

Zero Net Energy Test House Project

By:

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This is an analysis of components within a zero net energy test house (ZNETH) located in Omaha, Nebraska. The components are: the house's site orientation, the envelope, and phase change material (PCM). ZNETH is a residential two story house with 2800 sf of floor space, including the basement. It contains four bedrooms and three and a half baths. The house orientation on the site helped determine the shape of the envelope and location of the components. Two types of systems were used in building the outer shell of the house: insulated concrete forms (ICF) and a 2 x 6 framed construction. The envelope is composed of a multi-layered membrane system with EFFS on the outside, and sprayed insulation on the inside. PCM is an experimental additive that was combined with a natural cotton wall covering to create a temperature conductive coating on the walls in the first floor bathroom.

Keywords: Zero Net Energy Test Home, USGBC, Insulated Concrete Forms, Phase Change Material



Figure 1: Zero Net Energy Test House (ZNETH)

Introduction:

Designing homes that take full advantage of natural resources is a key step in utilizing free energy. The University of Nebraska has been dedicated to the research and development of zero energy homes. ZNETH (**Figure 1**) is a donor-funded project that was completed fall of 2011 and will be occupied by UNL students. Since the project's inception in fall of 2007, students have been involved in all aspects of design and construction. ZNETH's main purpose is for education and research in the area of sustainable construction. Future studies of the components of ZNETH will be crucial in assessing manufacturer claims for system performance verses actual performance of the house. The intent to use the ZNETH project as a template for future net zero homes; therefore, it is important to understand the reasoning behind component selection and design.

Orientation:

A key principle in the design of sustainable structures is to maximize use of free natural resources and minimize use of fossil fuels. Unfortunately, in the case of residential properties many plots of land do not have the freedom and flexibility in their directional positioning and shape that a larger undeveloped commercial building would. Often times, the house must be oriented in one direction as a result of

zoning codes, surrounding structures or street improvements. In the case of ZNETH, boundary lines had houses to the east and west, a detached garage to the north and an adjacent street to the south. Fortunately, these set parameters were favorable providing a south facing orientation as depicted by the yellow rectangle in **Figure 2**. In a climate like Nebraska, with hot summers and cold winters, a home facing to the south is the most beneficial because it “transmits the maximum solar radiation in the winter and the minimum in the summer.” (Balcom 1987)

