BIM-DRIVEN ECONOMIC ANALYSIS FOR ZERO NET ENERGY TEST HOME

Yong Cho, Assistant Professor, ycho2@unl.edu
George Morcous, Associate Professor, gmorcous2@unl.edu
Koudous Kabassi, Gradate Research Assistant, kaboudoukabassi@gmav.unomaha.edu
Jill Neal, Graduate Research Assistant, neal.jill@epamail.epa.gov
University of Nebraska, USA

ABSTRACT

This paper presents a case study that utilized a Building Information Model (BIM) for 5D cost estimation and energy analyses to support economic analysis of a research test bed called the Zero Net Energy Test House (ZNETH). The ZNETH has been designed and built with the goal of consuming a negligible amount of energy by offsetting usage through energy conservation and renewable energy generation. To offset the consumed energy of the household, a wind turbine and two solar panels were selected as the renewable energy sources for this project along with several sustainable materials and systems such as Insulated Concrete Foundation (ICF), Exterior Insulation Finishing System (EIFS), and a closed loop geothermal system. By integrating the highly graphical and intuitive analysis with a BIM of the house, this investigation introduces a framework to integrate renewable energy options and sustainable building materials for the ZNETH to predict its economic benefits. The theoretically consumed and generated energy levels were analyzed. It was found that the current design of ZNETH would not have greater economic benefit than cost. Finally, suggestions are presented to assist improving current ZNETH design for better economic returns. Findings from this research will be used for designing ZNETH II which is currently under investigation.

Keywords: BIM, 5D cost estimation, zero net energy test house, energy analysis, economic analysis.

1. INTRODUCTION

With global warming gaining momentum, a substantial cutback in energy consumption to help reduce carbon dioxide (CO_2) is more than needed (Kolk and Levy, 2004). Homes account for over 20% of the nation's energy use and as a result, for over 20% of CO_2 emissions in the United States (Jeswani et al. 2008). Furthermore, the certainty of rising prices of oil for the next 20 years or so along with the rise of natural gas prices and peak period electricity prices, energy efficient houses make good investment sense (Kolk et al. 2006). For a capital investment and maintenance costs, green houses should save energy and money in the long run.

In today's environment where quality is foremost, green buildings provide comfort and high quality, but at additional cost. However, buildings represent a large and long-lasting investment in financial term as well as in other resources (Oberg 2005). Therefore, a house constructed with natural elements, newest materials and technologies to reduce energy efficiency would satisfy the requirements for green and sustainable systems. Recently, congress passed legislation that gives federal subsidies and encourage the use of sustainable energy. Therefore, important monetary incentives could also be received for energy savings.

An investigation of economic benefits in the previously mentioned incremental capital costs is done by comparing the Zero Net Energy Test Home (ZNETH), a house with sustainable elements and systems, with ZTH, which has the same scope as the ZNETH but with traditional materials and without renewable energy systems. Data from Building Information Model (BIM) and theoretical energy analysis were also used.

2. OVERVIEW OF THE ZNETH

The Zero Net Energy Test Home (ZNETH) is a two-story house that will be a living and learning home for university students when it's completely done in fall 2010. The ZNETH, a 4 bedroom 4 bathrooms house, is being built using sustainable features that include solar panels, a wind turbine, and a geothermal system. A rated leadership in energy and environmental design (LEED) platinum house includes a variety of innovative and environmental friendly features. To achieve the LEED platinum rating, the ZNETH has been constructed using onsite and renewable power solutions. Figure 1 below is a south view of the house, showing two photovoltaic panels on the roof.

In relation to the fair climatic condition and surrounding environments, two 1 kWh photovoltaic solar panels were installed on the roof to take advantage of direct solar radiation. To convert the sunlight into electricity, the solar panels contain a power system that uses a net-meter along with an array and inverter. The electricity is therefore a direct measure of the amount of sunlight transmitted to the photovoltaic panels.

Figure 1: Front view of the ZNETH with two photovoltaic panels on the roof

Another friendly environmental power source used is for the ZNETH house is wind. The National Renewable Energy Laboratory (NREL) has developed a wind power classification per region, state and city to evaluate wind turbines' efficiency. Omaha, NE falls under class 3. Class 3 is considered "Fair" under resource potential (Wind Powering America 2010). To take advantage of this classification, a wind turbine will be installed to help generate energy for the ZNETH. Based on manufacturer's specification, the wind turbine is expected to generate about 2000 kWh per year ("WT 6500 wind turbine"). It will operate in a range of wind speeds from 2 mph to 42 mph in this area (Windtronics 2010).

