ENERGY ANALYSIS UTILIZING BIM FOR ZERO NET ENERGY TEST HOME

Yong K. Cho[1)]

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ABSTRACT: This paper presents the results of a theoretical energy analysis of a research test bed called the Zero Net Energy Test House (ZNETH) in Omaha, Nebraska in U.S.A. The ZNETH project is being designed and built with the goal of consuming a negligible amount of energy by offsetting remaining usage after energy conservation. The theoretically consumed and generated energy levels were analyzed using energy modeling software programs. By integrating a highly graphical and intuitive analysis with a Building Information Model(BIM) of the house, this investigation introduces strategies to include sustainable materials and systems to predict energy generation with a case study of ZNETH. In addition, this paper introduces parametric analyses for better envelope design and construction material selection by analyzing simulated energy consumption with various parametric inputs, e.g., material types, location, and size. It was found that the current design of ZNETH does not meet its goal of zero net energy. Sugeestions are presented to assist ZHETH in meeting its net zero energy goal.

KEYWORDS: Energy analysis, BIM, Zero Net Energy, Solar panel, Wind turbine

1. INTRODUCTION

There are more than 76 million residential and nearly 5 million commercial buildings in the U.S. today. By the year 2010, another 38 million buildings are expected to be constructed (ArchiCAD 2007). Buildings account for 40% of global natural resource consumption, 40% of the world's energy consumption and 65 % of total U.S. electrical consumption. They generate 60% of greenhouse gas emissions and as much waste as all of the municipal garbage in the U.S. every year. Sustainable architecture is the practice of designing, constructing and maintaining buildings in a way that minimizes their environmental impact (Huovila et al. 2005; NIBS 2007).

To address the best methods of designing and constructing homes that have a zero net effect on the environment, the University of Nebraska–Lincoln has started an innovative research project to build a Zero Net Energy Test House (ZNETH). The project is expected to be completed by fall of 2010. Engineering students and faculty from the construction and architecture departments are engaged in the research to address the required specifications and the appropriate materials required to lead to a zero net energy scenario. Some of these specifications and materials have been chosen while others are currently under examination. ZNETH is the first house of its kind in Nebraska, and has been designed to comply with the framework of the Leadership in Energy and Environmental Design (LEED) Platinum certification rating from the U.S. Green Building Council's LEED for home requirements.

As shown in Fig. 1, the house is traditionally designed,

<Fig. 1> Zero Net Energy Test House (ZNETH)

1)Associate Professor, Durham School of Architectural Engineering and Construction, College of Engineering, University of Nebraska-Lincoln (ycho2@unl.edu) (corresponding author)

consisting of a finished basement, main floor, and second floor. Several energy-saving technologies were implemented in this project. Insulated concrete forms (ICFs) were installed for the basement walls and the north, east, and west walls of the first floor, while 2x6 framing with closed cell, soy-based spray foam was planned to be used for all other external walls in the house. It is clad with an Exterior Insulation Finishing System (EIFS). In addition, various high efficiency window types were selected to reduce solar heat gain during the summer months and heat loss during the winter months. For plumbing, PEXtubes were used throughout the house because plastic pipe and fittings are dramatically lower in weight than metal piping and they save energy in transportation and construction. A PEX tube is a thermoset material made from medium or high density polyethylene that is modified to have improved properties (PPFA 1020). To lower the energy consumption of the heating system, horizontal and vertical geothermal wells were dug around the house. Two 250 ft (76 m) horizontal wells were looped at 8 ft (2.4 m) deep, and six vertical wells were drilled at 150 ft (46 m) deep. To further lower the energy consumption of the heating system, a radiant floor system was planned for the first and second floors.