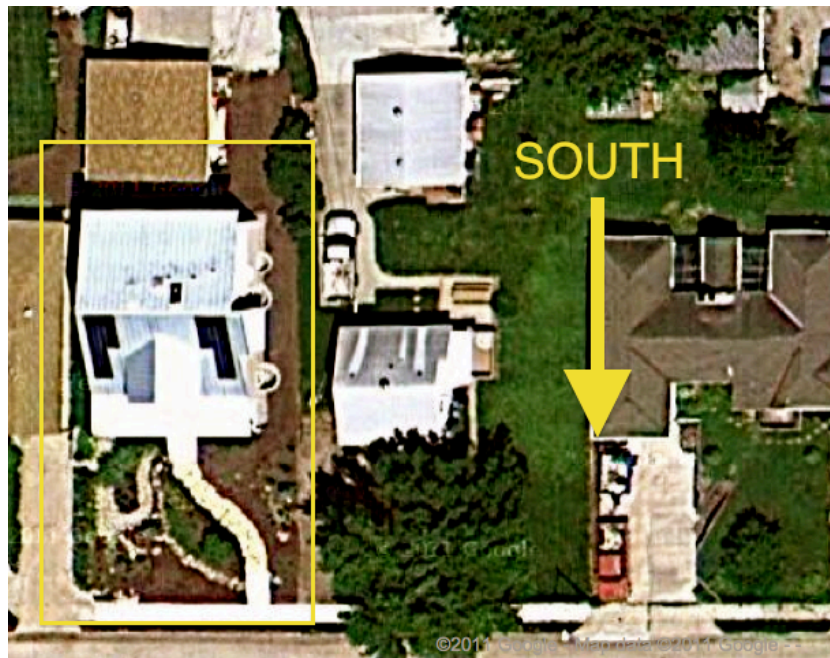


Figure 2: South-facing orientation allows for maximum solar heat gain by windows

A shading analysis determined the optimal placement of windows, optimum overhang lengths, and ideal location for Photovoltaic Laminate Strips (PVLs). Such an analysis can be helpful, but can also be a double-edged sword in design. Allowing too much light into a space can greatly increase the amount of solar heat gain, which raises cooling loads in the summer. As a result, every window is double paned argon filled, with a low-e coating. These windows allow visible light into the space yet reflect a majority of the heat from the sun reducing the solar heat gain factor (SHGF). A series of these windows were strategically placed along the south face to utilize the heat from the sun’s lower altitude in the winter. Conversely, the front porch overhang was designed to completely shade these same windows from the

high altitude summer sun. In addition, the surface area of ZNETH was reduced by stacking it upwards, keeping it compact and box-like in appearance.

Roof Design:

A determining element in the design of the roof was the photovoltaic laminates. These were ten 15.5-inch wide strips from Solar Laminate PVL Series from Uni-Solar with six-136 Watt 24 Volt panels 216 inches long and four-68 Watt 24 Volt panels 112.1 inches long; for a total system designed output of 1Kwh of power (Hemsath, Goedert, Schwer, & Cho, 2011). Typical solar panels are bulky, rigid and require



Figure 3: The steel is optimal for placing the PVLs in between its sections

extensive mounting hardware. These strips are small, flexible and can be easily integrated into the roofing design; producing a sleek contemporary aesthetically pleasing look. All Native Services tested the system efficiency using a SunEye from Solmetric; the results indicated a 96% annual solar access. This favorable solar access resulted from the use of a 10:12 roof pitch, which is only a few degrees off the optimum pitch of a 12:12 or 45 degree roof in a Midwest climate. The slight difference in pitch lowered the installation cost, yet did not affect the efficiency of the PVLs. Instead of using traditional asphalt petroleum based shingles, a galvanized standing seam metal roof was installed (Glickman

2010). These systems are made from recycled content and are 30% more effective at reflecting the sun's heat than white asphalt shingles (Lechner 2009). The steel is an optimal substrate for the PVLs and the raised seams are ideal for placing 15.5" wide strips in between sections as illustrated by **Figure 3**.

Along with high Solar Reflective Index (SRI) properties on the roof's external surface, insulation placed on the inside face of the OSB roof can reduce unwanted heat transfer inside the space. ZNETH has a total of 5 ½ inches of open cell insulation layered between roof joists. This creates a thermal break between roof components and greatly reduces the amount of heat transfer. Steel is also a great watershed and does not degrade over time like asphalt shingles. A common problem in roofing involves water seeping through nail holes or underneath flashing, then passing around OSB into the structure. The constant uninterrupted steel plane impedes water flow, providing a very durable roof. Additionally, the steel roof's lifecycle of 50-100 years is roughly 5-10 times greater than composite roofs (Lstiburek 2006).

The final roofing design consideration was the attic ventilation. In the past, unvented attics have dominated as the standard for roof construction. Often vents are placed below the soffits and along the

top of the roof's ridge. In climates with hot summers it is also common to place mechanical equipment inside the attic to help release rising hot air. Although these practices have been somewhat effective in removing heat from spaces, they do a poor job of conserving energy. Large losses occur when air escapes through vents, cracks and improperly sealed areas. Furthermore, using mechanical devices such as an attic fan to remove air from a space creates more pressure and temperature differences, thus driving up the heating and cooling bills for the rest of the house. A non-vented attic assembly was used in ZNETH. The combination of closed cell and open cell spray foam insulation forms an airtight seal. This creates an air barrier and vapor retarder, and when used in conjunction with an above deck vapor barrier it is highly effective at preventing any moisture from entering the space. Another advantage is that the temperature of the attic remains similar to the rest of the house. The use of an unvented attic is only recommended for homes that have tightly sealed envelopes.