The ZNETH also features an appropriate design of the building's envelope by reducing transmission losses with the use of more efficient HVAC technologies. Furthermore, a high efficient geothermal system was installed with its maximum capacity in the house including two 250 ft horizontal loops and six 140 ft vertical wells.

For the building insulation, insulated concrete forms (ICF) blocks with ½" reinforcement was installed for the basement and the first floor to reduce the energy consumption due to their superior thermal properties that will provide thermal stability, and help reduce heating and cooling loads. Exterior Insulation and Finish System (EIFIS) was used for the outside walls to keep moisture from damaging the house sheathing while providing a great exterior insulation. In additions, soy-based closed cell spray forms were applied to all inside walls on the 2^{nd} floor and roof ceiling.

Other sustainable design characteristics feature the ZNETH. For example, LED lights will help reduce energy consumption for lighting fixtures. They are designed to last about 9,000 more hours than incandescent lamps. Finally, high energy efficient windows were installed to provide a healthy indoor environment and conserve energy inside. The front yard landscaping used sustainable plants that will help reduce or eliminate the need for irrigation water. To see the energy usage performance of the current design of ZNETH, all aforementioned sustainable features were modeled and analyzed from the previous study (Cho et al. 2010).

3. OVERVIEW OF THE TRADITIONAL HOUSEFOR COMPARISON

A virtual traditional house(VTH) like the ZNETH, but without sustainable energy and green design characteristics, was modeled for comparison purpose with the ZNETH. The VTH is a 4-bedroom 4-bathroom house just like the ZNETH. It also has the same square footage as the ZNETH (about 2,800 sq. ft), but has different building materials and energy sources. The VTH has a poured concrete foundation, low maintenance vinyl siding, a drainage system with waterproofing and interior sump pit, vinyl flooring, relatively energy efficient windows, and conventional heating and cooling equipment. Note here that all building materials are just the ones that are commonly used and do not therefore qualify for energy rebates and incentives. The sole energy source of the VTH is electricity as well.

4. BUILDING INFORMATION MODEL (BIM)

Building Information Model (BIM) is the process of creating, managing, and ameliorating building data during its lifecycle. BIM is purposed to facilitate communication among those involved in the building's creation; and also evaluate different designs ideally at the early stage of project. Through its powerful multi-dimensional capabilities, BIM helps generate model's information that can be transmitting through shared database to produce very important analyses. This investigation took full advantage of this technology to generate 5D models for automatic quantity take-off for cost estimations, and energy models for energy simulations. Figure 2 shows the current ZNETH and the VTH modeled in 3D BIM.

Figure 2. BIM Models of the ZNETH (left) and the VTH (right)

4.1. Cost estimation using BIM

BIM uses a shared database that communicates coordination, quantities and resources available during the building's lifecycle to generate a cost estimate. Because BIM operates on a digital database, any change or variation of design scope and or resource would be automatically reflected on the estimate. This model enables precise quantities of materials and components that would help optimize projects' design costs. A 5D cost estimation presents objects linked with cost, and energy data based on construction classifications such as Uniformat, Uniformat II, and Master Format. A production and resource based cost would then help improve and ameliorate productivity by keeping the costs low. An efficient and optimized model can then be predicted and developed.

Using BIM, elements' sizes and materials costs were computed and totaled to generate a detailed cost schedule. The models were exported from a BIM modeling tool to an estimating tool by groups. Each building element was characterized and a resource was then associated with it. Labor, material, and equipment that contributed into making that element were also directly computed. Based on the required or desired productivity, these resources can be modified to have an efficient cost. This investigation applied the resources that were used during construction. Few other costs were given by local contractors. Through this process, the ZNETH house was estimated at total $213,408. The VTH, without the sustainable elements, was estimated at $170,000.

For the energy consumption analysis, the BIM models of the ZNETH and the VTH were converted into a gbXML format for energy analysis software package, ECOTECT™ and Trace 700™. Then, the simulated energy consumption results were used for further economic analyses. Figure 3 illustrates how model-based energy analysis and economic study were conducted in this study.

