

Exploring Residential Energy Conserving Options to Achieve Net Zero Homes for Cold Climate Areas: A Michigan Case Study

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There is a growing interest in the concept of Net Zero Energy Homes, which are homes that produce as much energy as they use by reducing the energy needs of the building and using a renewable energy source. Currently, homes consume 20.9% of the total energy consumed in the United States. Total residential energy is expected to increase 20.4% by 2030. There are numerous realistic and unrealistic options to reduce energy. The process of identifying the optimal options to achieve Net Zero Homes is quite complicated and time consuming. Decision makers need recommendations on the most effective options to start this process. This paper investigates the performance of different energy conserving options. Energy simulation software was used to model an affordable 1,120 square foot home located in Michigan. The Home Energy Rating System (HERS) was used to determine the efficiency gained by comparing the effects of different options on annual energy consumption. The results showed that minor modifications were required to qualify for the Energy Star label. Certain energy conserving options, such as ground source heat pumps and continuous insulation, could be implemented to yield a dramatic reduction in the home's annual energy use. The results of this limited case study can provide recommendations for decision makers on the most effective options to achieve net zero homes.

Key words: Net Zero Homes, cold climate, energy efficiency, Home Energy Rating System, Energy Star

Introduction

The United States uses 21.7% of the world's primary energy consumption while housing only 4.6% of the world's population. By 2030, the U.S. population is expected to increase by 21% and the number of homes by 25% (US DOE, 2009). To address the U. S.'s escalating residential energy demand, several federal, state, and local organizations are promoting energy use reduction in the residential sector. One of these programs is the ENERGY STAR label: homes earning this label imply an energy reduction of 15% below the minimum set by the 2004 International Residential Code (IRC) (ENERGY STAR, 2010). The Department of Energy (DOE)'s Building America research program and the U. S. Green Building Council (USGBC)'s LEED for Homes are other notable programs. Although these programs set higher standards of energy efficiency, the objective of significantly reducing U. S. residential energy use has not been achieved (ENERGY STAR, 2010; US DOE, 2009; U.S. Green Building Council, 2010). In addition, ever-improving products, materials, and methods are continuously entering the market (Sawhney et al. 2002).

The Building America research team has responded to calls for greater energy efficiency by striving to standardize a design for net zero homes (Baechler et al. 2006). A net zero home is a home that generates as much energy as it uses in one year (Torcellini et al. 2006). Limited research literature was found to address this problem; essentially, it investigates certain building components and correlations between exterior wall composites and building energy performance. Gajda (2001) explored 11 different wall types in all 25 ASHRAE climate zones in the U.S. and Canada using DOE 2.1E software. Chasar et al. (2002) compared Insulated Concrete Forms (ICFs) to stick frame construction by using data loggers to collect temperature, relative humidity, building electrical use, and HVAC energy use for four built homes near Dallas, Texas. Both research papers showed that ICF or Sandwich Panel construction consistantly outperformed other wall types in reducing energy. Others have focused on the building as a whole. Sawhney et al. (2002) reported the results of two Michign homes that were 74% more energy efficient than the 1993 Model Energy Code (MEC). Barley et al. (2003) realized an 89% heating and cooling energy savings and 83% electrical savings for a home in Denver, Colorado by using a passive solar airtight building envelope and thermal mass. These researchers also documented changes in occupant behavior, such as learning "to wear sweaters around the house with lowered thermostat settings." Farhar et al. (2004) indicated that 306 homes were sold in San Diego, California, in 2001 with zero energy home features such as solar water heating, solar radiant barriers, and photovoltaic systems. Wilkinson and Boehm (2005) investigated energy conservation methods for a net energy home in Southern Nevada. The final energy conserving strategy resulted in a 5% surplus of on-site generated electricity. Keesee (2005) reported that California builders have aggressively built over 100 Net Zero Homes in the Sacramento area. Norton and Christensen (2006, 2007) reported an affordable and simple-to-construct home that achieved 24% greater energy efficiency. They noted that the energy savings can be attributed to the occupant behavior of engaging in fewer activities.