Envelope:

The envelope of ZNETH was made tight using a built-up liquid applied system by STO Corporation and was finished with EIFS. A major advantage of this system over a common OSB-Tyvek configuration is in the way it prevents the infiltration of moisture into the envelope. Depending on exterior relative humidity, large amounts of water carried by the air can seep into the pores of materials and form water inside the envelope (Straube 2006). It is common for homes to face moisture related issues, because builders and designers do not understand the differences between vapor barriers, vapor retarders and air barriers. A perm is the unit of measure to describe how resistant a material is to the transmission of water. The lower the perm the greater the resistance. **Table 4** describes the various perm ratings designated by the International Building Code (IBC) and Canadian Standards Board (CSB). A vapor barrier is any type of material that does not allow moisture to pass through. Vapor retarders differ because they allow small amounts of moisture to pass through. Once this fundamental distinction is made, the remaining classifications are based on how much water can pass through materials. An air barrier is a function of the air infiltration and pressure over a surface. It is important to note that although the air carries moisture an air barrier does not refer in any way to moisture. Moisture classifications are expressed separately and not listed in Table 4 (Lstiburek 2006).

Table 4 Vapor Classifications
Vapor Barrier: Class I Vapor retarder or vapor impermeable (less than .1 perm)
Vapor Retarder: Class II Vapor retarder or semi impermeable (.1 perm > 1 perm)

Vapor Retarder: Class III Vapor retarder (1 perm > 10 perm) semi permeable
Vapor Permeable Greater than 10 perms

Lstiburek, J., Straube J. (2006, October 27). Research Report 0903: High R-wall Case Analysis.

Although exceptions exist, as a general rule of thumb, it is never good to use a vapor barrier within a building envelope. This rule hinges upon the idea that a barrier designed to keep water out will also keep it in. Therefore, if water ever does get by the barrier it will have no means of escape, which creates the perfect environment for mold growth inside the wall (Straube 2006). Preventing this from happening can be summarized by three methods:

1. Stop air, by creating a tight envelope on the inside and outside of structure.
2. Use materials that breathe, allowing trapped moisture to escape at any point within the wall.
3. Design a way for water to drain outside the surface (Straube 2006).

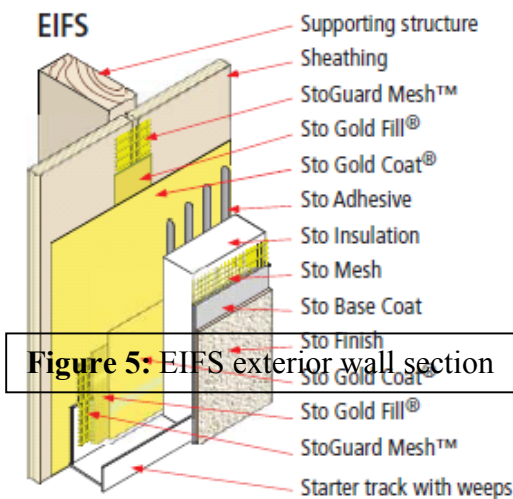


Figure 5: EIFS exterior wall section

These moisture prevention principles were elements utilized in the ZNETH envelope design. The EIFS wall section as depicted by **Figure 5** illustrates the various components within the built-up system (STO 2010). This membrane can be applied on cellulose and synthetic materials. This was ideal in the case of ZNETH as OSB sheathing and Insulated Concrete Forms (ICF) were used for the envelope. For the areas containing OSB sheathing the system was rolled and sprayed on in layers; and once it dries it is both an air barrier and Class II vapor retarder. One-inch rigid foam insulation is elevated off the wall by adhesive lines that run vertically down the envelope. These lines create a gap between the insulation and STO coated sheathing, which allows water to condense on the surface and run out the flashing. On the inside face of the OSB, foam insulation was sprayed in layers between the joists. The spray foam is a Class 2 vapor retarder and an air barrier. Having dual vapor retarders and air barriers on both the inside and outside wall surfaces of the envelope allows it to breathe from both sides, and creates a tight weather resistant envelope. For the sections containing ICF a less rigorous system was needed. Since the ICF already has foam on the outside, the STO layers from the insulation back to the sheathing (see Figure 5) are not necessary.