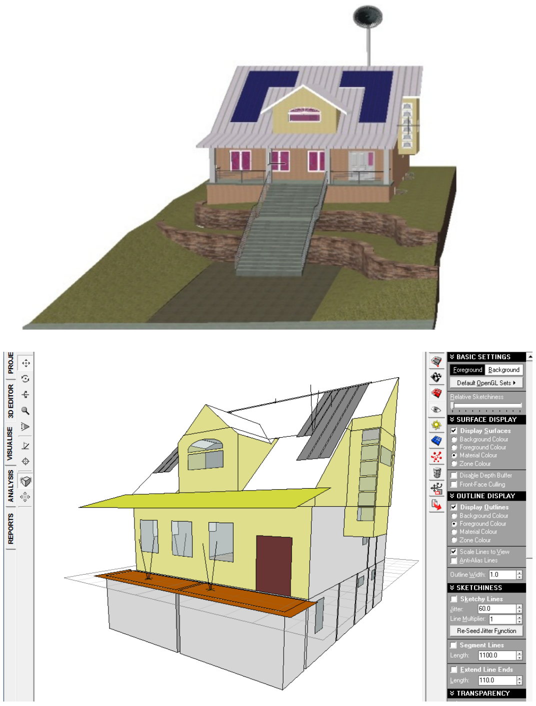
To offset the consumed energy of the household occupants, a wind turbine and photovoltaic panels (PVs) were selected as the energy production resources for this project. It was expected that the total energy production from a wind turbine and solar panels, combined with energy savings from the geothermal system, would be more than the house consumes. The unused energy would be sold back to the power company using a net metering system. The maximum assumed energy produced from the wind turbine, to be erected on the roof, is 2 kilowatts. Likewise, it was expected that a maximum of 2,219 watts would be produced by the PVs installed on the roof.

2. BUILDING INFORMATION MODEL (BIM) FOR ZNETH

Building Information Modeling is the process of generating a digital representation of pyhsical and functional characteristics of a facility, creating a shared knowledge resource for information about the facility that forms a reliable basis for decisions during its life cycle, from earliest conception to demolition (NIBS 2007; Eatman et al. 2008). BIM is a tool that builds a facility virtually, predicts and monitors energy performance to reduce energy usage, and examines material sustainability used in the facility over its lifecycle (Smith 2007; Krygiel and Nies 2008). In this study, two different BIM processes were conducted for the ZNETH energy modeling. First, object-oriented geometric information of ZNETH, e.g., envelope, doors, windows, walls, zones, was modeled. Second, as an expanded BIM concept, ZNETH's energy attributes, e.g., material heat resistance, facility energy usage, location, weather data, were modeled. The main advantage of using this approach is that the 3D geometric building information is transferred to the energy simulation tool rather than recreating 3D geometric information again from the energy simulation tool (Cho et al. 2009).

2.1 Energy Simulation Modeling

After examining several energy programs, Autodesk's Ecotect v5.6 was selected for the energy simulation. Ecotect has a variety of energy analysis functions. In 2005, the U.S. Department of Energy examined 20 energy programs to provide an overview of their features and capabilities. Ecotect was identified as a complete building design and analysis



⟨Fig. 2⟩ Geometric BIM in Constructor (up) and Exported BIM in Ecotect (down) software tool (Crawley et al. 2005). One of the most powerful features that Ecotect offers is its ability to view analysis results in various formats such as graphs, tables, and 3D objects (Riether and Butler 2008). Ecotect is a stand-alone energy analysis program capable of applying energy analyses such as thermal, solar, acoustics, and lighting throughout early design phases. Moreover, Ecotect allows results to be mapped directly over 3D objects, creating a more intuitive design process (Crawley et al. 2005). Ecotect can import and export a number of file formats such as IFC, gbXML, 3DS, DXF, and VRML. From several file conversion tests, gbXML was identified as the most accurate interoperable file format between BIM and energy programs (Cho et al. 2009). Fig. 2 shows the BIM models before and after the export process from Constructor to Ecotect.

2.2 Applying the renewable energy sources into the simulation model

Ecotect has a variety of tools and functions to perform the required analyses; however, there are limitations of modeling the renewable energy resources within the model. For example, Ecotect has 1) a limited solar panel tool, 2) no wind turbine tool, and 3) no geothermal system function. The strategies that have been taken in this research to solve these limitations are discussed in the sections below.

2.2.1 Photovoltaic Panels

To calculate the produced energy from the photovoltaic panels (PVs), two data sets have to be available: the electrical efficiency percentage, which is unknown in this study, and the available solar radiation for different seasons. Ecotect has a specific tool that operates as a PV, where some specifications can be entered manually, e.g., electrical efficiency percentage and space heating. However, the tool does not have an option to calculate or enter the available solar radiation for different seasons. Therefore, the electrical efficiency percentage was calculated using the trial and error method to find the required percentage that would produce the expected energy amount using the average available solar radiation for Omaha, Nebraska. That solar radiation was found to be 4.6 hours per day (Radarsign 2008).

