Analytical Modeling and Feasibility Study for Adoption of Renewable Energy Sources in a Single Family Dwelling

Jimmy B. Linn
Indiana State University

Jimmy B. Linn, M.S.E.E.
Teaching Instructor
Technology Systems
College of Engineering and Technology
linnj@ecu.edu

Professional Interests

Academic Background

M.S.E.E. Purdue University, West Lafayette, IN, USA, electrical Engineering, 2002
BSEE Rose Hulman Institute of Technology, Terre Haute, IN, USA, Electrical Engineering, 1973
Other Bachelors Rose Hulman Institute of Technology, Terre Haute, IN, USA, Mathematics, 1973

Certifications

Certified trainer for Mitsubishi RV-A and RV-SD series robots, 2010
Licensed Master Electrical Contractor in Indiana, ELE-0286M, 2003

Memberships

Member of American Society for Engineering Education (ASEE)
Member of Association of Technology Management and Applied Engineering (ATMAE)

WORK EXPERIENCE

Academic Experience

Teaching Instructor, East Carolina University (June, 2005 - Present).

Subject areas:
- Electricity/ electronics
- Electromechanical Systems
- Programmable Logic Controllers
- Robotics
- Mechatronics

Electronics Instructor, Ivy Tech State College (August, 1997 - August, 2005). Electronics Instructor - Evansville campus 1997 – 2005

Subject areas:
- Electricity/ electronics
- Control Systems
- Process Control
- Motors and motor control
- Mathematics

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Jimmy B. Linn

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COMMITTEE MEMBERS

Committee Chair: Dr. Tarek Abdel Salam

Professor, Department of Engineering

College of Engineering and Technology

East Carolina University

Committee Member: Dr. Merwan Mehta

Professor, Department of Technology Systems

College of Engineering and Technology

East Carolina University

Committee Member: Dr. David Beach

Professor Emeritus of Electronics and Computer Engineering Technology, Department of Electronics and Computer Engineering Technology

College of Technology

Indiana State University

ABSTRACT

In the last four or five decades, increased political and social pressure has been placed on commercial and residential consumers to reduce consumption of fossil fuels and invest in alternative methods of energy production for electricity, heating and cooling. Commercially, wind turbines and photovoltaic energy production equipment has sprung up all over the country. Other forms of energy production such as hydroelectric and geothermal energy production facilities have also been built. During this time however, very few residential ‘green energy’ investments have been made.

Only in recent years have residential home owners begun to “wet their feet” on ‘green’ energy equipment. Cost has been the major factor. Of late though, costs have been coming down and efficiency has been going up making home owners begin to sense that alternative energy may now be entering the realm of economic feasibility. Unfortunately, home owners have had no reliable or credible tools to assess economic viability of such systems.

The purpose of this research is to develop a tool to access the potential of alternative energy sources and test it statistically by surveying subjects in five different ‘green’ energy categories. Since atmospheric (air-to-air) heat pumps have been around for many years and represent a mature heating and cooling technology, upgrading older inefficient HVAC equipment to new high efficiency atmospheric heat pumps is the category used to baseline the experiment. Ground source heat pumps and direct solar heating systems were modeled and compared to the

baseline. Wind energy and photovoltaic energy production systems were modeled, surveyed and compared to using only grid supplied electricity.

Results show that in four of the five cases tested, the less mature ‘green’ energy equipment; photovoltaic solar, direct solar and ground source heat pump equipment are in general not economically viable without tax rebates to significantly lower the net investment. Setback rules and environmental and aesthetic ordinances against siting them in those counties severely restrict the population of wind energy devices so that an effective test of this category using the model could not be done.

The model performed well with the baseline data. Performance of the model with ground source heat pumps was reasonable, but improvements in the model reflecting differing features of ground source heat pumps need to be made. Performance of the model with photovoltaic energy production equipment was also good.

Extending the test population to all fifty states and extending the utility bill test range from one year to five years will provide much more useful data to test and improve the model.

Although the model development and testing done in this work only represents a small contribution to the bridging of a large gap in consumer confidence in green energy products, it represents a big step into an area that very few have attempted to venture into.

PREFACE

With rapidly advancing technology, strong social and political will to reduce the carbon footprint and go ‘green’, significant commercial investment in this area has been made and continues to be made. Commercial establishments have many tools to analyze the economic viability of such ventures. Residential home owners unfortunately have little to aid them in accurately assessing such economic viability. This research seeks to provide the home owner with one such tool with the hope that additional tools will be developed in the future and the one developed in this research project will spawn future research and the continued development of tools for the home owner to use to determine reliably if an investment in a green product is economically viable.

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CHAPTER 1

INTRODUCTION AND BACKGROUND

Introduction

In recent years, several conditions have evolved that will influence the direction of technological development and subsequent adoption of renewable energy resources as a viable alternative to the use of nonrenewable resources such as coal, natural gas, oil and nuclear energy. These conditions may be distilled into four major categories; (1) environmental, (2) economic, (3) political and (4) technological.

Fossil fuel consumption creates greenhouse gasses such as carbon dioxide that collect in the ozone layer of the atmosphere and trap heat that causes global warming. Experts claim that unchecked global warming may cause catastrophic climate destabilization and result in serious negative environmental impact. The subject of the depletion of fossil fuels has been a hotly contested debate for years. On one side of the argument are those that claim the world has enough oil to last several hundred years. On the flip side, many credible sources claim that the world is rapidly depleting those fossil fuel reserves, and that we will start to create shortages as soon as the first quarter of the 21^{st} century. M King Hubbert in his now famous paper titled Nuclear Energy and the Fossil Fuels [1] predicted that the US would hit peak oil production in the 1970s, and the world would hit peak production sometime in the first quarter of the 21^{st} century. His prediction for the peak production of coal in the US was somewhere around 2150. Ivanhoe [2] revised the Hubbard world oil peak to include more recent data to refine the prediction to 2010 with a longer lasting peak. Whichever side of the debate you side with, the important point is this. Fossil fuels are nonrenewable. It takes millions of years to produce them. Whether we run out within the next 10 years, the next 150 years or tomorrow, when this day comes in the reasonably near future, the world will be for all practical purposes permanently out of its main resource used to produce energy. Society may determine that nuclear energy is a viable substitute for fossil fuels when fossil fuels are depleted. This is certainly an option. However, recent historical disasters involving nuclear power plants, like the Three Mile Island, Chernobyl and the most recent Japanese earthquake and resultant tsunami that lead to the nuclear power plant disaster at the Fukushima Power Plant, are signs that this method of power production may not yet be mature enough to be safe since the Chernobyl and Fukushima incidents resulted in the harmful release of radiation into the ground and atmosphere. [3]

The economic impact of the above events is also significant. Over the last 50 years, shortages of oil have resulted in upward pressure on oil and gasoline prices. For example, before the Hubbard peak oil production time of 1970, according to the U. S. Bureau of Labor Statistics [4], gasoline was near $0.30/ gallon. After that time, shortage and increased dependence on foreign oil forced prices to a stable $1.00/ gallon of gasoline. More recently, as we near the point Hubbard predicted for peak world oil production, the price of gasoline has risen to about $4.00/ gallon. Although other factors also influence oil, gasoline and energy prices, it is clear that shortages do play a significant adverse role in energy prices. An additional upward pressure on energy prices is demand. In the two most recent decades, previously underdeveloped nations have begun to develop. Two key players here are China and India. As these and other countries develop, their energy demands have and will continue to increase. As these demands increase, as well as the overall demand for energy by already developed nations like the USA and Europe, further shortages will develop that will place greater upward price pressure on energy. According to British Petroleum (BP) [5] world energy demand will increase 40% between 2010 and 2030. Renewable energy resources are seen as a viable alternative or at least a complement to nuclear and fossil fuel energy resources.

Social and political issues will also play an important part in mapping the direction of renewable resource development and implementation. For example, wind energy, though significantly developed technologically over the last fifty or so years is seen by many as noisy, environmentally unfriendly, and aesthetically displeasing to the eye. Consequently, many locations forbid the use of wind turbines or at a minimum, impose significant setback rules that may preclude many from placing a wind turbine on their property. According to DSIRE [6], in Tyrell county, NC, a small 120 ft. tall wind turbine cannot be closer than 180 ft. from the property line, if a neighboring property has a structure built on it. Similar setback requirements are imposed in other North Carolina counties. Also, concurrently with these legal restrictions are state and federal tax incentives for installing renewable energy resources that encourage installation of green energy equipment. These are only examples that illustrate the complexity of the political influences on the adoption of renewable energy resources.

Finally, and probably the most significant factor influencing the adoption of renewable energy resources is technological. Technology affects all levels of adoption. The science, physics and engineering behind a specific renewable resource determines if, when, where and how a particular renewable resource may be adopted. For example, wind energy is far from a constant resource. Average wind speeds vary greatly from location to location and over time. Photovoltaic energy may be more consistent during the day, but produces no energy at all at night. Ground source heat pump technology has been around for about 50 years and is more efficient than wind and solar energy in terms of cost and return on investment. However, ground source heat pumps are most cost effective if installed with a horizontal trench to facilitate energy transfer. This requires space. Individuals with a small property will be forced to use the vertical well heat transfer method that is very costly and may make the installation impractical. Hydroelectric power is a well-developed technology and develops consistent electrical energy from a generator driven by water power. However, an individual wanting to take advantage of this technology may only do so if an adequate flow of water exists on his or her property. Air-to-air heat pumps are considered mature technologies and are widely used. However, they are not practical in northern or southern latitudes, and where weather is extremely cold like at high elevations. Solar assisted heat pumps are a new technology complementary to any heat pump and offers promise in the future of significantly improving the efficiency of existing heat pump. However, since this technology is new, little data exists that gives a clear indication of its overall effectiveness.

Clearly, the energy environment is complex. Environmental factors support and oppose the adoption of green energy products. Political climates shift and at the same time both support and oppose the adoption of green energy products. Long term economic pressures support a shift toward alternative energy adoption. However, short term economic pressures favor including fossil fuels in our energy mix. Experts cannot agree on the effects fossil fuels will have on the environment and our future. With these conflicting views, it is clear that the adoption of alternative energy products will not be smooth or quick. Consistent and steady research that slowly moves alternative energy implementation forward to achieve the best energy mix promises to be the best approach. It is toward this end that this dissertation research makes a contribution.

Problem Statement

As energy demands within the US continue to increase, the energy grid will continue to be placed under more and more stress resulting in more brownouts and blackouts. What is needed is a complete paradigm shift from how the grid functions now to something different. Currently, electricity is generated by large utility owned power plants and channeled through the grid to the consumer. In this paradigm, all consumer power must travel over the grid. In a different paradigm, a more distributed power production model that encourages consumers to produce as much power as is practical for them to do so, and further reduce total energy demand by using more efficient heating and cooling technologies and energy conservation measures will reduce the power burden on the electrical grid. If consumers adopt renewable energy production and consumption methods as well as implement possible practical energy conservation measures, significantly less power will be consumed from the energy grid. This will require an investment on the part of the consumer that in many cases will be significant. To convince consumers to make such an investment, they must trust their own judgment and that of the contractors they are working with. According to the North Carolina Sustainable Energy Association, a significant number of people are not well informed or misinformed about renewable energy products, and still more don't trust what contractors tell them. And with this, many people have purchased renewable energy products that have not produced a satisfactory return on investment. This has further restricted more people from investing in renewable energy.

The goal of this study was to model the decision making process for assessing the viability of implementing energy conservation and renewable energy into a residential energy system. An analytical model will be developed to allow a home owner or small business owner to reliably and accurately determine if renewable energy is a viable option to reduce one's energy bill. Modeling energy conservation and renewable energy viability assessment leads to the following research questions:

1. What environmental impacts will influence the choice to install or not to install a residential renewable energy product in North Carolina?

2. What political climates will influence the choice to install or not to install residential renewable energy products in North Carolina?

3. What technological issues might interact with the economic and environmental effects to determine if installing a residential renewable energy product is viable or not in North Carolina?

4. How will energy conservation measures affect the viability assessment of renewable energy products in North Carolina?

The goal of this research leads to the following hypothesis:

H_0: It is possible to predict cost savings from installing alternative energy products in a family dwelling.