Insulation:

Spray foam insulation allows the envelope to breathe on the inside of the OSB and adds thermal resistance and structural integrity to the wall. Differing amounts of insulation were used in ZNETH varying in thicknesses and R-values for the purpose of future research. The highest level of thermal resistance was needed for the exterior walls, windows and roof joists, because these areas experience the greatest amount of heat loss as depicted by **Figure 6** (Hemsath et al., 2011). In climates that have harsh winters and hot summers like Nebraska, these losses are further intensified. Currently, the common accepted heat loss prevention technique used by builders has been to place R-13 fiberglass insulation in a 2 x 4 wall cavity with a 3-½ inch air space. Though an adequate form of insulation, houses that use this type generally experience thermal bridging. This

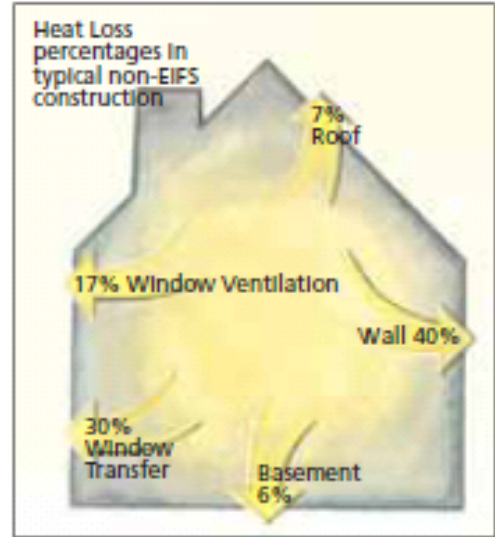


Figure 6: Typical heat loss areas in a home

occurs when areas in the outer envelope are not properly sealed and outdoor air is able to seep into the space via conduction or through air gaps. For instance, the rim joists above a stud wall are one common area that experiences this bridging effect, causing the R-value of the wall to underperform. A study by Lstiburek and Straube (2006) showed that in a standard R-13 wall the thermal bridging caused it to actually perform at around R-10. For ZNETH it was important to create an envelope that prevented thermal bridging and achieved much higher R-values. R-13 insulation was only used within the interior walls for sound deadening purposes rather than heat loss. The rest of the house was sprayed with a combination of closed cell and open cell foam insulation. These two insulation types are composed of a “spray applied polyurethane foam plastic system” (Demilec Sealection 2007).” Closed cell has an eco friendly polyurethane base made from recycled plastics and soy oils, which will only off-gas for a few minutes after it is applied. The open cell is environmentally friendly because it has a water-soluble base and does not off-gas (Demilec Heat Lok 2007). Both of these sprays helped reduce harmful organic compounds from being released into the interior space and outdoor air. By layering the amount of closed cell R-7.2/inch and open cell R-3.8/inch a higher R-value per inch than batt insulation was achieved at the optimal insulation price. In ZNETH, 2 inches of the closed cell and another 3.5” of the open cell were sprayed creating a 5.5-inch thick wall with a total of R-28 plus exterior foam.

Using ICFs instead of a standard concrete wall further adds to the thermal integrity of ZNETH’s envelope. The foam blocks are a fast and effective way to build a basement foundation wall. However, a

variety of complexities are involved anytime a basement is included in the schematic design of a house. For one, they are generally below grade and surrounded by soil. There are a number of factors that must be analyzed whenever soil is in direct contact with construction materials. One issue with the soil surrounding ZNETH was that it could contain radon. If not treated properly radon can seep into a house through the foundation wall or through cracks in the envelope that touch the soil. To prevent this, a radon abatement system was installed below the basement slab; allowing for the radon gas to safely flow out away from the foundation. In addition, a vapor barrier was placed underneath the concrete slab to prevent any moisture from being absorbed into the basement floor and for additional radon prevention. Another issue was the high moisture content of the soil. To insure proper drainage, pervious piping and layered levels of rock were placed around the continuous slab footing.

The ICFs selected were an 11-inch wide configuration called Fox Blocks, manufactured by Airlite Plastics Company. They include a six-inch concrete core with 5 inches of Expanded Polystyrene (Hemsath et al., 2011). The R-value of this configuration is 21.64 and outperforms a standard R-13 basement wall. The polystyrene foam is also a sound barrier with a 45 to 50 sound transmission class, moisture resistant, highly durable over time and easy to install. On the outer face of the blocks a water-soluble eco flex water-proofing membrane was used to prevent moisture absorption into the space. Studs were not needed in the interior to fur out the wall, as drywall was directly attached to plastic ties inside of each ICF form. The ICF's were an optimal choice for use with the EFFS because the wire mesh and grout levels can be directly applied to the outer face of the foam.