2.2.2 Wind Turbine

The inclusion of a residential wind turbine was difficult to implement into the energy model due to Ecotect's inability to directly incorporate it. Thus, wind turbine's energy production was separately estimated in this study. The National Renewable Energy Laboratory (NREL 2010) has developed a wind power classification per region, state and city to evaluate the efficiency of wind turbines. Omaha, Nebraska falls under Class 3. Class 3, with a wind speed between 5.1 and 5.6 m/sec at 33 feet (10 m), is considered "Fair" under resource potential.

2.2.3 Geothermal System

The geothermal system affects two aspects of the energy analysis: the thermal analysis and the energy consumption analysis. Ecotect does not have a function to calculate the thermal effect or the expected energy consumption of HVAC systems affected by a geothermal loop. To solve these issues, two steps were taken. First, for the thermal analysis, a natural ventilation system was added to each room to mimic the effect of the geothermal and radiant floor systems. Second, TRACE 700, another commercially available software program which has a specific tool for the geothermal system, was adopted to calculate ZNETH's total consumed energy. Extensive information, such as a room's area, volume, location, appliance specifications, and schedule, as well as structural components, needs to be available to build a model in TRACE 700. The calculation procedures are based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers manual (ASHRAE 1997).

3. ENERGY PERFORMANCE SIMULATIONS

Five analyses have been done so far for this research while ZNETH is under construction. The analyses performed were thermal, solar exposure, lighting analysis, shading and resource consumption. Brief descriptions of each of these analyses and their results are given below.

3.1 Thermal analysis

Thermal analysis helps the design team to examine the advantages and disadvantages of the materials selected in the design. The thermal analysis function has different calculation aspects such as hourly temperatures, hourly heat gains and losses, heating and cooling loads, and annual temperature distributions. Calculations were done for all visible zones.

3.2 Solar exposure analysis

Solar exposure analysis provides information about solar radiation incidents on one or more objects on a selected day. This information is very important to estimate the natural light and find out the best location for windows or PVs. The analysis contains four different calculation types: single day, average daily, total monthly and full hourly. The analysis shows that during the spring, summer and fall months, the amount of solar radiation passing through the front windows is very low. During the winter months when the house needs to be heated, the sun's radiation is minimal. The overhang blocks solar radiation to the front windows during the spring. This information helps the design teams estimate the required amount of produced energy from the photovoltaic panels.

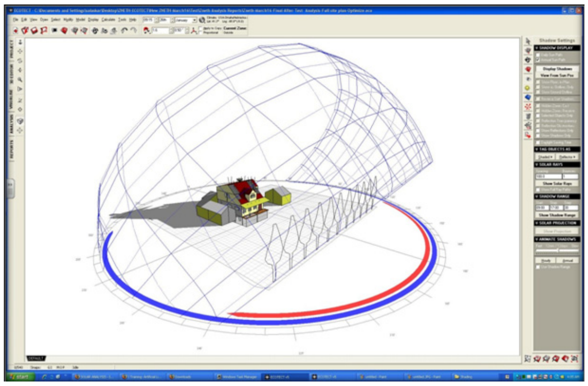
3.3 Lighting analysis

A lighting analysis computes the natural and electric lighting levels at chosen points or over an analysis grid (2D or 3D). This analysis was performed based on an average cloud cover in mid-winter, which is the worst case design scenario. This analysis gives a good indication of how much natural light will be present and how efficient the electric light system is. The result is presented in five different options: daylight factor, daylighting levels, electric light levels, overall light levels, and illumination vector.

A lighting analysis was conducted on the living room on the first floor of ZNETH. The daylight factor, which is the percentage of light available from the sky based on a worst case scenario, was investigated. The room has between 2.5% and 3.5% daylight passing through the windows. At this point in time, ZNETH's final lighting system has not been selected. Therefore, the analysis of the daylight factor was the key to design the electric lighting appliances for that room.

3.4 Shading analysis

A shading analysis is also a very useful tool that helps visualize the possible shadow effects on a model during annual or daytime periods. It acts as a good reference for design teams to choose the best location for the solar panels and windows. Fig. 3 displays the annual sun path for ZNETH.