$H_{0:}\ \bar{X}_m = \bar{X}_p$

$\bar{X}_m =$ mean measured monthly utility bill savings

$\bar{X}_p =$ mean predicted monthly utility bill savings

H_a: It is not possible to predict cost savings from installing alternative energy products in a family dwelling.

H_a: $\bar{X}_m \neq \bar{X}_p$

Statement of Purpose

The purpose of this effort is to create an analytical model from which a software tool may be developed that can be used by home owners and small business owners to reliably and accurately assess the viability of using renewable energy products or a combination of renewable energy products in conjunction with appropriate energy conservation measures to reduce their energy bill. Individuals using this model should then be able to make an informed decision about investing in renewable energy products.

Statement of Need

According to the U.S. Energy Information Administration, the demand for electrical energy is rising and will continue to rise. This will place increasing demand on an already aging energy grid system that could under peak loads cause brownouts and blackouts. The cost of supplying energy through this grid will continue to increase as energy demand is increased and maintenance and upgrade of the grid become necessary. This set of conditions poses an important question. With the increased grid load and the subsequent need to upgrade the electrical energy grid, would a distributed energy grid be more viable? Additionally, as nonrenewable energy resources face depletion, does it become viable to use supplemental renewable energy resources to reduce the demand and rate of depletion of our nonrenewable energy resources? Will rising demand for energy result in higher costs of grid supplied energy that will make energy conservation measures integrated with residential renewable energy an attractive option for home owners?

According to eHow [7] et al, climatologists, the effect of continuing to burn fossil fuels at an ever increasing rate is to produce more and more greenhouse gases. Greenhouse gases are gases such as carbon dioxide and methane that accumulate in the ozone layer of the atmosphere and have the effect of creating an insulating blanket around the earth and hold heat from the sun in and cause the ambient temperature of our world to increase. The effect of this temperature increase is not known for certain, but climatologically, the effect of whatever mechanism runs its course is to disastrously destabilize our environment.

According to geologists, our fossil fuel resource that we primarily depend upon for the production of electrical energy is depleting at a serious rate. The human race has been pumping oil from the ground for about 150 years. It is generally accepted that the oil being pumped out took millions of years to produce. So for all practical purposes, in a comparatively short and foreseeable future, oil will be depleted and is therefore a nonrenewable resource. Coal has been mined for about 800 years. It too suffers the same fate even though the time horizon is projected to be slightly longer than oil. [1]

A need therefore exists to reduce our overall consumption of nonrenewable resources, fossil fuels in particular, and focus much greater research effort on the development of renewable energy resources. The state of North Carolina is fortunate to have abundant amounts of solar energy, hydro power and wind energy. It is therefore incumbent on all citizens of North Carolina to support renewable energy resource development. [8]

Statement of Assumptions

With increased environmental concerns, both from the standpoint of conservation and adverse climate changes, it is apparent that future home construction is going to trend in the direction of green construction methods. [9] This trend will encompass the incorporation of residential renewable energy production within the construction of a residence. These methods will include but not be limited to solar, wind, geothermal, hydropower and the development of biodiesel generators. The purpose will be to augment and minimize the production and long distance transmission of large amounts of energy produced by nonrenewable energy recourses.

Statement of Limitations

Standard engineering technology analysis procedures and economic and statistical analysis methods will be used in this study.

Statement of Methodology

An assessment of the current technological state-of-the-art and economic viability of renewable energy products at residential levels will be made. Research will be conducted to determine regulatory and local ordinance limitations as well as tax incentives for investing in and using renewable energy products in North Carolina. This research will be conducted as a literature review that will be discussed in Chapter 2 of this dissertation. This research will provide the basis for the development of an analytical model to determine economic viability of investing in renewable energy products to lower an individual home owner’s or small business owner's energy bill. Energy conservation will also be a part of this model. To maximize the benefits obtained from renewable energy sources, all practical methods of energy conservation will also be considered.

Statement of Terminology

The following terms are used with significance in this dissertation and require defining.

Vertical axis wind turbine – a windmill device that generates mechanical rotating power about the vertical axis.

Horizontal axis wind turbine - a windmill device that generates mechanical rotating power about the horizontal axis.

Photovoltaic – the effect of converting light directly into electricity.

Gallium-Arsenide – chemical compound used in the semiconductor and solar industries.

Gallium-indium-phosphide – chemical compound used in the solar and semiconductor industries.

Ground source heat pump – refrigerant based thermal pump using the ground as the external heat exchange mechanism.

Geothermal – term describing the heat within the earth.

Hydroelectric – the conversion of or act of converting water energy to electrical energy.

Air-to-air heat pump – refrigerant based thermal pump using atmospheric air as the external heat exchange mechanism.

Seasonal Energy Efficiency Ratio - (SEER) – measured in BTU/W-hr. is an efficiency rating for AC units and heat pumps. The higher the SEER rating, the more efficient the unit.

Energy star rating - The national energy performance rating is a type of external benchmark that helps energy managers assess how efficiently their buildings use energy relative to similar buildings nationwide. The rating system's 1–100 scale allows everyone to quickly understand how a building is performing — a rating of 50 indicates average energy performance, while a rating of 75 or better indicates top performance.

Net Present Value (NPV) - the sum of the present values (PVs) of the individual cash flows of the same entity.

Internal Rate of Return - rate of return used in capital budgeting to measure and compare the profitability of investments.

Equivalent Uniform Annual Worth – is equal to the total benefit and cost of the system as if it was spread out evenly throughout the years of its life.

Annual Fuel Utilization Efficiency (AFUE) – rating – percent of fuel energy (BTU) turned into heat for the building

CHAPTER 2

REVIEW OF RELATED LITERATURE

Foundation for the Assessment of Residential Renewable Energy Technologies

The literature search that follows describes the body of knowledge and state of the art for renewable energy products summarized in this paragraph. Extensive effort has been put forth developing, producing, selling and studying commercial renewable energy equipment for the production of electricity by public utilities. A small effort has been made toward producing and selling residential wind turbine power production equipment. Photovoltaic power production equipment is scalable to any application, commercial or residential. Hydroelectric power production is a very mature technology and is very cost effective. However, for individual application, one must have substantial water flow on their property to utilize it. Heat pump technology is cost effective in warmer locations and is also a fairly mature and widely utilized technology. Ground source heat pump technology is a maturing technology that is gaining wide acceptance and is becoming well utilized. The important distinction is that there are two methods of installing ground source heat pump technology. A horizontal installation requires a trench to be dug and heat exchanger lines placed in the trench and covered up. The length of the trench depends on the size of the building being heated or cooled. The second method of installing the heat pump heat exchanger lines is the vertical well method that costs much more to install. A newer form of heat pump is solar assisted heat pump technology. This fairly new heat pump application uses solar energy to greatly improve the efficiency of the heat pump. Another form of renewable energy is direct solar heating. This form of energy requires thermal storage and is effective at heating but is expensive to install.

An Assessment of the State of the Art and Economic Viability of Commercial Wind Turbines

Considerable research has been done in the development of commercial wind farm turbines. The focus of this research however, is to concentrate on residential or small scale turbines that will not always have the high wind speeds found on commercial wind farms and do not have to produce megawatts of electricity. Consequently, the desired characteristics for these small scale turbines are different than those of large commercial wind turbines. There is a market for these residential wind turbines also, though not as large as the commercial market. Therefore, some significant progress has also been made in the technological development of small scale wind turbines. Two significant characteristics have evolved as critical in the technological development of wind turbines. Others may evolve in the future as residential wind turbines develop, but two characteristics are critical to small scale windmill technology development today. (1) The wind turbine must be able to scavenge sufficient power from the wind at low wind speeds. (2) The windmill must be quiet. The next seven paragraphs suggest that meaningful strides have been made in these two technology areas.

Bati and Leabi [10] contributed to wind turbine development by developing an automatic pitch angle controller. Though developed for commercial wind turbines, this technology can be scaled for small scale turbines as well.

Davenport et. al. [11] experimented with wind turbines at the National Renewable Energy Laboratory (NREL) to assess the aeroacoustic noise effects of three mid-range horizontal axis wind turbines. This contribution is most important to single family homes and small businesses in densely populated areas. The data collected by the authors will be applicable to a wide range of wind turbines that include the single family home or the small business owner.

Genesis Partners LP [12] developed an improved high efficiency gearbox for horizontal axis wind turbines in an effort to improve low wind speed performance of horizontal axis wind turbines. The U.S. Department of Energy Wind Energy Research Program has begun to develop wind technology that will enable wind systems to compete in regions that experience low wind speeds. The sites targeted by this effort have annual average wind speeds of 5.8 m/s, measured at 10-m height. Such sites are abundant in the United States, and would increase by twenty-fold the available land area which can be economically developed. The stated program goal is to reduce the cost of electricity from large wind systems in Class 4 winds to 3 cents per kWh for onshore systems or 5 cents per kWh for offshore systems, by the year 2012. A three-element approach has been initiated and consists of (1) concept design, (2) component development, and (3) system development. This work builds upon previous activities under the WindPACT project, the Next Generation Turbine project, and Phase I of the Low Wind Speed Turbine (LWST) project. If successful, DOE estimates that this new technology could result in 35 GW to 45 GW of additional wind capacity being installed by 2020.

Many researchers have studied, analyzed, and characterized loads on windmills. Darrow [13] extends this part of the body of knowledge of wind turbines by identifying the events that are most crucial to control design, thus enabling a more efficient and specific control design process.

This research validates a simulation program with a mid-range power output machine (600 kW. CART3) to identify the most crucial control characteristics. This simulation program could be more appropriately used for small wind turbines if the same simulation program were validated also by a small wind turbine designed for use at a single family home or small business.

A key concept that governs the optimal speed versus the number of blades a wind turbine should have is the determination of the optimal rotor tip speed ratio. Ragheb [14] discusses this in depth and the practicality of using wind energy is grounded in the research done by Ragheb. The bulk of wind turbine research and development has been for commercial wind farms that produce megawatts of power. The design requirements for this type of user are much different than those for a residential wind turbine that produces far less power and does not have the luxury of high wind speeds that exist at commercial wind farms. Technologists and engineers interested in designing and building residential wind turbines may find this work by Ragheb [14] of interest. The key concept to extract from this research is that increasing the number of blades on the wind turbine reduces the wind speed at which the turbine operates most efficiently. These lower speeds are the speeds more likely to be found at family residences or small business locations. Designing the turbine to operate most efficiently at lower speeds with more blades will allow the diameter of the turbine to be reduced to produce the same power which will offset the cost of additional blades and reduce stresses on the blades and lead to lower cost.

To expand the number of locations that small wind turbines may be found to be economically viable, an assessment of the wind characteristics such as wind speed, wind direction, turbulence, etc. must be made. To perform the economic analysis, some determination of the net present value must be done. Pisco [15] addresses these issues in an urban setting. His research allowed him to pick specific urban locations, conduct an economic analysis of those specific sites to determine if it is viable to site a wind turbine at those sites.

Another way of expanding the application of small scale wind turbines is to implement a concept called building integrated wind energy incorporating passive and active flow control techniques. Rao [16] validates this concept on bluff building envelops.

To further assess the economic viability of wind turbines in different areas, Domanski [17] assesses the viability of harvesting wind energy on low rise buildings. Coupled with the technology developments that were previously discussed in this chapter, markets will expand. This will drive competition up and prices lower. As a result, economic viability of small scale wind devices should increase.

According to Entertainment Close-Up [18], emerging as a feasible alternative to fossil fuels, wind energy is being increasingly utilized, due to its economic viability compared to other renewable forms of energy and because its cleaner than conventional energy sources. This growth trajectory in the wind energy industry is being primarily led by the U.S., China, Germany and Spain, which together accounted for 66 percent of global cumulative installed wind generator capacity in 2009.

These countries are riding on the growth wave of the wind energy industry. The industry witnessed a growth rate of 38 percent during 2008-09 in cumulative installed capacity and along with it; there was also a significant growth in components such as wind generators. Demand for wind generators in the booming wind markets - the U.S., Europe and China - continue to increase. The global wind generator production grew at a Compound Annual Growth Rate of 29 percent, from 18,000.

To conduct a more accurate economic analysis of a windmill site, geographic features of the site and its surroundings should be taken into account. Li [19] addresses this in his work in Oklahoma where winds are variable and also significantly affected by geographical factors.