Finally, specific research reports have identified the need to address cold climate specific issues. In response, DOE's Building America (BA) developed a standard package that achieves 50% energy savings for cold climate areas. Anderson and Roberts (2008) highlighted the need for cold climate homes to achieve a target of 70% energy reduction for net zero objectives. Builders have successfully constructed net zero homes in cold climates. However, the task of identifying the best options to achieve net zero can be complicated. Decision makers need a concise way to determine which building component upgrade is the most effective in reducing energy. The objective of this paper is to provide decision makers with cold climate specific strategies to achieve net zero homes using currently available products. The remainder of this paper will introduce the implemented methodology and the case study used. The results will then be presented and discussed. Finally, the study will be concluded and future work will be proposed to overcome the limitations of the current study.

Methodology

This study uses REM/Rate energy simulation software, developed by Architectural Energy Corporation (AEC), to predict the energy performance of the building. The governing factors for this selection were the accuracy, ease of use, and being designed according to the Home Energy Rating System (HERS). HERS is a scoring system for comparing the energy efficiency of a building to a reference home based on the 2009 International Energy Conservation Code (IECC) (Architectural Energy Corporation, 2010) and it tests the compliance of the home to the Energy Star label. Stein and Meier (2000) validated REM/Rate by comparing the HERS's prediction of annual energy consumption to actual utility bills and concluded that, on average, HERS predicted the annual energy use accurately. Homes are modeled in REM/Rate using over 200 data entry points to analyze the building system as a whole. Predictions of annual energy consumption can be presented using different reporting options.

An affordable 1,120 square foot home was selected as a base case for this project, primarily because its design is typical for affordable homes in Michigan. The REM/Rate 200 data entry points were extracted from the architectural plans. Table 1 illustrates a summary of the extracted entries.

Table 1

A Summary for the REM/Rate Base Case Entries

Building Component	Specification
Basement Walls	8" thick Solid concrete walls
Basement Type	Conditioned
Basement walls	Wood 2x4 framing, 24" o.c.; R-10 Continuous Insulation; R-11 Cavity Insulation
Slab	Uninsulated
Rim Joist	2x6, 16" o. c.
Above Grade Walls	Wood 2x6 framing spaced 24" o.c.; R-21 Cavity Insulation; R-5 Continuous Insulation
Windows	Double Pane, Vinyl; U-Value = 0.345; SHGC = 0.570
Doors	R-4.40
Attic	R-37 Floor Insulation; R-13 Cavity Insulation
Refrigerator	590 kWh/year
Dishwasher	0.71 EF
Lighting	Pin-Based 0%; CFL 100%

Dryer	Electric
Oven/range	Electric
Furnace	98.0 AFUE (%)
Air Conditioner	10.0 SEER; 2 ton
Water Heater	0.93 EF; 50 gallon
ACH	0.35

Missing data points were assumed to meet the Michigan Uniform Energy Code for Michigan's climate zone 1 (Michigan Department of Labor & Economic Growth, 2005). Additionally, the assumption was made that all appliances will be Energy Star compliant and that the built house would reach 0.35 air changes per hour (ACH) to meet the ASHRAE standard (ANSI/ASHRAE Standard 62.1-2007). R-Values for insulation types were taken from the Building Performance Institute (BPI) Technical Standards for the Building Analyst Professional (Building Performance Institute, 2010). U-Values and Solar Heat Gain Coefficient (SHGC) figures are from the Lawrence Berkeley National Laboratory (Center for Sustainable Building Research et al., 2010). All resulting utility bills are based on 10.92 cents per kWh plus $6.00 monthly service charge (Public Service Commission, 2010). All the extracted and assumed data were transferred into the REM/Rate data entry modules. Figure 1 demonstrates a sample data entry screen that was used to define an R-21foundation wall.