⟨Fig. 3⟩ The annual sun path for ZNETH

3.5 Resource consumption analysis

The resource consumption analysis is based on data for an entire year. In the ZNETH test case, the consumption resource is only electricity, and the production resources are from the solar panels and the wind turbine.

3.5.1 Produced Energy

To calculate the produced energy from solar panels, two pieces of data have to be available: 1) the electrical efficiency percentage, which is in our case unknown, and 2) the available solar radiation for different seasons. Ecotect has a specific tool that operates as a solar panel, where some specifications, e.g., electrical efficiency, space heating, can be entered manually. However, the tool does not have an option to calculate or enter the available solar radiation for different seasons. Therefore, the electrical efficiency percentage and the available solar radiation for different seasons have been calculated as follows:

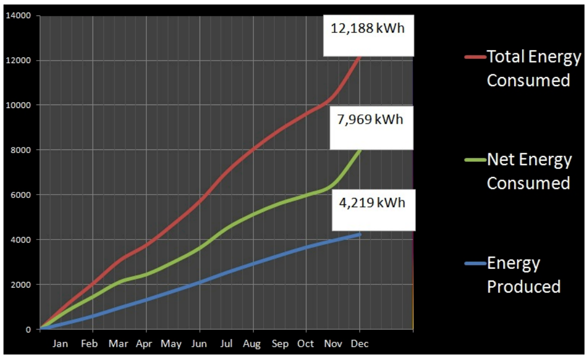
- The maximum electricity generated from the solar panels is 2 kW.
- The average available solar radiation for the Omaha area is 4.6 hours/day (Radarsign 2008).
- Multiplying the expected electricity by the average available solar radiation (2 x 4.6 = 9.2 kWh/day).

On the other hand, adding a wind turbine was difficult because the simulation software packages do not have a particular tool or function to be used as a wind turbine. To solve this issue, the daily produced energy was added to some of the appliances to offset the appliance consumption. To calculate the daily produced energy of the wind turbine, a few steps were taken. First, the mean annual wind speed of Omaha area had to be found. As previously described, Omaha falls under Class 3 (Fair). This zone produces wind speeds ranging from 5.1 to 5.6 m/sec. To take advantage of this classification, installation of a Honeywell WT6500 wind turbine from Windtronics is being considered to generate energy for the ZNETH. According to the specifications (Honeywell 2010), a Honeywell WT6500 will generate about 2,000 kWh/yr in Class 3 zones at 33 ft. (10 m) elevation and will operate in a range of wind speed from 2 to 42 mph (0.9 to 18.7 m/sec). Next, the annual produced energy (2,000 kWh/year) was divided by 365 days to produce the theoretical daily energy output of the turbine (5.48 kWh/day). Finally, the obtained theoretical output was tagged to the appliances to offset the energy consumption.

The house's consumed energy is from appliances and the heating and cooling system. In ZNETH, a geothermal system will be used as the source for cooling and heating the house. TRACE 700 has been adopted to calculate ZNETH's total consumed energy. Extensive information such as a room's area, volume, location, appliance specifications and their schedule, and structural components and their specifications need to be available to build a model in TRACE 700. The calculation procedures are based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) manual (ASHRAE 1997). The geothermal system was built in TRACE 700 by assuming that the current geothermal system has full capacity in the loop field to handle the full load of the house.

3.5.2 Analysis Results

The total cumulative energy generated by the solar panels and the wind turbine is calculated at 2,219 and 2,000 kWh/yr respectively based on the manufacturer's specifications. The total expected produced energy is 4,219 kWh/yr. The total consumed energy of ZNETH for the whole year was simulated and found to be 12,188 kWh/yr. Fig. 4 illustrates a comparison between the total cumulative energy consumption (top line), total cumulative energy production (bottom line) and the total cumulative energy consumption after subtracting energy production (middle line). The months are represented on the X-axis and produced energy is represented on the Y-axis in Fig. 4. It shows that the produced energies from the solar panels and the wind turbine are not enough to offset the total electrical consumption of ZNETH based on the current design.