Figure 7: 2 x6 framed wall at 24 inch on center spacing

ICF blocks were used for the basement and three of the four walls on the main floor. The only wall on the main floor that did not have ICF's was the southern exterior wall, which instead was a 2 x 6 framed (Figure 7). Contrary to typical 2 x 4 framing, the use of 2 x 6 stud walls is becoming a more common



Figure 8: 24 inch spacing creates more room in wall cavities

practice in industry (Lstiburek 2005). There are many reasons for this. The most practical is that in actual dimensions a 1 ½ inch x 5 ½ inch stud is 2 inches wider than a 1 ½ inch x 3 ½ inch stud. This greater width reduces stud waste by allowing for 24 inch on center (o.c.) spacing instead of 16 inches o.c. within walls. It also provides more room for running plumbing, electrical and structural components (Lstiburek 2006). **Figure 8** demonstrates that there was plenty of room within ZNETH's 2 x 6 wall cavity to run a steel post. The use of a 2x6 wall with the ICFs was crucial because the 12 inch ICF wall was much thicker than a typical stud wall, which created a greater sill depth on the windows installed in it. By using 2 x 6 studs on the south exterior wall it greatly reduced the window sill thickness disparity between the two differing wall types. In addition, the 5 ½" thickness and 24" spacing between the studs created a larger volume to spray more insulation increasing the overall R-value of the wall.

Phase Change Material

The advancements made in spray foam over fiberglass insulation helped ZNETH to achieve much higher R-values per square inch. However, there is always room for improving the envelope's thermal performance. Instead of solely using insulation for maintaining ambient temperature levels researches have been studying ways of placing additives in materials to help absorb and keep the energy within that space. These additives are known as Phase Change Materials, and can be combined with cellulose-based insulations, gypsums and other wall coverings. "PCM is a small wax octadecane which can freeze or crystallize depending on the temperature of the room" (Driscoll 2010). "A material's transition from solid to liquid phase often allows it to absorb large quantities of heat without significantly changing its temperature. **Figure 9** below shows how "this effect can be exploited to stabilize ambient temperatures inside buildings" (Wolfgang 2006). In ZNETH, approximately 1 gram per square/ square inch of the wax was added into the paint and seal coats of natural fiber wall covering in the powder room on first floor. This type of wall adhesive was a

perfect material to combine with the PCM because it adheres well to plaster based materials. Plasters also are an economical fire resistant material applied in varying thicknesses.