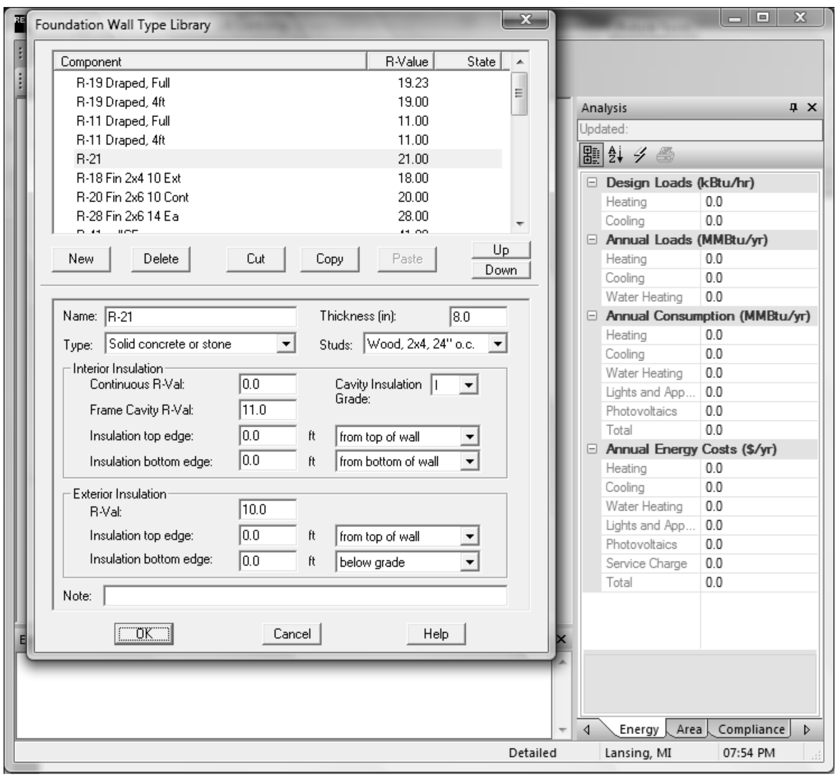

Figure 1: REM/Rate Defining Foundation Wall Type

After modeling the base case home, different possibilities for each major home component were gathered from the construction literature review (Gajda, 2001; Sawhney et al, 2002; Walsh et al., 2003; Wilkinson & Boehm, 2005). The base case REM/Rate model was then tailored to represent the different possibilities. Specifically, the following options were investigated.

- **<u>Basement Wall</u>**: Five (5) different basement wall types were examined by changing the modeled parameter and individually comparing the results to the base case. Changes to the base case included changing the framing from 2x4 to 2x6s and increasing the R-Value of insulation.
- **<u>Above Grade Walls</u>**: Four (4) different above ground wall types were simulated on the case home. Changes to the base were similar to the basement walls in that the framing was changed from 2x4 to 2x6s and R-Value of insulation was increased.

- **Windows**: Six (6) different types of windows were simulated. The windows' effects on the building followed the general rule that the lower the U-Value, the greater the reduction in energy use.
- **Heating and Cooling**: Improvements in cooling energy reduction came in the form of increased SEER air conditioners or using a ground source heat pump (GSHP)
- **Water Heating**: Improvements in water heating energy use resulted from either increasing the energy factor of a conventional water heater, using a GSHP for water heating, or attaching a desuperheater to a GSHP for space heating and cooling to assist with conventional water heating.

The results of each modification were compared to the base case model result and ranked based on their effectiveness in reducing energy consumption.

Results & Discussion

Base Case

The developed model predicted that the annual energy cost would be $2,380. This corresponded to the average energy consumption for homes in the Midwest Census region (US DOE, 2009). The actual annual energy cost is expected to be higher for this home once built due to changes during construction or use of the house. However, the comparison analysis results would not be affected because all factors, except the tested option, were held constant.

Basement Walls

Table 2:

REM/Rate Basement Walls Simulation Results

Foundation Wall	Foundation Wall Description	Prescriptive Method to Achieve R-Value	Total Cost	% Reduction
Base Case	R-21; Wood 2x4, 24" o.c.; Frame cavity R-11; Exterior Insulation R-10	R-11 = Cellulose, high density, R-3.2 @ 3.5"; R-10 = Polystyrene, extruded rigid board, R-5 @ 2"	$ 2,380	-0 %
1	R-20; Interior continuous R-10; Exterior Insulation R-10	R-10 = Polystyrene, extruded rigid board, R-5 @ 2"	$ 2,370	-0.42 %
2	R-27; Wood 2x6, 24" o.c.; Frame Cavity R-17.6; Exterior Insulation R-10	R-17.6 = Cellulose, high density, R-3.2 @ 5.5"; R-10 = Polystyrene Rigid Board, R-5 @ 2"	$ 2,315	-2.73 %
3	R-28; Interior Continuous R-14; Exterior Insulation R-14	R-14 = Polyisocyanurate Foam Board, R-7 @ 2"	$ 2,320	-2.5 %
4	R-47; Wood 2x6, 24" o.c.; Frame Cavity R-33; Exterior Insulation R-14	R-33 = Spray Foam, urethane, R-6 @ 5.5"; R-14 = Polyisocyanurate Foam Board, R-7 @ 2"	$ 2,262	-5.0 %
5*	R-41; Wood 2x6, 24" o.c.; Frame Cavity R-13; Interior Continuous R-14; Exterior Insulation R-14	R-13 = Fiberglass Batt, R-2.5 @ 5.5; R-14 = Polyisocyanurate Foam Board, R-7 @ 2"	$ 2,248	-5.5 %