〈Fig. 4〉 A comparison between the total cumulative energy consumption and total cumulative energy production

4. OPTIMIZING THE DESIGN OF ZNETH

Examining different design alternatives during early design stages, especially from an economic standpoint, helps design teams to produce economical, efficient designs. The design of ZNETH had not been completed prior to a full stage energy analysis. Therefore, some theoretical changes were made to the ZNETH model and tested to produce the most efficient design possible. The economical ramifications of any changes have not been considered in the scope of this paper. Two changes were made. First, the overhang width was optimized to produce the most efficient width that would block the sun's direct radiation during the summer only. Blinds were used in all windows to block the summer heat effects. To increase the natural light, some windows were resized and relocated. Second, a model was built similar to ZNETH, called ZNETH-NEW, with a new overhang width and window sizes. A comparison was conducted between the ZNETH-current and ZNETH-NEW using four different scenarios as follows:

1. As designed materials
2. ICF walls with wall thicknesses of 4", 6" and 8" for all walls
3. Closed cell soy-based spray foam as the insulation material for all walls
4. Traditional building materials

4.1 Overhang

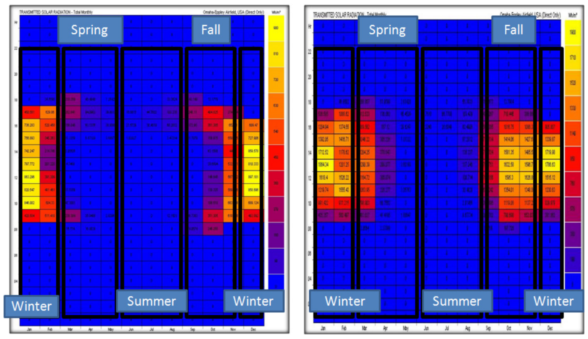
With an 8.12 ft (2.48 m) width, ZNETH's front porch overhang can be seen in Fig. 5. By using Ecotect, a solar analysis was conducted to calculate the total monthly solar radiation that would be transmitted through the front windows of the living room for the whole year.

As seen in Fig. 6 (a), during the spring, summer and fall months, the amount of solar radiation passing through those windows is very low. During the winter months when the house needs to be heated, the sun's radiation is minimal. The total transmitted radiation is 139.95 kWh/yr. The result indicates that the overhang width is oversized because it minimizes the sun's radiation during all four seasons.

Therefore, the overhang width has been minimized using different widths and tested by shading percent analysis and total monthly solar radiation analysis to produce the most efficient width that blocks the sun's radiation during the summer period only. Table 1 shows the different widths and their average shading percent. As can be seen, an overhang of 1.11 m (3.65 ft.) produces the most efficient shading during the summer months while allowing for a higher amount of radiation during the winter, spring and fall months. Also, Fig. 6 (b) shows the amount of solar radiation passing through the windows using the 1.11 m overhang. The total transmitted radiation is 390.10 kWh/yr. As can be seen, there is still a low amount of transmitted radiance through the summer months (dark color). However, there is more radiation (brighter color) during the spring, fall and winter seasons that helps to increase the heat sources for this room. It will also reduce the required heating loads and thus decrease the total energy consumption of the house.

A consumption analysis was conducted to calculate the expected heating load and the total consumed energy of the whole year for the ZNETH model before and after changing the overhang width. After using 1.11 m as the overhang width, the heating load required to heat the house was reduced by 204 kWh/yr. This is because there is more solar radiation entering the living room during the winter, fall and spring months. Also, this heating reduction would minimize the total energy consumption of the house by 189 kWh/yr. Table 2 shows a summary of the simulation analysis results

⟨Fig. 5⟩ The overhang at the ZNETH



⟨Fig. 6⟩ The transmitted solar radiation before (a) and after (b) resizing the overhang

⟨Table 1⟩ Average shading percent using different widths

Overhang width (m)	0.48	0.6	0.73	0.86	0.98	1.11	1.24
Months	Average shading (%)						
Jan	1	1	2	3	3	4	6
Feb	0	0	0	2	5	8	13
Mar	8	11	17	24	31	38	44
Apr	33	43	54	63	72	79	84
May	65	78	87	94	79	97	97
Jun	82	92	97	98	98	98	98
Jul	75	87	95	98	98	98	98
Aug	47	59	69	78	86	90	92
Sep	11	19	28	37	46	54	61
Oct	2	2	4	8	13	18	23
Nov	0	0	0	0	1	2	5
Dec	0	0	0	0	0	0	1

⟨Table 2⟩ Overhang analysis results (Unit: kWh/yr)

