best application of the technologies considered for the NZEH. Using energy modeling software, the zero-energy goal can be tested. If failed, changes can be made accordingly to achieve the zero-energy goal. Choosing the lowest wattage PV panel possible such that enough energy is produced is one method to develop a NZEH with a low cost but still ensures net zero energy usage[6]. This design factor is considered in the modeling phase, along with other appliances and methods for near perfect energy conservation.

4.3. Sealing the NZEH: An air-tightness standard of 0.6 to 1.5 ACH at 50 Pa. is most desired. It is also suggested that at certain climates, a 2.0 ACH may be acceptable. It is best to implement an Energy Star thermal By-Pass checklist short form to identify areas that need sealing[6]. Doing so will systematically ensure the entire home is sealed and considered.

Most often an auditor or rater will pressure the home using an in-door mounted machine, then test the time it takes for the home to restore to the ambient, un-affected pressure of the home. See Figure 4, Pressurizing Home, for a photo of the pressurizing process. Once the test is complete, the auditor will perform basic calculations to obtain understandable information. One calculation is converting the cfm50 value, (cubic feet per minute) to ACH (air changes per hour). Air change is when a volume of air equal to the volume of the house exchanges with outside air. At a negative pressure of 50 Pa., typically a home will leak at 15 air changes per hour, 15 ACH50[6].

Once the need for sealing the home is established, there are many other methods for completing this task. Sealing the outer sheathing and the drywall ceiling before the inside drywall is installed is best practice. Decide whether it is necessary to glue the area, tape it, or seal it based upon the size of the gap in question. While the blower door is running, see Figure 4, check for air leaks with hands or other means to ensure the house is leak free.

Figure 4: Pressurizing Home[6]

Always seal electrical boxes and any place plumping pipes enter the home. During the sealing process, make certain to keep a focused mind set and consider all potnetial areas of leak. This systematic approach will achieve complete sealent and will not comprise the NZEH[6].

4.4. Eliminate Thermal Bridging: It is best to eliminate thermal bridging during the design phase of the home. Similar to the Thermal Bypass Check List form, using a Thermal Enclosure Checklist can assist in eliminating possible thermal bridging locations. Upon consideration of decks, porches, and porch roofs, they should be designed separate from the house. This isolates the NZEH completely. In certain situations where thermal bridging cannot be avoided, using spray foam or aero gels will do[6].

4.5. Windows and Doors: Being the most signifcant sources of heat loss, windows and doors must be chosen such that minimal loss can be attained. Fiberglass doors are excellent choices. No less than 50% of the windows should be south facing. A 14% window-to-floor area (WFA) is best for the entireity of the NZEH. Triple pane windows with U-values of 0.2 are most desirable. Certain brands of these windows include; Thermotech, Alpen, Intus, Solar view, and Milgrad. A more efficienct type of window is the fixed window[6].

The casement window multi-point locking hardware is also a good choice. Consider windows that have the smallest frame profile. This is necessary because the frame has a higher thermal transmission than the glazing upon the windows. Less expensive triple pane windows can usually be the most cost-effective solution when deciding which window to use[6].

4.6. Humidity Considerations: Energy recovery ventilation or heat recovery ventilation systems should be installed. These systems will provide fresh and clean air to the NZEH. Some models worth implementing are the Venmar EKO 1.5 HRV, UltimateAir RecoupAerator 200DX ERV, and the Panasonic WhisperComfoAir. An airtight NZEH must pay close attention to the moisture content since it is sealed so efficiently. The inside moisture content should be 30% or less. A great moisture level could lead to problems related to condensation. Using vapor barrier paint on the interior of the sheet rock helps prevent moisture penetration. Additionally, for any home, it is necessary to reduce any possibility for mold. With the health hazards associated with mold, it is in the best interest of the home owner to implement such systems to ensure the safety of the home's occupants[6].

4.7. Lighting and Appliances: Among the simplest aspects of reducing the energy usage of the NZEH is to consider the lighting and appliances used in the home. Compact fluorescent lights and light emitting diodes (LEDS) are the best sources of lighting. For the areas of the home that require the most lighting, use the light emitting diode specific lighting. LED's tend to last longer and require much less energy to operate as other lighting alternatives. It should be a concern of the designer that the majority of the lighting is sourced from the sun. Artificial lighting can be implemented for office space or task areas[6].

To reduce energy use, Energy Star related appliances should be invested in and implemented in the NZEH. The Energy Star products website includes an exhausted list of those appliances worthy of any NZEH. There are additional resources that include the top ten energy efficient appliances in each category. Many appliances have their energy rating already posted on them, which makes choosing the most cost-effective appliance easy[6]. These appliances can be found in popular retail stores such as Lowes, Sears, and Home Depot.

Another simple act to diminish energy usage is to implement on/off switches on most every device in the home. This ensures that residual current draw, also known as phantom load, does not take place. An appliance can draw very small currents even when it is not in use. For most home owners, this is negligible, but with the NZEH, every bit of energy is important and useful. Even implementing power strips is effective for controlling many devices which are not needed throughout the day or during the night[6]. Timers could be another efficient method for controlling when appliances are active.

The timer would draw current of its own, but its implementation would assist a forgetful home owner. Ultimately, unplugging each device from the receptacle when not in use is most desirable.

5. Conclusion

The most important aspect of the NZEH is the realization that it is, in fact, a concept. This concept is one which is specific to the designers and future owners of the home. Whether a design implements complete on-site resource harvesting, or only partial, it is most important that the owner acts as a steward of the earth for its longevity and for this generation's posterity. The NZEH is most popular for its implementation of photovoltaic systems as a source of electricity for the home. Earlier, the roof mounted PV system along with the canopy style was both explored. With regard to passive energy applications, south facing homes with open windows and sealed tight gaps are most desired. Implementing energy star appliances and energy efficient windows/doors will ensure the NZEH only uses/losses a minimal amount of energy. Now that a brief exploration of the Net Zero Energy House has been completed, a well informed understanding of the concept, aspects, and function has been developed.

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