* Indicates the home option that is compatible with the Energy Star Label

Table 2 illustrates the results of the REM/Rate simulations for the different basement wall options. This table demonstrates the predicted annual energy consumption cost for different options and the resulting percent reduction compared to the base case. Changing the basement wall to follow option 5 in Table 2 will result in qualifying the home for the Energy Star label. This indicates that the basement wall is a focus area for achieving Energy Star rating with minimal effort beyond the Michigan Uniform Energy Code. The results indicate the superiority of continuous insulation over increasing cavity R-Value with regard to reducing energy use. For example, the R-41 basement wall having a cavity R-Value of 13 and continuous R-Value of 28 reduced more energy than the R-47 basement wall with a cavity R-Value of 33 and continuous R-Value of 14. It should be noted that Insulated Concrete Form (ICF) basement walls did not perform as expected, given the continuous insulating nature of ICF construction. This may be attributed to REM/Rate modeling error inherent in the software for ICFs. This corresponds to the results of other studies that specifically address the issue of ICFs in energy modeling software (Kosny et al. 1998).

Above Grade Walls

Table 3:

REM/Rate Above Grade Walls Simulation Results

Above Grade Wall	Above Grade Wall Description	Prescriptive Method to Achieve R-Value	Total Cost	% Reduction
Base Case	R-23; Exterior Insulation R-5, Frame Cavity R-20	R-5 = Polystyrene, extruded rigid board, R-5 @ 2”; R-20 = Spray Foam, urethane, R-3.7 @ 5.5”	$ 2,380	-0 %
1*	R-32; Exterior Insulation R-10, Frame Cavity R-33	R-10 = Polystyrene, extruded rigid board, R-5 @ 2”; R-33 = Spray Foam, urethane, R-6 @ 5.5”	$ 2,305	-3.2 %
2*	R-37; Exterior Insulation R-14, Frame Cavity R-33	R-14 = Polyisocyanurate Foam Board, R-7 @ 2”; R-33 = Spray Foam, urethane, R-6 @ 5.5”	$ 2,290	-3.8 %
3*	R-35; SIP 7 3/8	R-35 = Polystyrene, extruded rigid board, R-5 @ 7.375”	$ 2,305	-3.2 %
4*	R-66; SIP 12 3/8	R-61 = Polystyrene, extruded rigid board, R-5 @ 12.375”	$ 2,243	-5.8 %

* Indicates the home option that is compatible with the Energy Star Label

Table 3 illustrates the results of the REM/Rate simulations for the different above grade wall options. The annual energy consumption cost was predicted for different options and the resulting percent reduction compared to the base case. According to these results, any tested modified wall types qualified the home for the Energy Star rating. As with the basement wall, this indicates that the above grade wall is one area of focus for achieving Energy Star rating with minimal effort beyond the Michigan Uniform Energy Code. The results indicate that changing the wall type from 2x6 framing to a Structural Insulated Panel (SIP) wall of similar thickness did not improve the energy efficiency of the home. For example, an R-32 2x6 framed wall reduced as much energy as the higher R-Value 35 SIP wall. This indicates that if the R-Value of the 2x6 wall was increased to R-35, it would have reduced more energy than the R-35 SIP wall.