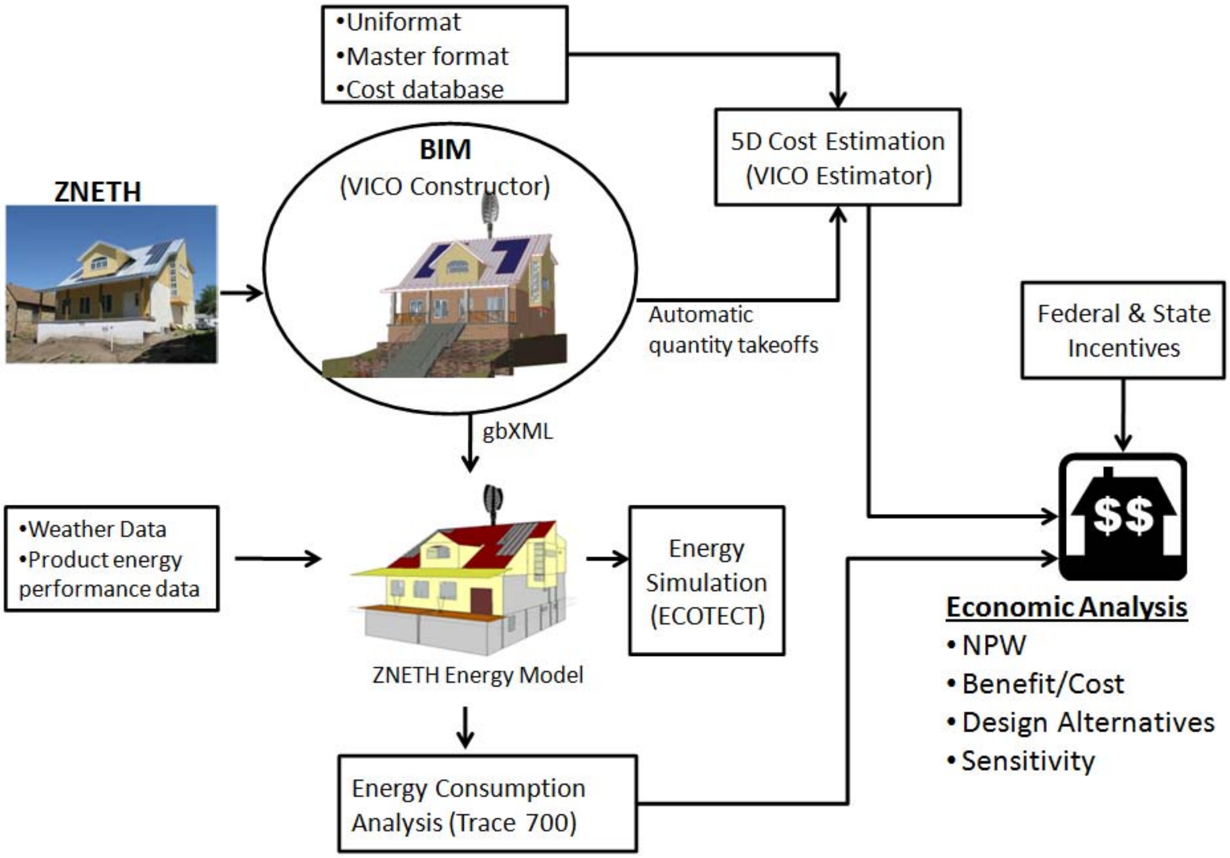

Figure 3. Structure for BIM-driven Economic Analysis

4.2 BIM energy model

BIM is also 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). Therefore, to gauge how much energy was produced and consumed by both houses, a series of analyses were performed from the previous study. A combination of solar, thermal, lighting, shading, resource consumption, produced energy analyses showed that the ZNETH house produced $4,219 kWh per year and consumed 11,478 kWh per year. The net energy consumed would therefore be 7,529 kWh per year. From the same process, it was found that the VTH consumes a total of 15,285 kWh per year. The difference in energy consumption leads to a saving in electricity costs for the ZNETH. More detailed analysis results can be found elsewhere (Cho et al. 2010).

5. ECONOMIC ANALYSIS

5.1 Costs associated with the ZNETH

The state of Nebraska gives incentives to new and existing homeowners for installing sustainable materials and systems to their homes. For the comparison analysis, it was assumed that full incentives would be given back as rebates. A life cycle of 20 years was assumed for the analysis because the wind turbine has the shortest life, 20 years. Each 1kWh solar panel costs $254. Installation costs are estimated at $5000 per kWh, and an inverter along with batteries would cost about $400 for the system. The inverter is designed and warranted for 10 years, so it was assumed that an inverter would have to be replaced in 10 years. Maintenance of solar panels essentially means that someone would have to go up on the roof to wipe up dust and clean panels. Therefore, maintenance is considered to be $0. For the wind turbine, the model which will be installed at the ZNETH costs $4,500 and about $1,000 to install. Yearly maintenance should be estimated at 1% of sum of unit cost and installation cost. $55 was computed to be annual maintenance cost for the wind turbine. The geothermal system costs about $17,000 with installation. The ICF block walls are estimated to be $10,000 and the difference to use the windows versus regular windows is estimated to be $7,000. Table 1 below shows the cost of those sources and materials. For the cost analysis, some costs have been estimated based on quotes received by local contractors.