To get a more complete review of the state of renewable energy, it is advantageous to look at a hybrid model where two or more renewable energy sources work together. Rivera [20] presents an optimization model to design a hybrid renewable energy system consisting of wind turbines, photovoltaic modules, batteries, controllers and inverters. To use this model, a data bank is required where detailed specifications and cost of the equipment must be available. It must also include the wind speed and solar radiation data for the desired site. Using the proposed optimization model with the data bank, the optimal configuration of necessary equipment required for the project to supply energy demand at the lowest possible cost is determined. To evaluate if the project is a good investment, an economic analysis is performed to calculate the net present value of the project over a period of 20 years. For the island of Puerto Rico a database of published wind speed and solar radiation was created. Optimization procedures were applied to residential loads at three different locations on the island. The results show that renewable energy projects are a good investment for Puerto Rico as long as the renewable system is connected to the utility grid benefiting from a net metering program, and is designed to supply the exact energy demand of the residential load. For systems not connected to the utility grid, places like the coast of Fajardo, where wind is abundant, the system is cost effective. But in parts of the island where wind speed is less, the system required the use of photovoltaic solar panels increasing the system cost. These systems have a payback period greater than 20 years.

In North Carolina, probably the most important factor to consider if one is considering the installation and use of a wind turbine for electrical power generation according to Greenville Utilities, Greenville, NC is restrictions in the various counties and state. State restrictions are not as stringent as county restrictions and focus on military and civilian air traffic safety. [9] This does not usually affect residential wind turbine sites. However, serious consideration must be given to county and city or town restrictions. Many counties and cities or towns in North Carolina place significant restrictions on the installation and use of wind turbines. For example, in Tyrell County, according to DSIRE [6] significant restrictions are imposed on anybody wishing to install and operate a wind turbine in Tyrell County, North Carolina. Appendix A describes those restrictions.

A number of models for wind turbines have been developed. Most of them are engineering and technical models. However, a valuable economic model was developed by Church [21]. The work by Church developed three models, one for systems component losses, one for cost analysis and one for reliability analysis. These models were then combined into a complete economic viability model.

An Assessment of the State of the Art and Economic Viability of Direct Solar Energy Production

Solar energy power from the sun is a vast and inexhaustible resource. Once a system is in place to convert it into useful energy, the fuel is free and will never be subject to the ups and downs of energy markets. Furthermore, it represents a clean alternative to the fossil fuels that currently pollute our air and water, threaten our public health, and contribute to global warming. Given the abundance and the appeal of solar energy, this resource is poised to play a prominent role in our energy future.

In the broadest sense, solar energy supports all life on Earth and is the basis for almost every form of energy we use. The sun makes plants grow, which can be burned as "biomass" fuel or, if left to rot in swamps and compressed underground for millions of years, in the form of coal and oil. Heat from the sun causes temperature differences between areas, producing wind that can power turbines. Water evaporates because of the sun, falls on high elevations, and rushes down to the sea, spinning hydroelectric turbines as it passes. But solar energy usually refers to ways the sun's energy can be used to directly generate heat, lighting, and electricity.

According to Clean Energy [22] the amount of energy from the sun that falls on Earth's surface is enormous. All the energy stored in Earth's reserves of coal, oil, and natural gas is matched by the energy from just 20 days of sunshine. Outside Earth's atmosphere, the sun's energy contains about 1,300 W/m^2. About one-third of this light is reflected back into space, and some is absorbed by the atmosphere (in part causing winds to blow).

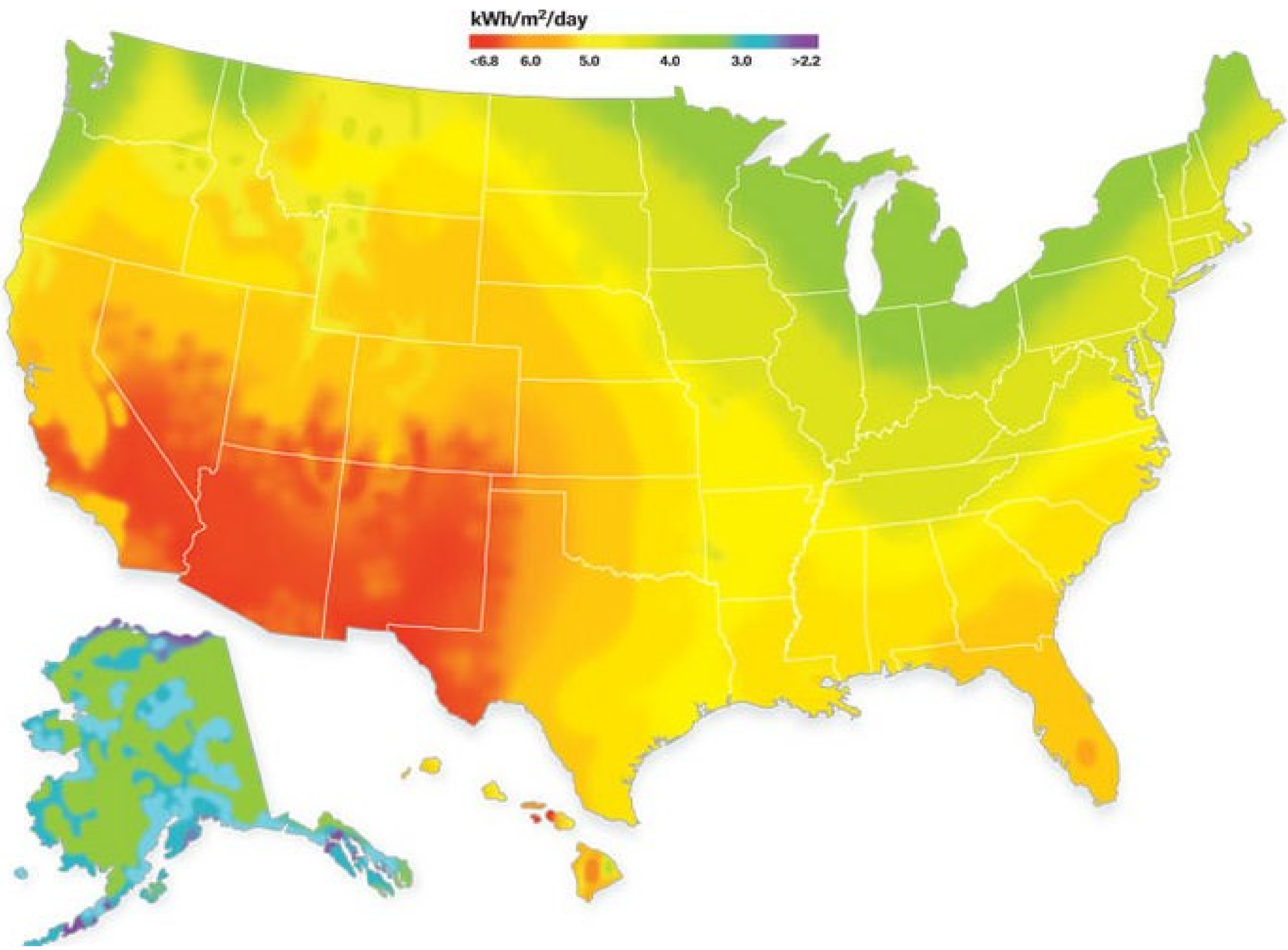

Fig. 1 Solar energy available in the United States [22]

By the time it reaches Earth's surface, the energy in sunlight has fallen to about 1,000 watts per square meter at noon on a cloudless day. Averaged over the entire surface of the planet, 24 hours per day for a year, each square meter collects the approximate energy equivalent of almost a barrel of oil each year, or 4.2 kilowatt-hours of energy every day. Deserts, with very dry air and little cloud cover, receive the most sun—more than six kilowatt-hours per day per square meter. Northern climates, such as Boston, get closer to 3.6 kilowatt-hours. Sunlight varies by season as well, with some areas receiving very little sunshine in the winter. Seattle in December, for example, gets only about 0.7 kilowatt-hours per day. It should also be noted that these figures represent the maximum available solar energy that can be captured and used, but solar collectors capture only a portion of this, depending on their efficiency. For example, a one square meter solar electric panel with an efficiency of 15 percent would produce about one kilowatt-hour of electricity per day in Arizona. Figure 1 illustrates that the solar energy striking the earth is not uniform. Because the earth is round and the angle light strikes the earth varies with latitude, elevation, air pollution and other atmospheric conditions, the light intensity available for conversion to electric power varies significantly around the globe. The map shows that solar intensity is very high in the desert southwest part of the U.S. while northern latitudes get less light. The desert southwest would be good candidates for installing photovoltaic solar electricity production equipment while the northern latitudes would in general not be likely candidates for photovoltaic solar electricity production. [22]

Direct solar heating systems have been in use for many years. Because of their extensive cost, they have been used and continue to be primarily used in large buildings with large heating loads. For small residential applications, they are generally not cost effective.

Due to rising interests of utilizing energy more efficiently, Boling [23] explores new ways of maximizing the efficiency in heating and cooling systems. Although natural gas furnaces and central air conditioners are the most common heating and cooling systems used, geothermal heat pumps are also being used more. There are also two new technologies that use solar energy as the primary source of energy to power these heating and cooling systems. One system is an absorption air conditioner unit that uses direct solar heating, and the other is called a thermally driven heat pump. There are several computer programs that simulate the two common systems; however, there are no known programs that calculate the energy and cost during operation for the systems that use solar energy.

Because there are no models that predict the cost and energy usage of all four systems, an Excel(TM) workbook was developed to analyze all four of these systems in the same home figuratively placed in five different U.S. cities. These cities represent the different climate regions in the country since the heating and cooling loads will vary depending on the climate of the city the home is in. The workbook allows one to enter data and from that data determine which system will be cost-effective compared to a condensing gas furnace and high-efficiency central air conditioner assembly. It also determined what the costs of natural gas and electricity will have to rise to in order for certain systems to be cost-effective. Based on a life cycle cost analysis, the results show which system to choose for the residence.

The results show that the vertical ground source heat pump always paid back the quickest in all five cities. The absorption unit never paid back in any of the cities. The thermally driven heat pump paid back in Louisville, Kentucky and Minneapolis, Minnesota. Increasing the energy costs and decreasing solar panel costs independently to get the solar-powered systems to pay back within twenty years showed that these increased energy prices or decreased solar panel costs are probably unlikely.

In recent years, solar combisystems have received an increasing amount of attention in both the European and U.S. markets due to their ability to increase the energy savings provided by residential active solar water heaters. However, since the extra savings are accompanied by extra installation costs, it is not trivial as to whether or not these systems are a worthy investment, especially when compared to solar water heaters (SWHs). Sustar [24] attempts to answer this question. To help answer the question of whether or not these systems are cost-effective, the annual performance of these systems, as a function of location, size and load, was simulated using a TRNSYS model of a typical combisystem. The model was validated using data from a residential combisystem installed in Carbondale, Colorado, which was monitored as part of a Building America research project.

The TRNSYS model was then used to study the annual performance of combisystems for residential applications in six locations within the U.S. The six locations were Phoenix, Atlanta, San Francisco, Denver, Boston, and Chicago. For collector area sizes of 96 ft^2 or smaller, the performance of these systems is measured by the incremental energy savings it yields in comparison to a SWH (solar water heater) of the same system size. Additionally, the combisystems' energy savings are evaluated based on the reduced auxiliary energy required to meet the thermal loads as compared to a reference system without any solar component.

This study found that combisystems are able to provide significant energy and cost savings relative to both small SWHs and reference systems. In terms of incremental savings from the combisystem as compared to a SWH of the same size, the largest incremental savings will occur when DHW (domestic hot water) loads are small and space heating loads are high. The economic analysis revealed that electric combisystems in the locations of Denver, Boston, and San Francisco yield the highest incremental cost savings and highest incremental breakeven costs relative to a SWH.

Regarding the cost-effectiveness of combisystems relative to a reference system, the analysis reveals that the economics could be favorable for combisystems in the locations of

Denver, Boston, and San Francisco, provided that these systems are electric, and the thermal loads in these homes are high. However, if evaluating the economics of combisystems in applications for lower space heating loads due to more efficient construction, combisystems--given their current high installation costs--are not a cost-effective option in any location evaluated.

Boling [23] and Sustar [24] established that a well-known fact about direct solar heating is still true today. That is, direct solar heating is only cost effective if the buildings they heat are large and have large heating loads. The average American home in general will not be heated cost effectively by direct solar heat.