Windows

Table 4:

REM/Rate Windows Simulation Results

Window Type	Window Type	U-Value	SHGC	Total Cost	% Reduction
Base Case	Double Pane	0.35	0.57	$ 2,380	-0 %
1	LoE Double Pane	0.26	0.33	$ 2,344	-1.5 %
2*	LoE Triple Pane	0.20	0.44	$ 2,299	-3.4 %
3*	LoE Triple Pane	0.18	0.53	$ 2,281	-4.2 %
4*	LoE Triple Pane	0.15	0.45	$ 2,267	-4.7 %
5*	LoE Triple Pane	0.18	0.44	$ 2,287	-3.9 %
6*	LoE Kypton Gas Triple Pane	0.13	0.30	$ 2,265	-4.8 %

* Indicates the home option that is compatible with the Energy Star Label

Table 4 illustrates the results of the REM/Rate simulations for window options. This table demonstrates the predicted annual energy consumption cost for different options and the resulting percent reduction compared to the base case. According to these results, any window having U-Values =/< 0.20 qualified the home as Energy Star. Triple pane windows are typical of these values. Solar Heat Gain Coefficient (SHGC) followed no particular pattern, which indicates that priority should be placed on U-Values when selecting windows for cold climate areas. Converting the windows to triple pane windows presents the simplest route to greater energy efficiency.

Heating and Cooling

Table 5:

REM/Rate Heating and Cooling Simulation Results

Equipment Type			Total Energy Cost	% Reduction
Air Conditioner (cooling only)	A/C SEER 10		$ 2,380	-0%
	A/C SEER 18.0*		$2,352	-1.2%
GSHP (heating and cooling)	COP	EER		
	3.5	15.8	$1,536	-35.5%
	4.2*	21	$1,514	-36.4%

Table 5 illustrates the results of the REM/Rate simulations for different heating and cooling options. This table demonstrates the predicted annual energy consumption cost for the different options and the resulting percent reduction compared to the base case. The results indicate that increasing the Seasonal Energy Efficiency Ratio (SEER) from 10 to 18 resulted in a 36% reduction in cooling energy consumption. However, since REM/Rate reports that annual energy consumed for cooling represented only 3% of the total energy costs, improving the efficiency of the air conditioner only resulted in a 1% reduction in overall energy cost. A ground source heat pump (GSHP) operating in the dual role of space cooling and heating results in average overall energy savings of 36% compared to the base case.

Water Heating

According to the results, the replacement of electric water heating with a GSHP qualifies the home for Energy Star. The results indicate a reduction of 10.8% in overall energy use when compared to the base case. A heating and cooling GSHP with a desuperheater to assist in water heating results in a 37.7% reduction while having a separate GSHP water heating unit results in a 47.1% reduction in overall energy use. REM/Rate indicated that an instant water heater would show no improvement in building energy performance.

Overall, based on the results of this study, decision makers can generate a simple list of the most efficient strategies to achieve net zero homes. For example, not considering cost factors, the following order could be followed: a combined heating, cooling, and water heating GSHP; triple pane windows; higher R-Valued above grade walls; and finally higher R-Valued basement walls. For the house walls, decision makers should focus on continuous insulation.

Conclusion

This paper explored the need to reduce energy in the residential sector and the need for cold climate specific solutions. One of the leading research groups in this area is the Building America research team which strives to standardize the design for net zero homes in cold climate areas. Research literature has reported the success of net zero homes, but highlighted the need for occupant behavioral changes. A case study research approach was used to model an affordable house and investigate the effectiveness of different energy conserving options. REM/Rate was used to estimate the annual energy consumption for the case study home and the different energy options. Data was extracted from the architectural plans and missing data was assumed to meet current energy code. Results proved that GSHP was the most efficient strategy to reduce energy use and that minor home upgrades can result in qualifying the home for Energy Star label. Also, continuous insulation should be a focus when considering net zero homes. According to the results, GSHP reduced overall energy use by 47.1%. Triple pane windows, higher R-Valued above grade walls, and higher R-Valued basement walls reduced overall energy use by 4.8%, 5.8%, and 5.0% respectively. Decisions makers will be able to rank the offered options according to their effectiveness in reducing energy.

Future Work

This is a very limited study and no generalizations can be made as to how all home types across Michigan or other cold climate areas would perform. This study used only one home type in one climate zone in Michigan. More case studies should be evaluated within cold climate zones to validate the hypothesis in this study. In addition, this study did not investigate the cost effectiveness or constructability of the different options. These factors are key factors for successful implementation of net zero options. The benefits of internal heat gains were simplified in this study and should be further investigated. A limited amount of options were evaluated, and other options may prove to be more effective in reducing energy consumption.

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