Table 1: Summary cost of sustainable elements of the ZNETH

Cost	Solar Panels	Wind Turbine	Geothermal System	ICF Blocks	Windows
Unit Cost	$508	$4,500	$17,000	**$10,000	$7,000
Installation Costs	$10,000	$1,000	Included	Included	Included
Yearly Maintenance Cost	$0	$55	$0	$0	$0
Other Costs	*$400	$55	$0	$0	$0

* Price includes battery and inverter.
**The price is how much more one would have to pay for ICF blocks as opposed to traditional building insulation.

As mentioned previously, the government offers rebate programs for sustainable owners. Using a building information model (BIM) integrated estimating technique (5D), the whole ZNETH house was estimated in details at $213,408. The initial cost of the sustainable elements of the ZNETH is calculated to be $43,408. Therefore, the VTH, without the sustainable elements, would cost $170,000. Typically, owners make monthly payments to pay off mortgages and or loans. Table 2 shows the monthly payment difference between the VTH and the ZNETH.

For this comparison, a 30 year mortgage with a 4.875% fixed interest rate was considered. A deposit of 0.5% would also be required to obtain the mortgage. The table below compares costs associated with mortgage payments for both houses.

Table 2: Mortgage Payments of both houses

Items	VTH	ZNETH
Cost of House	$170,000	$218,224.20
Deposit (0.5 % of cost)	$850	$1,091.12
Interest rate	4.875%	4.875%
Yearly Property taxes (1.5 % of cost)	$2,550	$3,273.36
Yearly Homeowner insurance (Premium Quote Estimate)	$481	$481
Principal and Interest, PMT(169150, 4.875%, 30)	$895.16	$1,149.09
Taxes and Insurances (Property Tax + Homeowner Insurance)/12)	$227.58	$312.86
Private Mortgage Insurance (Estimate)	$80	$80
Total monthly payment	$1,202.74	$1,541.95

5.2 Benefits of the ZNETH

For most sustainable elements installed in a house, the government would offer up a rebate of the purchase and installation costs. The ZNETH is qualified for 30% rebates of the unit cost and installation costs for the solar system, the wind turbine, and the geothermal system. The database of state incentives for renewable and efficiency publishes the rebates and subsidies for each state (DSIRE 2010). The maximum tax credit received back from the ICF system, doors and windows was $1,500. The rule is that the tax credit is 30% of the total cost, or up to a maximum of $1,500. However, geothermal heat pumps, solar water heaters, solar panels, fuel cells, and wind generators are qualified for 30% rebate without $1500 limit. Table 3 shows the total benefit of $11,524 obtained as a tax rebate for the ZNETH.

Table 3: Table showing rebates

Items	Total Cost after Rebate	Tax Rebate Amount
Two Solar Panels	$10,908	$3,274.40
One Wind Turbine	$5,500	$1,650
Geothermal System	$17,000	$5,100
ICF Walls, doors, and Window	$10,000	$1,500
Total	$43,408	$11,524

From the previous study, the total cumulative produced energy of the ZNETH was calculated at 4,219 kWh per year and the total consumed energy was 11,748 kWh per year. The net energy consumed would therefore be 7,529 kWh per year. Also, it was found that the VTH would consume a total of 15,285 kWh per year. Based on OPPD's residential rates (OPPD 2010), the average cost charged for basic houses is about $0.068 per kWh, whereas the ZNETH qualifies for a conservation rate which averages to about $0.065 per kWh. These rates would help find annual and monthly electricity rates.