An Assessment of the State of the Art and Economic Viability Photovoltaic Solar Energy Production

According to Clean Energy [22], in 1839, French scientist Edmund Becquerel discovered that certain materials would give off a spark of electricity when struck with sunlight. This photoelectric effect was used in primitive solar cells made of selenium in the late 1800s. In the 1950s, scientists at Bell Labs revisited the technology and, using silicon, produced solar cells that could convert four percent of the energy in sunlight directly to electricity. Within a few years, these photovoltaic (PV) cells were powering spaceships and satellites.

The most important components of a PV (photovoltaic) cell are two layers of semiconductor material generally composed of silicon crystals. On its own, crystallized silicon is not a very good conductor of electricity, but when impurities are intentionally added—a process called doping—the stage is set for creating an electric current. The bottom layer of the PV cell is usually doped with boron, which bonds with the silicon to facilitate a positive charge (P). The top layer is doped with phosphorus, which bonds with the silicon to facilitate a negative charge (N).

The surface between the resulting "p-type" and "n-type" semiconductors is called the P-N junction (see figure 2). Electron movement at this surface produces an electric field that only allows electrons to flow from the p-type layer to the n-type layer.

When sunlight enters the cell, its energy knocks electrons loose in both layers. Because of the opposite charges of the layers, the electrons want to flow from the n-type layer to the p-type layer, but the electric field at the P-N junction prevents this from happening. The presence of an external circuit, however, provides the necessary path for electrons in the n-type layer to travel to the p-type layer. Extremely thin wires running along the top of the n-type layer provide this external circuit, and the electrons flowing through this circuit provide the cell's owner with a supply of electricity.

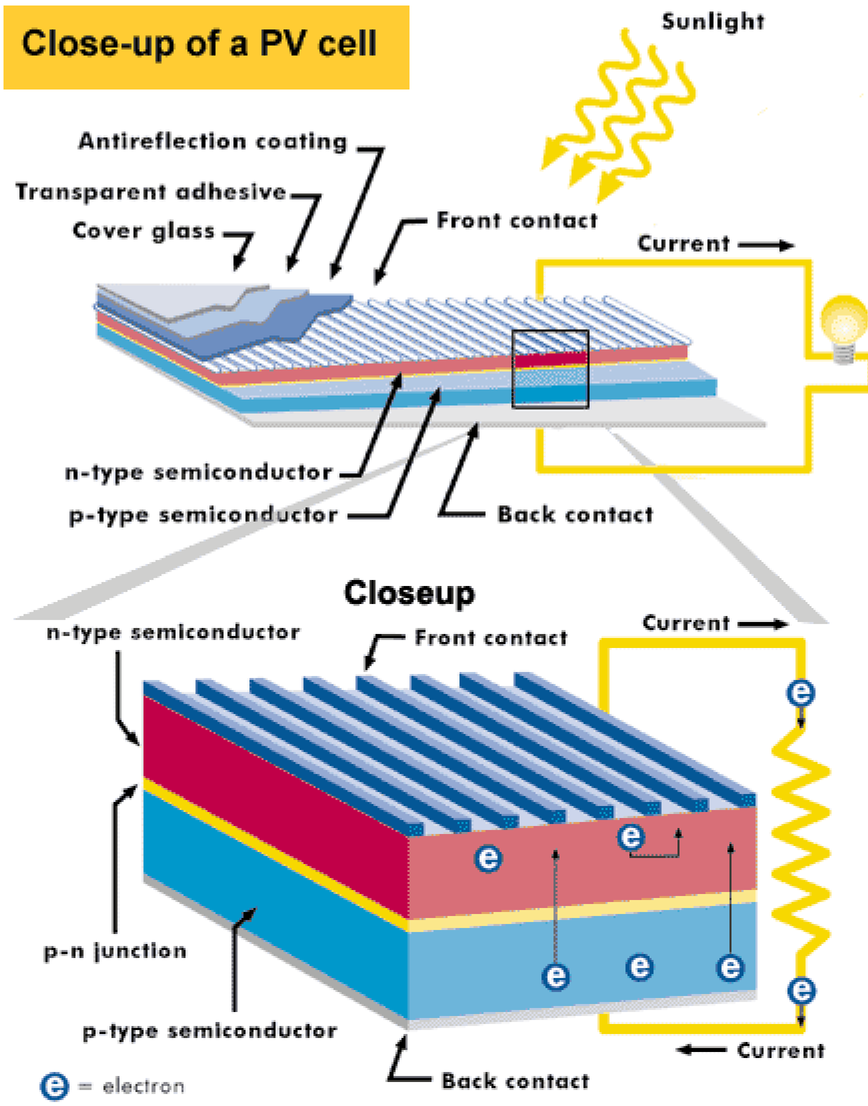

Fig. 2 Illustration of the construction of a photovoltaic cell. [22]

Most PV systems consist of individual square cells averaging about four inches on a side. Alone, each cell generates very little power (less than two watts), so they are often grouped together as modules. Modules can then be grouped into larger panels encased in glass or plastic to provide protection from the weather, and these panels, in turn, are either used as separate units or grouped into even larger arrays.

The three basic types of solar cells made from silicon are single-crystal, polycrystalline, and amorphous. [22]

1. Single-crystal cells are made in long cylinders and sliced into round or hexagonal wafers. While this process is energy-intensive and wasteful of materials, it produces the highest-efficiency cells—as high as 25 percent in some laboratory tests. Because these high-efficiency cells are more expensive, they are sometimes used in combination with concentrators such as mirrors or lenses. Concentrating systems can boost efficiency to almost 30 percent. Single-crystal accounts for 29 percent of the global market for PV.

2. Polycrystalline cells are made of molten silicon cast into ingots or drawn into sheets, then sliced into squares. While production costs are lower, the efficiency of the cells is lower too—around 15 percent. Because the cells are square, they can be packed more closely together. Polycrystalline cells make up 62 percent of the global PV market.

3. Amorphous silicon (a-Si) is a radically different approach. Silicon is essentially sprayed onto a glass or metal surface in thin films, making the whole module in one step. This approach is by far the least expensive, but it results in very low efficiencies—only about five percent.

A number of exotic materials other than silicon are under development, such as gallium arsenide (Ga-As), copper-indium-diselenide (CuInSe2), and cadmium-telluride (CdTe). These materials offer higher efficiencies and other interesting properties, including the ability to manufacture amorphous cells that are sensitive to different parts of the light spectrum. By stacking cells into multiple layers, they can capture more of the available light. Although a-Si accounts for only five percent of the global market, it appears to be the most promising for future cost reductions and growth potential.

In the 1970s, a serious effort began to produce PV panels that could provide cheaper solar power. Experimenting with new materials and production techniques, solar manufacturers cut costs for solar cells rapidly, as the following graph shows.

One approach to lowering the cost of solar electric power is to increase the efficiency of cells, producing more power per dollar. The opposite approach is to decrease production costs, using fewer dollars to produce the same amount of power. A third approach is lowering the costs of the rest of the system. For example, building-integrated PV (BIPV) integrates solar panels into a building's structure and earns the developer a credit for reduced construction costs.

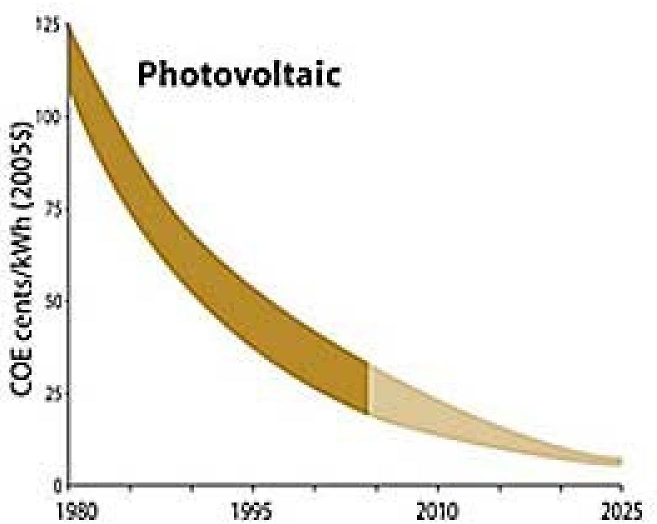

Fig. 3 Photovoltaic costs (Source: NREL) [22]

Innovative processes and designs are continually reaching the market and helping drive down costs, including string ribbon cell production, photovoltaic roof tiles, and windows with a translucent film of a-Si. Economies of scale from a booming global PV market are also helping to reduce costs. Figure 3 shows the significant drop in cost per kW-h. of photovoltaic electricity from 1980 to 2004 when this chart was created and the projected drop in cost out to 2025.

Historically, most PV panels have been used for off-grid purposes, powering homes in remote locations, cellular phone transmitters, road signs, water pumps, and millions of solar watches and calculators. Developing nations see PV as a way to avoid building long and expensive power lines to remote areas. And every year, experimental solar-powered cars race across Australia and North America in heated competitions.

More recently, thanks to lower costs, strong incentives, and net metering policies, the PV industry has placed more focus on home, business, and utility-scale systems that are attached to the power grid. In some locations, it is less expensive for utilities to install solar panels than to upgrade the transmission and distribution system to meet new electricity demand. In 2005, for the first time ever, the installation of PV systems connected to the electric grid outpaced off-grid PV systems in the United States. As the PV market continues to expand, the trend toward grid-connected applications will continue.

This distributed-generation approach provides a new model for the utilities of the future. Small generators, spread throughout a city and controlled by computers, could replace the large coal and nuclear plants that dominate the landscape now.

The cost of photovoltaic power production has been declining over the last decade. According to the NC Sustainable Energy Association, the installed cost per watt (W) of solar PV in North Carolina has decreased from $8.50/W to $5.44/W from 2006 to 2011. In all, that is a 36 percent drop in price, making solar power more accessible in North Carolina. But even with this significant drop in installed cost, in general, the cost of installing a residential photovoltaic system is still too expensive to produce a reasonable payback period. To bridge this cost gap, other financial incentives will be necessary.

Adachi [25] looks at one form of bridging this cost gap. Traditionally, high initial capital costs and lengthy payback periods have been identified as the most significant barriers that limit the diffusion of solar photovoltaic (PV) systems. In response, the Ontario Government, through the Ontario Power Authority (OPA), introduced the Renewable Energy Standard Offer Program (RESOP) in November, 2006. The RESOP offers owners of solar PV systems with a generation capacity under 10MW a 20 year contract to sell electricity back to the grid at a guaranteed rate of $0.42/kWh. While it is the intent of incentive programs such as the RESOP to begin to lower financial barriers in order to increase the uptake of solar PV systems, there is no guarantee that the level of participation will in fact rise. The "on-the-ground" manner in which consumers interact with such an incentive program ultimately determines its effectiveness.

The purpose of Adachi's research is to analyze the relationship between the RESOP and solar PV system consumers. To act on this purpose, the experiences of current RESOP participants are presented, wherein the factors that are either hindering or promoting utilization of the RESOP and the adoption of solar PV systems were identified.

Adachi's thesis was conducted in three phases – a literature review, preliminary key informant interviews, and primary RESOP participant interviews – with each phase informing the scope and design of the subsequent stage. First, a literature survey was completed to identify and to understand the potential drivers and barriers to the adoption of a solar PV system from the perspective of a consumer. Second, nine key informant interviews were completed to gain further understanding regarding the specific intricacies of the drivers and barriers in the case of Ontario, as well as the overall adoption system in the province. These interviews were conducted between July and September, 2008. Third, interviews with 24 RESOP participants were conducted; they constitute the primary data set. These interviews were conducted between November and December, 2008.

Findings suggest that the early adopters of solar PV systems have been motivated by their self-identified sustainability-oriented social attitudes, rather than the lowering of the financial barrier. Only six of 24 respondents noted that they would not have purchased a solar PV system in the absence of the RESOP. For nine of 24 respondents, the catalyst for the purchase of the solar PV systems was not the creation of the RESOP, but instead the presence of a community-based co-operative purchasing group (CBCPG) that had selected a vender and that provided a support service to help the consumer navigate the administrative processes associated with the RESOP.