Analysis type	Before	Suggested design	After	Improvements
Transmitted radiations	139.95	Optimizing the overhang for the living room	390.10	250
Total heating load	2,430		2,226	204
Total consumed energy	11,874		11,685	189

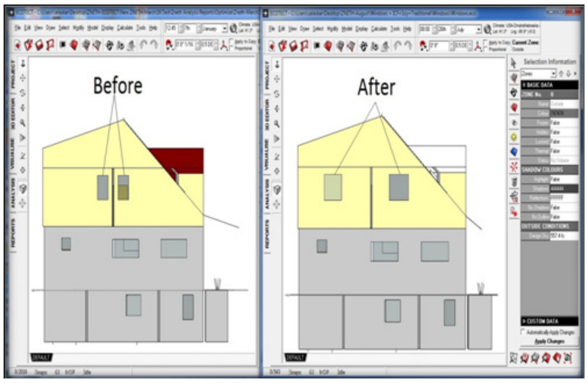
before and after optimizing the overhang.

4.2 Resizing windows

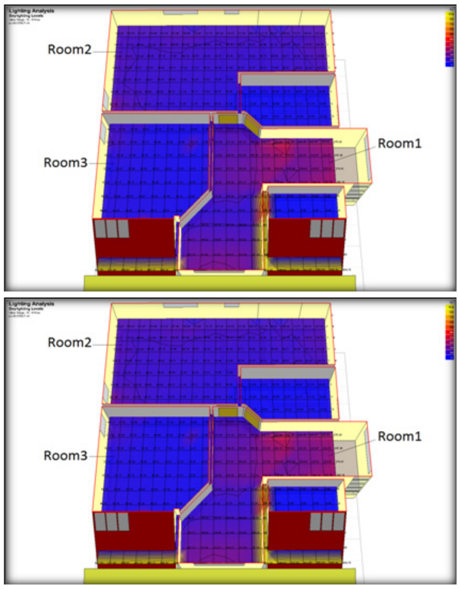
To improve the lighting design, some windows in the second floor were enlarged and relocated to allow for more natural light into the house. These windows were selected because there are no barriers that would block the sunlight. Fig. 7 gives a representation of window placements before and after resizing and relocating the windows.

The daylighting levels were measured before and after resizing the windows. As shown in Fig. 8 (a) and based on the actual design, rooms (1),(2) and (3) have an average of 160 Lux, 110 Lux, and 45.5 Lux (lumens per square meter), respectively. Fig. 8 (b) shows the daylighting levels after the changes were applied. By resizing the windows in areas (1), (2) and (3), the available daylight increased over the previous results. These changes allow the natural daylight to enter these rooms throughout the day.

Table 3 summarizes the results of the analysis conducted for ZNETH after resizing the windows.



〈Fig. 7〉 ZNETH before and after changing window size (west side)



〈Fig. 8〉 Daylighting levels for the second floor (a) before and (b) after enlarging some of the windows

4.3 Comparison Scenarios

After selecting and examining the overhang width and window sizes, they were added to a model called ZNETH-NEW and compared with the ZNETH-current, which is as designed with no changes.

The first scenario is using as-designed materials of the exterior walls. Two exterior wall systems were used in the actual design of ZNETH. First, ICF walls were used in the exterior walls of the basement and at the north, east and west walls of the first floor. These walls have a 15.24 cm concrete thickness with 6.35 cm expanded polystyrene (EPS) in both sides. The total R-value for this system is 26.34 h.ft2.oF/Btu (4.64 K.m2/W). Second, an EIFS system, 2x6 framing and closed cell soy- based spray foam were used in the south wall of the first floor and in all the second floor's walls. The total R-value of this system is 34.55 h.ft2.oF/Btu (6.08 K.m2/W). The combination of these two systems is expected to lead to highly heat flow resistant walls.

Second, Insulated Concrete Form (ICF) walls are used for all exterior walls with wall thicknesses of 4, 6 and 8 inches. ICF is a hollow mold with 5-inch forms made of polystyrene or polyurethane insulation. These forms are connected together by steel or plastic rods. The gap between the forms is filled by concrete. The concrete thickness varies based on the design load. For this research, 4, 6 and 8-inch concrete thicknesses are used and tested individually. The R-values for the 4, 6 and 8-inch thick ICF walls are 26.17, 26.34 and 26.5 h.ft2.oF/Btu (about 4.64 K.m2/W), respectively.