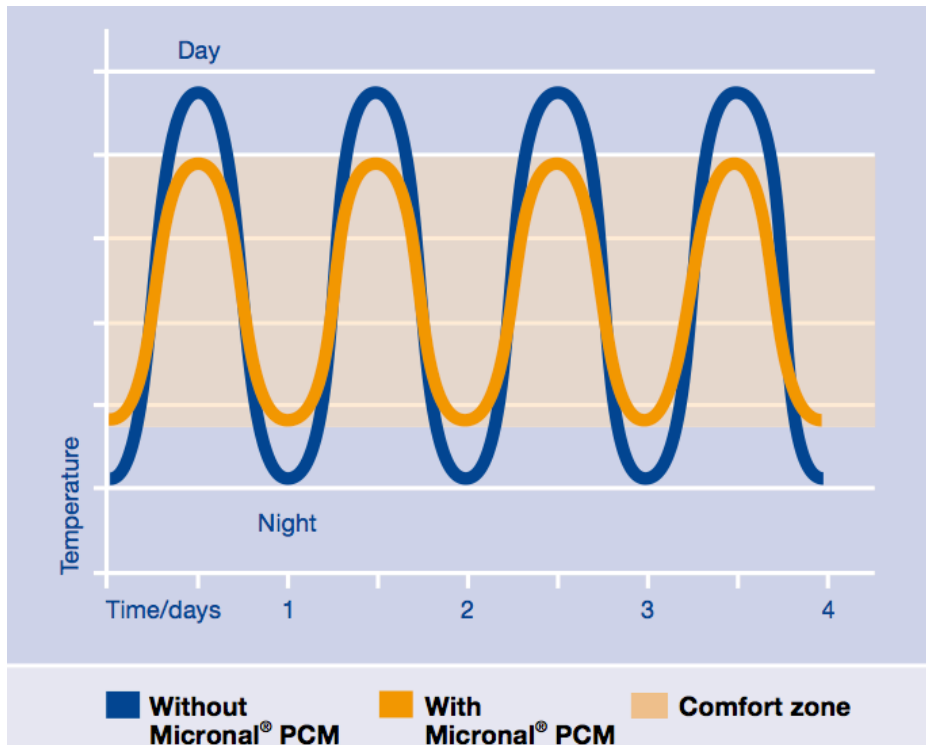


Figure 9: PCM stabilizes temperatures inside building, increasing thermal efficiencies of the envelope

Occupancy Sensors:

Like PCM, occupancy monitoring software is another experimental technology that is incorporated within ZNETH. Residential electricity consumption currently constitutes about 21% of U.S. energy demand (Williams & Matthews, 2007). Increased consumption has left some electric utilities struggling to meet peak demand, which typically occurs in the afternoons on hot summer days. Despite increasing demand, residential energy management and control systems lag behind the sophisticated technologies employed in the commercial and industrial sectors. Thus there is an opportunity to develop residential electricity management and control technologies, in service of zero-net energy housing. Recent commentators (e.g., Grunwald, 2009; Parks, 2009) describe a future in which physical or virtual in-home monitors (so-called "energy dashboards") provide real-time electricity consumption data to residents, who are anticipated to

use this information to actively manage home power consumption. These devices are marketed to consumers and electrical utilities with the twin goals of reducing electrical energy consumption, and reducing or shifting residential electrical demand. Most of these devices and systems apparently assume that tracking home electricity use will become a national hobby, though the novelty for homeowners will likely wear off quickly. None of the devices or systems targeted to residential consumer use offer any automated power management capability: all require homeowners to manually switch electrical loads, which will limit the effectiveness of these devices and programs, since past research clearly shows that programs which rely on users to switch off electrical loads do not produce persistent savings (e.g., Newsham & Tiller, 1994). Further, none of these devices or systems will produce demand savings, since peak demand occurs in the afternoon when most residences are vacant, and hence no one is present to switch off selected electrical loads in response to signals sent by the utility, or in response to criteria established by the homeowner. Persistent electrical energy and demand savings require an automated switching component that is missing from all current products and solutions. ZNETH includes residential electricity monitoring, management and control technology that manipulates selected residential electrical loads when houses are vacant, and then switches these back on again just before occupants return, without sacrificing comfort or convenience. The specific inefficiencies targeted in this work are electrical appliances and other consumer electronics that remain switched on, or in the case of an air conditioner, work harder than necessary, drawing power when houses are vacant. Williams and Matthews (2007) have estimated that application of more sophisticated management and control to residential electricity consumption could save between 3% to 30% of residential electricity use.

Conclusion

The Zero Net Energy Test House models effective methods for building a home and utilizing its environment. Furthermore, many of the techniques and materials selected have not been tested or verified in the field. In the coming years the data acquired will be vital to builders and researchers and will act as a catalyst in the progression of more net zero homes with similar components to ZNETH.

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Dr. Schwer is a UNL College of Engineering professor in the Durham School of Architectural Engineering and Construction. He is the director of the ZNETH Project, which is a net zero test house next to the campus. He teaches sustainable construction courses and is developing an online program in sustainable design and construction. His research focuses on the investigation of renewable and high performance building applications. Dr. Schwer serves on the Board of Directors for the USGBC Nebraska Chapter and has been recognized for service by Habitat for Humanity and United Way. Twelve of his student's research projects and course papers have won national and regional awards. He has earned the University of Nebraska Award for Distinguished Teaching.

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Dr. Tiller has been active in the area of human factors in building energy for more than 15 years. Tiller's more recent work has investigated the development and application of occupancy sensor

networks to enhance building energy management and security. This work, sponsored by the U.S. Department of Energy, provides the technical foundation for the work described in this proposal and it shows that occupancy sensor networks, consisting of several independent detectors monitoring the same space, provide more accurate occupancy measurement and more cost effective control than are possible with a single point of detection.