Regarding the functioning of the RESOP, interview respondents reported lengthy periods of time to secure electrical connection, hidden additional fees, and arduous administrative processes. Based on their experiences interacting with local distribution companies, vendors, and the OPA, respondent evaluations of the overall adoption process ranged from extremely positive (some interviewees praised the RESOP for its ease of participation and utility), to extremely negative (other interviewees condemned the RESOP because of its administrative complexity and hidden costs and fees). A key finding from this research is that weaknesses in the administration and promotion of the RESOP have been mitigated by the presence of CBCPGs and third parties aiding consumers in the purchase, installation, administration, and connection of their solar PV system. Recommendations of this work include the creation of new CBCPGs and enhancement of existing CBCPGs, a simplification of the required administrative processes, and an increase in the rates of compensation.

An Assessment of the State of the Art and Economic Viability of Geothermal Heat Pump Technology

Residential geothermal energy though not used residentially in North Carolina to produce electricity is widely used to efficiently heat and cool homes. Shen [26] shows the dramatic savings that geothermal heat pumps on a commercial scale can produce. The Heating, Ventilation and Air Conditioning system (HVAC) is one of the most important aspects of building energy efficiency. In order to enhance energy efficiency, design strategies always pay primary attention to the HVAC system design. The Ground Source Heat Pump is a relatively new system which has high performance with respect to energy efficiency and reduces carbon emissions correspondingly.

This research focuses on the energy consumption and economic benefits of a Ground Source Heat Pump installation. This system has been installed in the Pudong natatorium in Shanghai, a building which was formerly serviced by a conventional package variable air volume (VAV) system with natural gas boiler. Measurements were made of system performance and energy use for the former system and repeated for the newly installed Ground Source Heat Pump system. Computer simulation tools were also applied for the two systems and the results compared with measured data. Computer simulations were based on the simulation tool---Equest 3-63(DOE2). The researchers anticipated the result would prove the Geothermal Heat Pump has a high performance on energy efficiency and economic saving.

The result shows the alternative I model, which is GSHP model, consumes 1064.7 thousand kW-h. In comparison, baseline model consumes 1516.4 thousand kW-h. GSHP saves 29.7% energy every year for Pudong natatorium. The difference initial investment between GSHP and conventional HVAC system can be compensated through the yearly saved utility fee in less than ten years. The total life expectancy of the GSHP is 50 years. [21]

Swenka [27] evaluates residential ground-source heat pumps throughout the state of Iowa. The ground-source heat pumps were evaluated based on performance, efficiency, and economics. The study was limited to similar homes throughout the state of Iowa, recent constructions (1997 to 2001), and vertically or horizontally configured loops. Energy audits were conducted for each home to obtain building characteristics. Using the characteristics, heating and cooling loads were estimated for each home. Utilizing the heating and cooling loads along with utility bill and weather information, performance data were calculated for each home. The energy analyses showed that cooling loads are not accurately tracked using this method as a result of occupant schedules. The heating load performance showed that there is a negligible difference between the performance of a vertical and horizontal loop system. The economic analysis evaluated the cost difference between using a ground-source heat pump and natural gas furnace. The analysis showed that a significant amount of money could be saved during the heating season when using a ground-source heat pump. It was determined that several homeowners were interested in the installation of a ground source heat pump but did not fully understand the technology. An extensive literature review was completed and an educational document was produced for homeowner’s education. Homeowners tend to be highly interested in estimating the amount of money that can be saved using a ground-source heat pump. To estimate a home’s annual savings using a ground source heat pump in comparison to other means of conditioning a home, a savings calculator was developed. The calculator was able to closely estimate most homes evaluated in this study. Swenka's work validates the claim that residential ground source heat pumps can save on the electric bill and produce a reasonable payback period. It also establishes that people are interested in renewable energy if it can save them money on their utility bills and pay for itself in a reasonable length of time.

Air-to-air heat pumps (AAHP) are also established and proven renewable energy savers. This technology is mature and can compete with ground source heat pumps with regard to energy costs to heat and cool a building. Two additional factors affect the choice between GSHP and AAHP. The AAHP is cheaper to install than the GSHP. And AAHP are not effective or efficient at temperatures below 20º F. [28]

An Assessment of the State of the Art and Economic Viability of Hydroelectric Technology

Hydroelectric energy has been around since man created his first civilization. Needless to say then, it is a very mature technology and according to Greenville Utilities Energy Conservation Department, Greenville, North Carolina, is the most energy efficient and practical of all the renewable energy sources. It is also the most widely used renewable energy resource. It has however, one significant drawback for residential use. The property owner must have sufficient water flowing through his or her property to make use of this very efficient resource. Unlike wind and solar, very few people have an adequate source of water flowing through their land to make use of this technology. For this reason, it is not considered practical as a general residential use renewable energy resource.

A Review of Current Building Energy Conservation Measures

In the previous paragraphs of this chapter, commonly available renewable energy products were reviewed. However, energy conservation should always be considered to optimize the cost effective reduction of the residential energy bill. This is the subject of this section.

France, [29] researches the cost effectiveness of incorporating energy conservation measures and photovoltaic panels into four Leadership in Energy and Environmental Design, (LEED) homes in Las Vegas, NV. The study focuses on the cost benefit of including specific energy efficient upgrades in future homes built at the development. Though all proposed upgrades offer reductions in energy use, most offer little improvement relative to their additional installation costs. High-efficiency windows and heat recovery ventilators have been deemed appropriate upgrades for future homes. All homes at the development are to be equipped with photovoltaic arrays; increasing the size of the arrays will reduce net energy consumption in a cost-effective manner. The results of this study point out the importance of cost effectiveness in every aspect of the effort to reduce the energy bill. Even in energy conservation, not every measure is cost effective though it may reduce the energy bill. Table 1 illustrates comparative payback periods for various high efficiency additions to a home. Note that Energy savings are significantly less than would be achieved had the same measures been applied to code built homes. The homes in this study are built to standards that are significantly above code, so the payback periods are significantly greater than would be expected in standard code built buildings. However, significant meaning can be extracted from a comparison of the payback periods.

Another important consideration when thinking about purchasing energy conservation material or equipment is the significance it has on the overall energy load. For example, if a device will save 50% on infiltration, as figure 4 shows, the overall effect infiltration has on

Table 1: Cost benefits of individual energy efficient components [28]

Efficiency measures	Average annual energy savings	Average simple payback period
High-efficiency windows	$15.24	9.0
17.5 SEER air conditioner	$31.78	74.1
20 SEER air conditioner	$56.19	59.3
Heat recovery ventilator	$114.40	19.1
2"x6" walls + R-19 cellulose	$17.10	129
R-30 floor insulation	$5.74	132
R-36 Icynene attic insulation	$21.89	43.1
Raised roof battens	$0.18	1,244
2.280-kWp PV array	$110.00	29.1
3.192-kWp PV array	$305.00	27.3

energy consumption is only 6%. So the overall effect this device will have on energy savings is only 3%. Figure 4 displays the building components commonly responsible for energy loads, averaged for all building types in developed countries. The chart shows the extent of each component's contribution to total energy demands. Components that comprise the thermal envelope show loads corresponding to their respective contribution of total space heating and cooling energy losses. The chart demonstrates that no single solution will transform a conventional building into a low energy building.

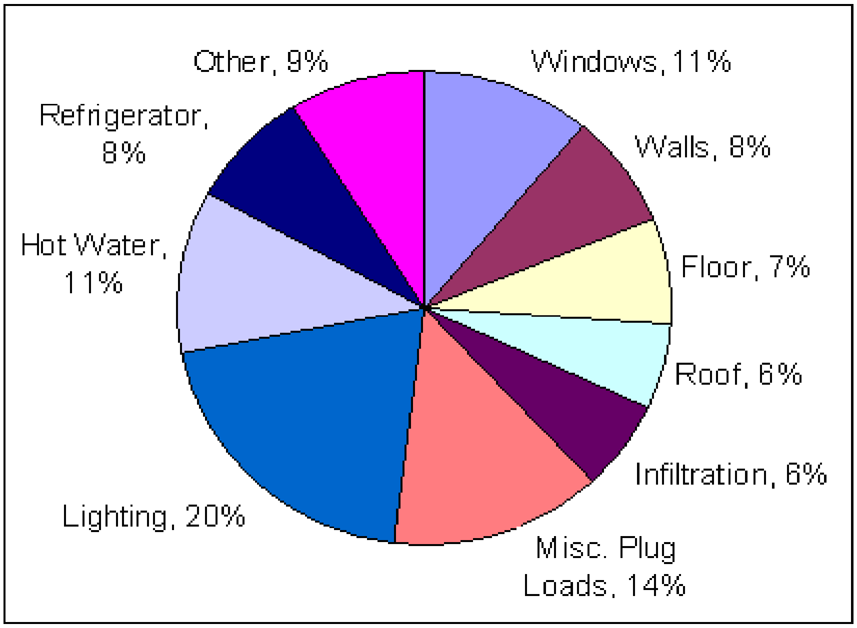

Fig. 4 Average energy end-uses and component contributions to building [28]

It has been proposed by Underwriter Laboratories (UL®) that through the proper installation and use of energy using devices and appropriate energy conservation measures, the energy usage can be reduced by as much as 30% [29]. This underscores the importance of including energy conservation into the energy mix.

Results of the Literature Search

Five things may be noted from this literature search as it applies to North Carolina:

- Most research and development for wind generating systems has been focused on commercial utility electric generating systems.
- Due to environmental impacts of wind turbines such as noise, avian impacts, and the perception by many that wind turbines are aesthetically displeasing to the eye,

wind turbine adoption in residential areas has not been as significant as it would have been in the absence of these factors.

- Photovoltaic technology has made steady and significant strides in energy efficiency and cost in the last decade due to advances in the semiconductor industry.
- Geothermal GSHP and AAHP technologies have made significant improvement in efficiency and cost over the last three decades.
- Compared to wind generating equipment, there are few environmental restrictions on solar, PV, and heat pump systems.
- A need exists for a tool to allow small consumers of electricity such as home owners and small business owners to cost effectively determine the correct mix of renewable resource equipment and energy conservation measures to employ to reduce their energy costs in such a way that a reasonable and acceptable payback period for the investment may be calculated.

The next chapter of this work proposes a means for assessing the viability of using residential renewable energy systems in conjunction with energy conservation measures to cost effectively reduce the residential energy bill. An economic model will be proposed that will enable a home owner, small business owner or other consumer of energy to reliably determine the most cost effective combination of renewable energy products and energy conservation measures to take to reduce the energy bill.

CHAPTER 3

CREATION OF AN ANALYTICAL MODEL FOR ASSESSING THE VIABILITY OF RENEWABLE ENERGY OPTIONS BY SINGLE-FAMILY HOMEOWNERS

Rationale for Further Work

The main obstacle to expanding the residential or small business owner use of renewable energy is a thorough understanding of the playing field of pros, cons and regulations involving the installation and use of renewable energy equipment. Chapter two of this dissertation discussed characteristics and potential regulatory hurdles of all practical renewable energy equipment available for use in North Carolina that must be considered to make an informed and rational decision about whether or not to invest in renewable energy equipment. If after deciding that investing in renewable equipment may be viable, what types and sizes will produce the optimum results? At the present time, no practical instrument exists that will allow residential and small business owners to correctly assess this viability with confidence. Lacking a reliable tool to make an informed and reliable decision about investing in renewable energy, consumers are forced to rely on contractor salesmen to give them this information and trust that the information is accurate and that all the information they should have to make the right decision is provided to them by the contractor before making the decision. Research suggests that many times this is not the case and individuals who would like to use renewable energy make a bad decision to invest in renewable energy, or do not invest in the right renewable energy source for them. Word gets around on this and soon, many people who were thinking about investing in renewable energy equipment are deciding not to. This environment of misinformation, lack of information and bad advice does not justly and ethically promote renewable energy usage. The result is that adoption of renewable energy is slowed down and the consequences of continuing to use nonrenewable resources continue to mount up.

A reliable tool that digests appropriate information, performs an engineering economic analysis and presents the consumer with appropriate output to allow home owners and small business owners to make an informed and cost effective decision about investing in renewable products and what renewable products to invest in is needed and will be developed in this dissertation.. This tool will provide the user two main advantages. The first is that it will educate consumers about renewable energy. The second is that it will provide a reasonable gage to calculate a reliable return on investment comparison between standard energy usage or production equipment and renewable energy equipment. A more educated and well informed public with accurate and reliable tools to confidently determine economic viability will induce more people to get serious about investing in renewable energy and contribute to reducing our dependence on fossil fuels and reduce the carbon footprint in the atmosphere.