- VTH electricity cost =15,285 kWh/ year x $0.068/kWh = $1039.68/year = $86.61/month
- ZNETH electricity cost = 7,529kWh/ year x $0.065/kWh = $489.38/year =$40.78/month
- Savings on electricity = $1039.68/year - $489.38/year = $550.3/year = $45.84/month

5.3 LLC Analysis

To evaluate the cost effectiveness of the ZNETH, the life cycle cost (LCC) methodology was used. Here, all future costs were discounted to present value using the investor's minimum acceptable rate of return (MARR). The Department of Energy (DOE) has recommended a rate of 2.7% in the Annual Supplement to handbook 135, Energy prices indices and Discount Factors for life cycle cost analysis. Furthermore, for energy analyses where the study period is more than 10 years, 2.7 % is recommended to be used for minimum attractive rate. Data used for the analysis are as follows:

- Initial Investment on the ZNETH is $201,884 (with 30% federal rebates)
- Initial Investment on the VTH is $170,000
- Expected service life: 20 years (The selected wind turbine has the shortest design life of 20 years)
- Minimum attractive rate of return (MARR): 2.7%
- Yearly maintenance costs for the ZNETH are the ones used in Table 1.
- Assumed that the VTH would not have any maintenance costs.
- Annual electricity costs for the ZNETH and the VTH would be respectively $489.385 and $1039.68.

5.3.1 VTH

- Initial Investment = $170,000 and annual cost of initial investment = $170,000 / (A/P, 2.7%, 20) = $11,113
- Energy Consumption Costs = $1,039/ year.
- Present value of Consumption Costs = $1,039 x (P/A, 2.7%, 20) = $15,902.

- Net Present Worth (NPW) of costs = $170,000 + $15,902 = $185,902

5.3.2 ZNETH

- Initial Investment = $201,884. Annual cost of initial investment = $201,884 / (A/P, 2.7%, 20) = $13,198
- Energy Cost = $489/year.
- Present Value of Energy cost = $489 x (P/A, 2.7%, 20) = $7,487
- Maintenance Cost = $55.
- Present Value of maintenance cost = $55 x (P/A, 2.7%, 20) = $841
- Present Value of inverter/battery cost= $400 (P/F,2.7%,10)= $306.4
- Net Present Worth (NPW) of costs = $210,518.4

In this analysis, inflation was not considered. Table 4 below shows the detailed estimated results.

Table 4: Present and Annual costs of the ZNETH

	Present Value	Annual Value
Initial Investment	$201,884	$13,198
Energy Costs	$7,487	$489
Maintenance Costs	$841	$55
Batter/Inverter	$306.4	$400 at Year 10

5.3.3 Comparison

Table 5 below compares costs associated with both buildings.

Table 5: LLC costs associated with the ZNETH and VTH

Present Value Costs	VTH	ZNETH	Net Savings
Initial Investments	$170,000	$201,884	-$31,884
Energy Costs	$15,902	$7,487	$8,415
Maintenance/Inverter Costs	$0	$1,147.4	-$1,147.4
Total Present Value life cycle costs	$185,902	$210,518.4	-$24,616.40

The net savings is negative so the ZNETH is not cost effective over 20 years. Other design alternatives need to be considered to find a combination between solar panels and wind turbines that would yield return over the 20 year study period.

5.4 Cost-Benefit Analysis

To find the combination to balance benefit to cost, a relationship between solar panels and wind turbines was further analyzed. Let the number of 1kW solar panel be x and the number of wind turbine be y. Table 6 below shows the costs associated with solar panels, wind turbines. Other costs designate the total cost of windows, geothermal system and ICF blocks. All the initial costs already include the government rebates. It costs 1% of the cost of the wind turbine each month for maintenance.

- Annual cost to maintain y wind turbine = 1%(5500y) x 12 =660y

Table 6: Costs of sustainable items of ZNETH house

Items	Initial Costs($)	Annual Costs($)	Cost at Year 10($)
Solar Panels	3677.80x	0	400
Wind Turbines	3850y	660y	0
Other costs	34000	0	0

With the same variables, the net benefits of the ZNETH house can be computed.
Energy produced at the ZNETH house can be calculated knowing how much kWh per year can be produced for a 1kW solar panel (x) and a wind turbine(y).