The third scenario is using traditional house materials for

〈Table 3〉 Resizing windows analysis

Analysis type	Before	Suggested design	After	Improvements
Daylighting levels (Lux)	126.86	Resizing the overhang for the living room	215.19	+ 88.33

Lux: Lumens per square meter

the exterior walls. 8-inch concrete walls and 2x4 framing are used for the basement walls and 2x6 framing is applied for the first and second floor walls. A typical insulation material (e.g., fiberglass batt) is selected to insulate all walls. The total R-value is 12.19 h.ft2.oF/Btu (2.15 K.m2/W)for the basement walls and 21.65 h.ft2.oF/Btu (3.81 K.m2/W) for each floor above ground (U.S Department of Energy, 2009a).

The fourth scenario is similar to the third scenario, but instead of using a Fiberglass Batt, closed cell soy-based spray foam is used as the insulation material for all walls. The closed cell soy-based spray foam used in the ZNETH has a high R-value of 6.5 per inch (U.S Department of Energy, 2009b). The total R-values for the basement walls are 22.22 h.ft2.oF/Btu (3.91 K.m2/W) and 34.55 h.ft2.oF/Btu (6.08 K.m2/W) for the first and second floor walls. Table 4 summarizes all four scenarios and their R-values.

4.4 Comparison Analysis

Two analyses were conducted to evaluate the two models, ZNETH-current and ZNETH-NEW. The first one was a thermal analysis and the second one was a total consumed energy analysis. The results are presented below.

4.4.1 Thermal Analysis

An hourly heat gain and loss analysis was chosen to compare the heat gains between the two models, because it calculates how much heat gets through the wall material during the hottest day, which is July 26th. Table 5 shows the heat gains through the walls material, in kilowatt-hours (kWh) for the two models under the four scenarios. The ZNETH-current model under the first scenario has the lowest heat gain, because this scenario has the highest thermal resistance value (R-value). On the other hand, ZNETH-NEW under all four scenarios has higher heat gains because the enlarged windows reduce the thermal resistance (R-value) of the second floor walls.

4.4.2 Consumption Analysis

A total consumed energy analysis was conducted to compare the total consumed energy between the two models, ZNETH-current and ZNETH-NEW, under the four scenarios and before and after using blinds. Table 6 shows the total consumed energy for the whole year in kilowatthours (kWh/yr). Enlarging the windows (ZNETH-NEW) would decrease the R-value of the walls, which would increase the total consumed energy. On the other hand, using blinds has an impact on reducing the total energy consumption. Also, using closed cell soy-based spray foam as insulation for all walls is the best material alternative to promote energy conservation in both models.

4.5 Design for Net Zero Energy Consumption

If the ZNETH uses Scenario 4 with blinds in summer as shown in Table 6, it would consume 11,748 KWh/year. Since the geothermal system was built in the simulation with their assumed full capacity in the loop field to handle full load of the house and with the size of the loop there should be, there is no room for additional energy savings from the geothermal system.

〈Table 4〉 Summary of the four scenarios and their R-values (h.ft2.oF/Btu*)

	Description	Floors	R-Values
Scenario 1	As designed	basement	26.34
		first and second	34.55
Scenario 2	ICF-4"	Basement, first and second	26.17
	ICF-6"		26.34
	ICF-8"		26.5
Scenario 3	Traditional house	basement	12.19
		first and second	21.65
Scenario 4	Closed cell soy-based spray foam	basement	22.22
		first and second	34.55

* 1 h.ft2.oF/Btu = 0.1761 K.m2/W

〈Table 5〉 Heat gains through the fabric in kilowatt-hours (kWh)

	Description	ZNETH-current	ZNETH-NEW
Scenario 1	As designed	16.370	26.403
Scenario 2	ICF-4"	17.587	24.778
	ICF-6"	17.257	24.488
	ICF-8"	17.224	24.457
Scenario 3	Traditional house	24.755	33.822
Scenario 4	Closed cell soy-based spray foam	17.055	26.692

ZNETH-current: as designed
ZNETH-NEW: after optimizing the overhang and resizing the windows

〈Table 6〉 Total consumed energy for one year in kilowatt- hours (kWh/yr)