Work Focus

This work will develop an analytical model that small business owners and home owners can use to determine the economic viability for them to use renewable energy products in conjunction with appropriate cost effective energy conservation measures to reduce their energy bill. The emphasis is not placed on simply lowering the energy bill, but to do so in a cost effective way that takes into account the upfront costs the consumer must bear to purchase, install and maintain the renewable equipment beyond that of purchasing, installing and maintaining conventional energy equipment. The same is true of energy conservation measures. The cost of implementing energy conservation measures is every bit as important as the money they save you on the utility bill.

The model will have two layers. The first layer will be called the sub-element model (SEM) layer. These SEMs will model each renewable energy technology that has been found in chapter two to be practical in North Carolina. These technologies are:

1. Wind energy used to produce grid connectable electricity
2. Photovoltaic energy used to produce grid connectable electricity
3. Direct solar heating
4. Geothermal (Ground Source Heat Pump) heating and cooling
5. Air-to-air heat pump heating and cooling
6. Energy Conservation

These SEMs will have inputs and outputs. The inputs will be classified into two categories. Category 1 will consist of inputs that are specific to the technology being modeled. Category 2 will include generic information that may apply to other SEMs as well. For example, Category 1 inputs for wind energy are average local wind speed, electric output as a function of wind speed and cost to purchase, install and maintain the wind energy device. Category 2 inputs might be the area of the living space of the house, number of people living in the house, and monthly utility bills. Outputs of the SEMs are payback period, Internal Rate of Return (IRR) and Equivalent Uniform Annual Worth (EUAW). A comprehensive list of inputs is as follows:

Proposed renewable energy and energy conservation equipment

1. Average local wind speed
2. Technical specifications and cost of wind energy device:
    a. Electrical output as a function of wind speed
    b. Purchase, installation and maintenance cost
    c. Equipment lifetime
3. Local ordinances and regulations restricting use of wind energy
4. Applicable federal and state tax incentives for using wind energy systems
5. Average local incident solar radiation
6. Technical specifications and cost of photovoltaic energy device
    a. Electrical output as a function of solar radiation
    b. Purchase, installation and maintenance cost
    c. Equipment lifetime
7. Local ordinances and regulations restricting use of PV equipment
8. Applicable federal and state tax incentives for using PV equipment
9. Technical specifications of direct solar heating device
    a. BTU output as a function of solar radiation
    b. Purchase, installation and maintenance cost
    c. Electrical power consumption
    d. Equipment lifetime
10. Local ordinances and regulations restricting use of direct solar heating equipment
11. Applicable federal and state tax incentives for using direct solar equipment
12. Average local ground temperature
13. Technical specification of GSHP
    a. BTU output as a function of ground temperature
    b. SEER rating
    c. Purchase, installation and maintenance cost
    d. Electrical power consumption
    e. Equipment lifetime
14. Applicable federal and state tax incentives for using GSHP equipment
15. Average local winter and summer ambient temperature
16. Technical specifications of AAHP
    a. BTU output as a function of temperature
    b. SEER rating
    c. Purchase, installation and maintenance cost
    d. Electrical power consumption
    e. Equipment lifetime
17. Proposed R rating of ceilings, walls and doors after improvement
18. Cost of insulation installation

19. Proposed R rating of windows and doors after improvement
20. Cost of installation of windows and doors

Current state of building and energy equipment in use

21. R rating of ceiling, walls and floor
22. % wall space occupied by windows and doors
23. R rating of windows and doors
24. Area of living space of home
25. Number of people living in home
26. Utility bills for a minimum of 12 months
27. Air infiltration
    a. Doors and windows caulked
    b. Outside facing wall outlets sealed
28. Energy Star rated appliances
    a. Dollars per year saved, (found on yellow EStar tag)
    b. Number of EStar appliances (add up dollars saved on tag)
29. Technical specifications of current HVAC equipment
    a. BTU output per cu. ft. of gas if gas furnace
    b. BTU per kW if electric furnace
    c. BTU per kW for AC
    d. AFUE rating for gas furnace
    e. SEER rating for AC

The SEM outputs will serve as the inputs to the model's second layer, called the Comprehensive Element Model (CEM). The CEM will use the SEM outputs to calculate a comprehensive economic viability output. These outputs are payback period, IRR and EUAW for the entire system. This output will allow any home owner, small business owner or other single end user of electricity from the grid to make an informed, accurate and cost effective decision about what renewable energy products (if any) to use and what energy conservation measures to implement.

Forty to fifty residents and small business owners in North Carolina that currently use at least one of the five green energy products discussed in this research will be surveyed to provide input to the model discussed in Chapter 4. The above category 1 input information shall be obtained from the people being surveyed. In addition to this information, utility bills for 12 months following installation of the renewable energy product(s) they installed will be obtained. The input information prior to renewable energy product installation will be input into the model and the prediction results statistically compared to the actual results. This data will be used to calibrate the model to optimal performance as well as perform the final quantitative statistical validation of the optimized model.

CHAPTER 4

ECONOMIC VIABILITY MODEL

Model Description

In this chapter the model proposed in Chapter 3 will be discussed in detail. As stated in Chapter 3 the model will have two layers, a sub element model layer (SEM) and a comprehensive element model layer (CEM). The sub element model will model five different green energy devices and have two types of inputs. The first input type will be universal to all green energy devices. Examples of this type might be the size of the home or building and the number of people that occupy the building. These types of inputs are the same regardless of whether the green energy device is a wind turbine a photovoltaic system a direct source heat energy system or heat pump. The second input type will be particular to the type of green energy device being modeled. For example, local wind speed and the wind turbine electrical output are inputs that are particular to the wind turbine device. Outputs of the SEMs are payback period and Internal Rate of Return (IRR). These outputs will be the inputs to the comprehensive element model (CEM). The comprehensive element model (CEM) will compare these inputs to optimize the payback period and internal rate of return (IRR). The output of the comprehensive element model (CEM) will provide the consumer the necessary information to make a reliable economic decision about investing in the considered green energy equipment.

Wind Energy Model

The following are the inputs to the wind energy SEM.

1. Occupied area of the building in $ft^2 = I_1$
2. Number of people occupying the building or residence = I_2
3. Average local wind speed in km/h = I_3
4. Maximum electrical output of wind turbine in kW = I_4
5. Minimum wind speed in km/h at which maximum output can be produced = I_5
6. Turbine cut in speed in km/h = I_6
7. Mean price per kW-h of customer's electricity* = I_7
8. Purchase and installation cost = I_8
9. Total federal and state tax incentive = I_9
10. Annual maintenance cost = I_{10}
11. Lifetime of equipment in years = I_{11}
12. Average annual electrical usage in kW-h = I_{12}
13. Average annual natural gas or propane usage cost = I_{13}
14. Average annual utility bill cost = I_{14}

*This figure depends on the agreement between the utility customer and the utility regarding reimbursement for power produced by the customer. If net metering is employed, the cost savings is directly from the utility bill and the utility will not reimburse customers for electricity produced that exceeds that consumed by the customer.

Since a wind turbine is an electricity producing device, electricity consumption rate is not a factor except in choosing the proper size of wind turbine and generator. (See footnote above.) First, the output of the wind energy device must be calculated. These calculations are based on a per annum cost of electricity production P_0 over the lifetime of the purchased equipment. Equation 4-1 [30] calculates the average annual production of electricity in kW. Equation 4-2 calculates the total electrical energy produced E_{T1} by the wind energy device in kW-h. for one year. The consumer should next compare this calculation with the average annual electrical usage in kW-h. (I_{12}). The utility provider will generally only allow consumers to offset their electricity bill. They will not reimburse electricity costs above the bill for that year. So for the purpose of this model, the consumer should use the lesser of the two figures. Equation 4-3 calculates the annual cost savings from the electricity produced.

$$P_o = I_4(I_3 - I_6)/(I_5 - I_6) \qquad \text{Equation 4-1}$$

$$E_{T1} = 8760P_o \qquad \text{Equation 4-2}$$

$$C_{S1} = E_{T1}I_7 - I_{10} \qquad \text{Equation 4-3}$$

Next, the annualized cost of the wind turbine system must be calculated. This calculation is performed in equation 4-4.

$$C_{A1} = (I_8 - I_9)/I_{11} + I_{10} \qquad \text{Equation 4-4}$$

The consumer should then compare the cost savings calculated in equation 4-3 with the annualized cost calculated in equation 4-4. If the result obtained in equation 4-4 is larger than that obtained in equation 4-3, do not go any further. The equipment under consideration is not cost effective. If the savings calculated in equation 4-3 is greater than the result calculated in equation 4-4, the following calculation obtained from equation 4-5 and 4-6 [31] should be considered. Equations 4-5 and 4-6 calculate the Internal Rate of Return (IRR). Generally, the equities market will give a 10% rate of return and this is considered by most financial advisors to be the best investment one can make. If the considered investment in wind energy equipment is greater than this 10%, then the wind energy investment will be the better investment. First we define the internal rate of return with the following formula;

$$PV = FV[(1+R)^N-1]/[R(1+R)^N] \quad \text{Equation 4-5}$$

Where:

$PV = I_8 - I_9$

$FV = C_{S1} - I_{10}$

$N = I_{11}$

R = Internal Rate of Return

In an iterative process of selecting (guessing) an IRR (R) and calculating the NPV, the IRR is found when the NPV becomes zero. This is symbolized in Equation 4-6.

$$(P/A,R,N) = [(1+R)^N-1]/[R(1+R)^N] \quad \text{Equation 4-6}$$

Equation 4-7 [30] calculates the payback period.

$$P = (I_8 - I_9)/(C_{S1}) \quad \text{Equation 4-7}$$

The electrical consumer using this model should also be aware that other factors besides economic factors are also critical to making a correct decision regarding the use of wind energy devices.

Photovoltaic Energy Model

The following are the inputs to the photovoltaic SEM.

1. Occupied area of the building in square feet = I_1
2. Number of people occupying the building or residence = I_2
3. Average site specific incident solar radiation over the course of a year in kW-hrs./m^2/day = I_{15}
4. Total area of solar panels (m^2) = I_{16}
5. Solar panel yield (%) = I_{17}
6. Solar panel performance coefficient = I_{18}
7. Mean price per kW-h of customer's electricity* = I_{19}
8. Purchase and installation cost = I_{20}
9. Total federal and state tax incentive = I_{21}
10. Annual maintenance cost = I_{22}
11. Lifetime of equipment in years = I_{23}
12. Average annual electrical usage in kilowatt hours = I_{24}
13. Average annual natural gas or propane usage cost = I_{25} = I_{13}
14. Average annual utility bill cost = I_{26}

*This figure depends on the agreement between the utility customer and the utility regarding reimbursement for power produced by the customer. If net metering is employed, the cost savings is directly from the utility bill and the utility will not reimburse customers for electricity produced that exceeds that consumed by the customer.

Since a photovoltaic system is an electricity producing device, electricity consumption rate is not a factor except in choosing the proper size of system. (See footnote above.) First, the output of the photovoltaic system must be calculated. These calculations are based on a per annum cost of electricity production over the lifetime of the purchased equipment. Equation 4-8 [32] calculates the average annual production of electricity in kW-h. Equation 4-9 calculates the annual cost savings from the electricity produced.

$$E_{T2} = A*r*H*PR \qquad \text{Equation 4-8}$$

$A = I_{16}$

$r = I_{17}$

$H = I_{15}*365$

$PR = I_{18}$

$C_{S2} = E_{T2}*I_{19} - I_{22}$ Equation 4-9

Next, the annualized cost of the photovoltaic system must be calculated. This calculation is performed in equation 4-10.

$C_{A2} = (I_{20} - I_{21})/I_{23} + I_{22}$ Equation 4-10

The consumer should then compare the cost savings calculated in equation 4-9 with the annualized cost calculated in equation 4-10. If the result obtained in equation 4-10 is larger than that obtained in equation 4-9, do not go any further. The equipment under consideration is not cost effective. If the savings calculated in equation 4-9 is greater than the result calculated in equation 4-10, the following calculation obtained from equation 4-5 and 4-6 [31] should be considered. Equations 4-5 and 4-6 calculate the Internal Rate of Return (IRR). If the considered investment in photovoltaic equipment is greater than 10%, then this investment will be the better investment. Utilizing equation 4-5 with the following inputs, the internal rate of return R is calculated.