- Energy produced (kWh) = 2000y +1109.5x

Recall that the simulated energy consumption was 11,748 kWh and the cost of energy consumed was $763.62 per year. The price of the energy consumed at the VTH was calculated to be $1039.38 per year.
Therefore,

- Cost of net energy at the ZNETH($) = -763.62 + 0.065(2000y +1109.5x)
- Net Benefit of ZNETH ($) = Cost of Energy of VTH – Cost of Energy of ZNETH
= 1039.38-(-763.62 + 0.065(2000y +1109.5x))=1803 – 130y – 72.1175x
- NPW of renewable energy cost($) = 3677.8 x + 400 (P/F, 2.7%, 10) + 3850y + 660y(P/A, 2.7%,20) + 34,000 = 3677.8 x + 13948 y + 34306.4
- NPW of renewable energy benefit($) = (1803 – 130y – 72.1175x) (P/A, 2.7%, 20)
= 27585.9 – 1989y – 1103.4 x

From these equations, it can be concluded that the NPW of renewable energy cost is minimum when both x and y equal zero. Along the same lines, NPW of renewable energy benefit is at the highest when both x and y are zero. Therefore, the ZNETH without solar panels and wind turbines would give a better benefit or lower cost. The current ZNETH design which has two solar panels and one wind turbine would cost $65,880 and benefit by $22,504 for the 20 year life cycle. In summary, based on the investment on other sustainable elements and the benefits that both solar panels and wind turbines give, the return on investment cannot be made during the 20 year study period under the given design and economic conditions.

6. CONCLUSION

In this paper, an economic feasibility study for the Net Zero Energy Test Home (ZNETH) which is under construction at the University of Nebraska was introduced as an on-going research project. As a major research methodology, 3D and 5D BIM concepts were used to create energy models and cost models which were used for economic analyses. Instead of re-creating and collecting data to build an energy model and to estimate a cost from a scratch, the research team strongly agree that the proposed seamless stream line of modeling process using BIM significantly saved modeling time and provided more accurate results due to the automated data transfer from BIM to another application.

Although there will be obviously more benefit than cost since this house has been built with many industry support and donations along with students and faculty participation in design and construction, this study conducted economic feasibility study from a general home owner's perspective. The results show that the high initial costs that consisted of two solar panels; a wind turbine; a geothermal system; and other sustainable elements, still ended up offsetting the energy benefits over a study period of 20 years.

The research team felt that the current ZNETH could have saved more energy and costs, if these analyses had been conducted in its design stage. Rather than relying predominantly on ‘active’ systems to bring a building to ‘zero’ energy, more passive house design concepts could have been adopted. Optimizing house orientation and window location, better design of shade, limitation of thermal bridging, heating by passive solar gain and internal gains are the good examples of the passive house design concepts. As current efforts, design and construction methods of ZNETH are being re-evaluated to identify areas for improvement. The findings will be incorporated into the ZNETH II house design which is also currently under investigation. The framework for BIM-driven economic analysis for a zero net energy house introduced in this study can be readily applied to other energy efficient house design or retrofit analysis for existing homes.

ACKNOWLEDGEMENTS

The authors thank to Dr. Avery Schwer from the University Nebraska-Lincoln for making ZNETH available and usable for this research and this project is partially supported by the United States Environmental Protection Agency (EPA).

REFERENCES

Cho, Y., Alaskar, S., and Bode, T. (2010). BIM-Integrated Sustainable Material and Renewable Energy Simulation. *ASCE, Construction Research Congress (CRC) 2010 conference in Banff, Alberta, Canada*, pp.288-297

DSIRE: DSIRE Home. Web. (10 may 2010). <http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US36F&re=1&ee=1>.

Jeswani, H., Wehrmeyer, W., and Mulugettam, Y. (2008). “How Warm Is the Corporate Response to Climate Change: Evidence from Pakistan and the UK,” *Business Strategy and the Environment* (17) 1 pp. 46-60

Kolk, A., and D. Levy. (2004). Multinationals and Global Climate Change: Issue for the Automotive and Oil Industries. *Mult.inationals, Environment and Global Competition.*

Kolk, A., and J. Pinkse. (2006).Stakeholder Mismanagement and Corporate Social Responsibility Crises. *European Management Journal* 24: pp. 59-72

Krygiel, E. and Nies, B. (2008). *Green BIM*, Wiley Publishing Inc., Indiana.

Oberg, M. (2005). *Integrated Life Cycle Design - applied to concrete multi-dwelling buildings*. Lund University, Division of Building Materials. Lund, Lund University.

Smith, D.K. (2007). Building Information Modeling Overview. 51st Annual CSI Show and Convention, Baltimore, MD, June 20-22.

WindTronics. Web.(9 June 2010). < http://www.earthtronics.com/honeywell.aspx>.

Wind Powering America. Web.(9 June 2010). < http://www.windpoweringamerica.gov/maps_template.asp?stateab=ne>.

WT 6500 Wind Turbine: Web.(3 Mar 2010). < http://greennclean.ca/wind-turbines/windtronics/>