	Description	No blinds			With blinds in summer		
		ZNETH-current	ZNETH-NEW	difference	ZNETH- current	ZNETH-NEW	difference
Scenario 1	As designed	12,189	12,478	-289	11,874	12,006	-132
Scenario 2	ICF-4"	12,325	12,506	-181	12,024	12,076	-52
	ICF-6"	12,253	12,487	-234	11,956	12,065	-109
	ICF-8"	12,179	12,439	-260	11,872	12,038	-166
Scenario 3	Traditional house	15,336	15,494	-158	15,285	15,352	-68
Scenario 4	Closed cell soy-based spray foam	12,079	12,417	-338	11,748	11,940	-191

〈Table 7〉 Possible combinations of renewable energy resources

No. of Solar panels (1109.5 kWh/panel)	No. of Wind turbines (2000 kWh/unit)	Energy Generation (kWh/year)	Cost
2	5	12,219	$26,885.6
3	5	13,329	$30,563.4
4	4	12,438	$30,391.2

By considering the net surface area of south roof (67.26 m^2),up to 4 kW of solar panels can be installed, which are estimated to generate 4,438 kWh/yr (4 panels x 1,109.5 kWh). The local cost for a 1 kW solar panel including materials, installation, and inverter is about $4,000 after a 30% incentive rebate.

To generate more energy by using only wind turbines, six wind turbines need to be installed (6 units x 2000 kWh = 12,000 kWh 〉 11,748 kWh). One unit of the Honeywell wind turbine costs about $3,850 including materials and installation after a 30% incentive rebate. Thus, a wind turbine is a better choice over a solar panel in terms of cost per unit and energy generation per unit.

Table 7 shows several possible combinations of renewable resources to generate more than the annual energy consumption (11,748 kWh). Theoretically, five wind turbines with the current two solar panels and geothermal system would be the most economical combination to achieve net zero energy with the current design of the ZNETH house.

While theoretically feasible, it may not be easy to install five six-foot (182 cm) diameter wind turbines on the roof or around the yard of the house. Not only is it financially challenging, but local building codes, obtaining the city's approval for the wind turbines, and covenants established by local homeowners associations are all issues that need to be addressed before any design changes can be applied.

5. CONCLUSIONS

1. The objective of this research is to evaluate the energy efficiency of a research test bed called ZNETH, and suggest improvements to its sustainable design by using two energy modeling programs, Ecotect and TRACE700. Several energy analyses were conducted for evaluating ZNETH, and the results from the energy consumption analysis show that ZNETH's current design will not meet its goal of zero net energy based on the simulated energy analyses.

In addition, resizing some of the windows and reducing the overhang size of the windows were considered in order to improve the design. These two changes were analyzed and the following conclusions can be drawn:

1. Optimizing the overhang width will lead to:
   a. Increasing the transmitted radiation for the living room area by 178.7%
   b. Reducing the total heating load needed for the ZNETH by 8.4%
2. Resizing some windows will
   a. Increase the lighting level for the second floor area by 69.5%

After analyzing the above changes, the results were added to a model called ZNETH-NEW. Thermal and energy consumption comparisons between ZNETH-NEW and ZNETH-current were then completed.

The energy consumption comparison results in the following conclusions:

1. The fourth scenario, which has 20.32 cm (8-inch) concrete

walls and 2x4 framing for the basement walls and 2x6 framing for the first and second floor walls with closed cell soy–based spray foam as the insulation material for all external walls, is the best alternative for both models (ZNETH–current and ZNETH–NEW).

2. Enlarging the windows would minimize the R–value, which would increase the total consumed energy.
3. Using blinds during the summer seasons has a large effect on reducing total energy consumption.
4. Assuming that the current installed geothermal system has full capacity of the house load, additional solar panels and wind turbines are required to meet the goal of zero net energy.

Several benefits can be realized from this research:

- This research demonstrates a methodology to incorporate renewable energy resources such as a wind turbine, geothermal system and solar panels with BIM and energy analysis programs.
- Evaluated design changes found to improve ZNETH's overall building performance can be incorporated into the ZNETH II house design research which is currently under investigation.

Future studies include economic analysis of the current ZNETH design and comparison of actual energy performance of ZNETH to the simulated data studied in this paper.

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