$PV = I_{20} - I_{21}$

$FV = C_{S2} - I_{22}$

$N = I_{23}$

R = Internal Rate of Return

In an iterative process of selecting (guessing) an IRR (R) and calculating the NPV, the IRR is found when the NPV becomes zero. This is symbolized in Equation 4-6.

Equation 4-11 calculates the payback period.

$$P = (I_{20} - I_{21})/(C_{S2}) \qquad \text{Equation 4-11}$$

The home owner should also keep in mind that access to direct sunlight is critical to the performance of a photovoltaic electricity production system. Any objects such as trees or tall buildings near the photovoltaic panels could seriously impair the IRR and payback period.

Direct Solar Heating Model

The following are the inputs to the direct solar system SEM.

1. Occupied area of the building in $ft^2 = I_{29}$
2. Number of people occupying the building or residence = I_{30}
3. Seasonal Energy Efficiency Rating (SEER) for the direct solar heating system = I_{31}
4. Total exposed wall area in $ft^2 = I_{32}$
5. Total exposed ceilings area in $ft^2 = I_{33}$
6. Total exposed floor area in ft^2. = I_{34}
7. Total door and window area in $ft^2 = I_{35}$
8. R value of walls = I_{36}
9. R value of ceilings = I_{37}
10. R value of floors = I_{38}
11. R value of doors and windows = I_{39}
12. Mean price per kW-h of customer's electricity = I_{40}
13. Purchase and installation cost = I_{41}
14. Total federal and state tax incentive = I_{42}
15. Annual maintenance cost = I_{43}
16. Lifetime of equipment in years =I_{44}
17. Seasonal Energy Efficiency rating for replaced equipment = I_{45}

Since direct solar heating consumes electricity rather than producing it, cost savings must be viewed from a different perspective. More specifically, since heating comfort consumes electricity to heat and cool a home, heat loss calculations must be performed on the building to determine the average cost of electricity the building will require to maintain a given inside temperature. First, since we are considering a heating only system, the mean winter temperature for the area is required. This would be the average temperature for all months the heating system is expected to be turned on. This model will assume the heating system will be turned on 6 months out of the year. It should be noted that this figure will vary from household to household and from location to location. This figure will be used to calculate the mean difference in temperature between the outside and inside of the building during the heating season. These figures may be obtained from the National Weather Service. Next, heat load calculations must be done. First obtain the total exposed wall surface area less doors and windows. In rooms where there are windows and doors, calculate the % area of doors and windows for all walls where there are doors and windows. Multiply this figure by the total wall space containing windows and doors. This will be the total window and door area. Next, calculate the total ceiling area and floor area that is exposed to the outside. In most cases, these figures will be equal. Finally, determine the R-value for the walls, ceilings, floors and doors and windows. Armed with these figures, the heating load calculations are next. Equation 4-12 calculates the mean difference between the outside and inside temperature during winter months.

$$\Delta T = T_{in} - T_{oa} \qquad \text{Equation 4-12}$$

ΔT annual mean difference between outside and inside temperature in ºF.

T_{in} inside temperature in ºF

T_{oa} mean outside winter temperature in ºF

Equation 4-13 [33] calculates the heat load for the heating system.

$$Q = I_{32}\Delta T/I_{36} + I_{33}\Delta T/I_{37} + I_{34}\Delta T/I_{38} + I_{35}\Delta T/I_{39} \qquad \text{Equation 4-13}$$

Q = total heating load in Btu/h.

Equation 4-14 [33] calculates the mean hourly electrical consumption.

$$E_{T3} = Q/I_{31}/1000 \qquad \text{Equation 4-14}$$

E_{T3} mean electrical energy consumption in kW

Q total heating load in Btu/hr.

Equation 4-15 calculates the annual electrical energy requirement of the direct solar heating system.

$$E_{ADS} = E_{T3}*4380 \qquad \text{Equation 4-15}$$

E_{ADS} annual electrical energy requirements of the direct solar heating system

Equation 4-16 [33] calculates the annual electrical energy requirements for the unit replaced.

$$E_{ARU} = Q/I_{45}/1000*4380 \qquad \text{Equation 4-16}$$

E_{ARU} Annual electrical energy requirement of the replaced heating system

Equation 4-17 calculates the annual cost savings from the electricity usage reduction.

$$E_{CS3} = (E_{ARU} - E_{ADS})I_{40} - I_{43} \qquad \text{Equation 4-17}$$

Next, the annualized cost of the direct solar heating system must be calculated. This calculation is performed in equation 4-18.

$$C_{A3} = (I_{41} - I_{42})/I_{44} + I_{43} \qquad \text{Equation 4-18}$$

The consumer should then compare the cost savings calculated in equation 4-17 with the annualized cost calculated in equation 4-18. If the result obtained in equation 4-18 is larger than that obtained in equation 4-17, do not go any further. The equipment under consideration is not cost effective. If the savings calculated in equation 4-17 is greater than the result calculated in equation 4-18, the following calculation obtained from equation 4-5 and 4-6 [31] should be considered. Equations 4-5 and 4-6 calculate the Internal Rate of Return (IRR). If the considered investment in a direct solar heating system is greater than this 10%, then the heating system will be the better investment. Utilizing equation 4-5 with the following inputs, the internal rate of return R is calculated.

$PV = I_{41} - I_{42}$

$FV = E_{CS3} - I_{43}$

$N = I_{44}$

R = Internal Rate of Return

In an iterative process of selecting (guessing) an IRR (R) and calculating the NPV, the IRR is found when the NPV becomes zero. This is symbolized in Equation 4-6.

Equation 4-19 calculates the payback period.

$P = (I_{41} - I_{42})/(E_{CS3})$ Equation 4-19

Atmospheric Heat Pump Model

The following are the inputs to the atmospheric Heat Pump System SEM.

1. Occupied area of the building in $ft^2 = I_{46}$
2. Number of people occupying the building or residence = I_{47}
3. Seasonal Energy Efficiency Rating (SEER) for the atmospheric Heat Pump = I_{48}
4. Total exposed wall area in $ft^2 = I_{49}$
5. Total exposed ceilings area in $ft^2 = I_{50}$
6. Total exposed floor area in $ft^2 = I_{51}$
7. Total door and window area in $ft^2 = I_{52}$
8. R value of walls = I_{53}
9. R value of ceilings = I_{54}
10. R value of floors = I_{55}
11. R value of doors and windows = I_{56}
12. Mean price per kW-h of customer's electricity = I_{57}
13. Purchase and installation cost = I_{58}
14. Total federal and state tax incentive = I_{59}
15. Annual maintenance cost = I_{60}
16. Lifetime of equipment in years = I_{61}
17. Seasonal Energy Efficiency rating for replaced equipment = I_{62}
18. Mean price per cu. ft. of natural gas = I_{63}
19. Mean price per cu. ft. of liquid propane = I_{64}

Just as with direct solar heating, an atmospheric heat pump consumes electricity rather than producing it. So cost savings must be viewed from a different perspective. More specifically, since heating comfort consumes electricity to heat and cool a home, heat loss calculations must be performed on the building to determine the average cost of electricity the building will require to maintain a given inside temperature. The mean summer and winter temperature must be determined. The mean winter temperature will be the average temperature of all the months the heating system is expected to be turned on. The mean summer temperature will be the average temperature of all the months the cooling system is expected to be turned on. These figures will be used to calculate the mean difference in temperature between the outside and inside of the building while the heating and cooling systems are in operation. This model will assume the heating and cooling systems will each be turned on 6 months out of the year. It should be noted that this figure will vary from household to household and from location to location. These figures may be obtained from the National Weather Service. Next, heat load calculations must be done. First obtain the total exposed wall surface area less doors and windows. In rooms where there are windows and doors, calculate the percent area of doors and windows for all walls where there are doors and windows. Multiply this figure by the total wall space containing windows and doors. This will be the total window and door area. Next, calculate the total ceiling area and floor area that is exposed to the outside. In most cases, these figures will be equal. Finally, determine the R-value for the walls, ceilings, floors and doors and windows. Armed with these figures, the heating and cooling load calculations are next. Equation 4-20 calculates the mean difference between the outside and inside temperature for the heating system.

$$\Delta T_W = T_{in} - T_{ow} \qquad \text{Equation 4-20}$$

ΔT_W annual mean difference between outside and inside winter temperature in ºF

T_{in} inside temperature in ºF

T_{ow} mean outside winter temperature in ºF

Equation 4-21 calculates the mean difference between the outside and inside temperature for the cooling system.

$$\Delta T_S = T_{in} - T_{os} \qquad \text{Equation 4.21}$$

ΔT_S annual mean difference between outside and inside summer temperature in ºF

T_{in} inside temperature in ºF

T_{os} mean outside summer temperature in ºF

Equation 4-22 [33] calculates the heat load for the heating system.

$$Q_H = I_{49}\Delta T_W/I_{53} + I_{50}\Delta T_W/I_{54} + I_{51}\Delta T_W/I_{55} + I_{52}\Delta T_W/I_{56} \qquad \text{Equation 4-22}$$

Q_H winter heating load in Btu/hr.

Equation 4-23 [33] calculates the average heating electrical energy requirements of the atmospheric heat pump system.

$$E_{TW} = Q_H/I_{48}/1000 \qquad \text{Equation 4-23}$$

E_{TW} mean electrical energy consumed by the heating system in (kW-h.)/hr.

Q_H winter heating load in Btu/hr.

Equation 4-24 calculates the annual electrical energy requirement of the atmospheric heat pump system during winter months in kW-h.

$$E_{AAW} = E_{TW}*4380 \qquad \text{Equation 4-24}$$

Equation 4-25 [33] calculates the cooling load for the cooling system.

$$Q_C = I_{49}\Delta T_S/I_{53} + I_{50}\Delta T_S/I_{54} + I_{51}\Delta T_S/I_{55} + I_{52}\Delta T_S/I_{56} \qquad \text{Equation 4-25}$$

Q_C summer cooling load in Btu/hr.

Equation 4-26 [33] calculates the average cooling electrical energy requirements of the atmospheric heat pump system in Btu/hr.

$$E_{TS} = Q_C/I_{48}/1000 \qquad \text{Equation 4-26}$$

E_{TS} mean electrical energy input to cooling system in kW-h.

Q_C summer cooling load in Btu/hr.

Equation 4-27 calculates the annual electrical energy requirement of the atmospheric heat pump system during summer months in kW-h.

$$E_{AAS} = E_{TS}*4380 \qquad \text{Equation 4-27}$$

Equation 4-28 calculates the total annual electrical energy requirement for the atmospheric heat pump.

$$E_{AAT} = E_{AAW} + E_{AAS} \qquad \text{Equation 4-28}$$

Equation 4-29 [33] calculates the annual electrical energy requirements for the unit replaced.

$$E_{ARU} = (Q_H + Q_C)/I_{62}/1000*4380 \qquad \text{Equation 4-29}$$

E_{ARU} Annual electrical energy requirement of the replaced heating system (kW-h.)

Equation 4-30 calculates the annual cost savings from the electricity usage reduction.

$$E_{CS5} = (E_{ARU} - E_{AAT})I_{57} – I_{60} \qquad \text{Equation 4-30}$$

Next, the annualized cost of the atmospheric heat pump system must be calculated. This calculation is performed in equation 4-31.

$$C_{A4} = (I_{58} – I_{59})/I_{61} + I_{60} \qquad \text{Equation 4-31}$$

The consumer should then compare the cost savings calculated in equation 4-30 with the annualized cost calculated in equation 4-31. If the result obtained in equation 4-31 is larger than that obtained in equation 4-30, do not go any further. The equipment under consideration is not cost effective. If the savings calculated in equation 4-30 is greater than the result calculated in equation 4-31, the following calculation obtained from equation 4-5 and 4-6 [31] should be considered. Equations 4-5 and 4-6 calculate the Internal Rate of Return (IRR). If the considered investment in an atmospheric heat pump system is greater than 10%, then the heat pump system will be the better investment. Utilizing equation 4-5 with the following inputs, the internal rate of return R is calculated

$PV = I_{58} – I_{59}$

$FV = E_{CS5} – I_{60}$

$N = I_{61}$

R = Internal Rate of Return

In an iterative process of selecting (guessing) an IRR (R) and calculating the NPV, the IRR is found when the NPV becomes zero. This is symbolized in Equation 4-6.

Equation 4-32 calculates the payback period.

$$P = (I_{58} – I_{59})/(E_{CS5}) \qquad \text{Equation 4-32}$$

The above model development for atmospheric heat pumps makes the assumption that the unit being replaced is a normal heat pump using only electricity as its power source. However, in some locations, an alternate type of unit called a “gas-pack” is used. These units combine the use of both gas and electricity to heat and cool the building, and the gas may be either natural gas (NG) or liquid propane (LP). If this is the case, equation 4-30 changes to the following alternate equation 4-33.

$$E_{CS5} = (4380Q_HI_{63}/1050000/I_{62} + 4380Q_HI_{64}/2500000/I_{62}) – (4380Q_HI_{63}/1050000/I_{48} + 4380Q_HI_{64}/2500000/I_{48}) + (4380Q_C/1000/I_{62} – 4380Q_C/1000/I_{48})I_{57} – I_{60} \qquad \text{Equation 4-33}$$

To properly use this equation, if the building is supplied with natural gas, the correct price for natural gas (NG) should be entered as I_{63} and zero entered for the price of liquid propane (LP) gas. If the building is supplied with LP gas, a zero should be entered as the price for NG and the correct price entered for LP. The correct price per kW-h. of electricity should be input as I_{57}.

Ground Source Heat Pump Model

The following are the inputs to the ground source Heat Pump System SEM.

1. Occupied area of the building in $ft^2 = I_{65}$
2. Number of people occupying the building or residence = I_{66}
3. Seasonal Energy Efficiency Rating (SEER) for the direct Ground Source Heat Pump = I_{67}
4. Total exposed wall area in $ft^2 = I_{68}$
5. Total exposed ceilings area in $ft^2 = I_{69}$
6. Total exposed floor area in $ft^2 = I_{70}$
7. Total door and window area in $ft^2 = I_{71}$
8. R value of walls = I_{72}
9. R value of ceilings = I_{73}
10. R value of floors = I_{74}
11. R value of doors and windows = I_{75}
12. Mean price per kW-h of customer's electricity = I_{76}
13. Purchase and installation cost = I_{77}
14. Total federal and state tax incentive = I_{78}
15. Annual maintenance cost = I_{79}
16. Lifetime of equipment in years = I_{80}
17. Seasonal Energy Efficiency rating for replaced equipment = I_{81}
18. Mean price of natural gas (NG) = I_{82}
19. Mean price of liquid propane (LP) gas = I_{83}

The atmospheric heat pump modeled above consumes electricity and uses this energy to transfer heat from the atmosphere where the temperature is lower than inside the building to inside the building by alternately compressing and decompressing refrigerant to create a condition in the heat exchanger coils where the temperature in the atmospheric heat exchanger is lower than the atmospheric temperature to absorb heat and the temperature in the heat exchanger inside the building is above the inside temperature so it will dissipate heat and warm the building. This process works in reverse to cool the building in the summer. The fundamental difference between the ground source heat pump and the atmospheric heat pump is the medium used to transfer heat outside the building. Where the atmospheric heat pump uses the atmosphere, (air) the ground source heat pump as the name implies uses the ground as the medium of heat exchange. This is advantageous because the ground is a solid denser material that can absorb and dissipate much more heat than the less dense air used as the medium of heat exchange in the atmospheric heat pump. This makes the efficiency of the ground source heat pump much greater and is reflected in the higher seasonal energy efficiency rating (SEER). The disadvantage that has to be weighed against the advantage just discussed is that installation is much more expensive and in some cases may be cost prohibitive. The economic analysis for the ground source heat pump follows the same course as for the atmospheric heat pump.

The mean summer and winter temperature must be determined. The mean winter temperature will be the average temperature of all the months the heating system is expected to be turned on. The mean summer temperature will be the average temperature of all the months the cooling system is expected to be turned on. These figures will be used to calculate the mean difference in temperature between the outside and inside of the building while the heating and cooling systems are in operation. This model will assume the heating and cooling systems will each be turned on 6 months out of the year. It should be noted that this figure will vary from household to household and from location to location. These figures may be obtained from the National Weather Service. Next, heat load calculations must be done. First obtain the total exposed wall surface area less doors and windows. In rooms where there are windows and doors, calculate the percent area of doors and windows for all walls where there are doors and windows. Multiply this figure by the total wall space containing windows and doors. This will be the total window and door area. Next, calculate the total ceiling area and floor area that is exposed to the outside.

In most cases, these figures will be equal. Finally, determine the R-value for the walls, ceilings, floors and doors and windows. Armed with these figures, the heating and cooling load calculations are next. Equation 4-34 calculates the mean difference between the outside and inside temperature for the heating system.

$\Delta T_W = T_{in} - T_{ow}$ Equation 4-34

ΔT_W annual mean difference between outside and inside winter temperature in ºF

T_{in} inside temperature in ºF

T_{ow} mean outside winter temperature in ºF

Equation 4-35 calculates the mean difference between the outside and inside temperature for the cooling system.

$\Delta T_S = T_{in} - T_{os}$ Equation 4-35

ΔT_S annual mean difference between outside and inside summer temperature in ºF

T_{in} inside temperature in ºF

T_{os} mean outside summer temperature in ºF

Equation 4-36 [33] calculates the heat load for the heating system.

$Q_H = I_{68}\Delta T_W/I_{72} + I_{69}\Delta T_W/I_{73} + I_{70}\Delta T_W/I_{74} + I_{71}\Delta T_W/I_{75}$ Equation 4-36

Q_H winter heating load in Btu/hr.

Equation 4-37 [33] calculates the average heating electrical energy requirements of the ground source heat pump system.

$E_{T4} = Q_H/I_{67}/1000$ Equation 4-37

E_{T4} mean electrical energy consumed by the heating system in kW-h.

Q_H winter heating load in Btu/hr.

Equation 4-38 calculates the annual electrical energy requirement of the ground source heat pump system during winter months.

$$E_{AGW} = E_{T4}*4380 \quad \text{Equation 4-38}$$

Equation 4-39 [33] calculates the cooling load for the cooling system.

$$Q_C = I_{68}\Delta T_S/I_{72} + I_{69}\Delta T_S/I_{73} + I_{70}\Delta T_S/I_{74} + I_{71}\Delta T_S/I_{75} \quad \text{Equation 4-39}$$

Q_C summer cooling load in Btu/hr.

Equation 4-40 [33] calculates the average heating electrical energy requirements of the ground source heat pump system.

$$E_{T6} = Q_C/I_{67}/1000 \quad \text{Equation 4-40}$$

E_{T6} mean electrical energy input to cooling system in kW-h.

Q_C summer cooling load in Btu/hr.

Equation 4-41 calculates the annual electrical energy requirement of the ground source heat pump system during summer months.

$$E_{AGS} = E_{T6}*4380 \quad \text{Equation 4-41}$$

Equation 4-42 calculates the total annual electrical energy requirement for the ground source heat pump.

$$E_{AGT} = E_{AGW} + E_{AGS} \quad \text{Equation 4-42}$$

Equation 4-43 [32] calculates the annual electrical energy requirements for the unit replaced.

$E_{ARU} = (Q_H+Q_C)/I_{81}/1000*4380$ Equation 4-43

E_{ARU} Annual electrical energy requirement of the replaced heating system

Equation 4-44 calculates the annual cost savings from the electricity usage reduction.

$E_{CS6} = (E_{ARU} - E_{AGT})I_{76} – I_{79}$ Equation 4-44

Next, the annualized cost of the ground source heat pump system must be calculated. This calculation is performed in equation 4-45.

$C_{A5} = (I_{77} – I_{78})/I_{80} + I_{79}$ Equation 4-45

The consumer should then compare the cost savings calculated in equation 4-44 with the annualized cost calculated in equation 4-45. If the result obtained in equation 4-45 is larger than that obtained in equation 4-44, do not go any further. The equipment under consideration is not cost effective. If the savings calculated in equation 4-44 is greater than the result calculated in equation 4-45, the following calculation obtained from equation 4-5 & 4-6 [31] should be considered. Equations 4-5 & 4-6 calculate the Internal Rate of Return (IRR). If the considered investment in a ground source heat pump system is greater than this 10%, then the heat pump system will be the better investment. Utilizing equation 4-5 with the following inputs, the internal rate of return R is calculated

$PV = I_{77}– I_{78}$

$FV = E_{CS6} – I_{79}$

$N = I_{80}$

R = Internal Rate of Return

In an iterative process of selecting (guessing) an IRR (R) and calculating the NPV, the IRR is found when the NPV becomes zero. This is symbolized in Equation 4-6.

Equation 4-46 calculates the payback period.

$P = (I_{77} - I_{78})/(E_{CS6})$ Equation 4-46

The above model development for the ground source heat pumps makes the assumption that the unit being replaced is a normal heat pump using only electricity as its power source. However, in some locations, an alternate type of unit called a "gas-pack" is used. These units combine the use of both gas and electricity to heat and cool the building, and the gas may be either natural gas (NG) or liquid propane (LP). If this is the case, equation 4-44 changes to the following alternate equation 4-47.

$E_{CS6} = (4380Q_H I_{82}/1050000/I_{81} + 4380Q_H I_{83}/2500000/I_{81}) - (4380Q_H I_{82}/1050000/I_{67} + 4380Q_H I_{83}/2500000/I_{67}) + (4380Q_C/1000/I_{82} - 4380Q_C/1000/I_{67})I_{76} - I_{79}$ Equation 4-47

To properly use this equation, if the building is supplied with natural gas, the correct price for natural gas (NG) should be entered as I_{82} and zero entered for the price of liquid propane (LP) gas. If the building is supplied with LP gas, a zero should be entered as the price for NG and the correct price entered for LP. The correct price per kW-h. of electricity should be input as I_{76}.

Comprehensive Element Model

Since five green energy devices are considered in this economic model, a comparison must be made to determine which of up to five different green energy devices is the best choice. In some cases it may be advantageous to consider two different types of green energy devices.

Since it would generally not make sense to consider two different types of heating systems, selection of two different types of green energy devices is restricted to a power source such as wind and a heating/cooling source (HVAC) device. In a few rare circumstances, this might make sense. However, in general, the savings created by one green energy device become redundant to the other. For this reason, it is normally not cost effective to combine two different green energy devices such as these solely for cost benefit. To determine if this is the case, use equation 4-5. Now PV is the sum of both total purchase and installation costs minus tax credits. FV can at most be the total utility cost minus total maintenance costs for both green energy devices over the shortest lifetime of the two devices under consideration. This would be the most complex calculation performed by the CEM, and will in most cases not be required. The main function of the CEM is to compare all IRRs of the equipment considered and pick the highest one. Compare this with the 10% equities rate to see if it makes sense to invest in any of the choices. In addition, the customer should also pay attention to the payback period calculation. If this figure gets over 10 years, serious thought needs to be given to how long the customer plans on living in the house.

This comprehensive element model together with the five sub element models make up the total green energy economic viability model. This model should provide an energy consumer with all the information required to make an informed and accurate economic decision about investing or not investing in residential green energy equipment.

CHAPTER 5

RESULTS, CONCLUSIONS AND RECOMMENDATIONS

Overview of Results

Chapter 4 developed a model to allow residential homeowners and business owners to assess the economic viability of investing in and installing one or more of five different green energy products and implementing this model in MS Excel. Subjects that have previously invested in this equipment were surveyed to test the model. The five categories of green energy products surveyed are as follows: 1.) Wind energy systems, 2.) Photovoltaic energy systems, 3.) Direct solar heating systems, 4.) Atmospheric heat pump systems and 5.) Ground source heat pump systems.

Twenty-seven subjects were surveyed in the atmospheric heat pump systems category. Ten subjects were found and surveyed in the ground source heat pump systems category. Five subjects were found and surveyed in the photovoltaic energy systems category. And no subjects were found or surveyed in the wind energy systems category or direct solar heating systems category.

Before evaluating the statistics in each category to determine model confidence and accuracy, it is important to note the significance of the numbers surveyed. No people were found to survey in the wind energy systems category or the direct solar heating systems category. Let's look at each category separately.

After discussing this with wind energy systems contractors and county permitting agencies and referring to Chapter 2 of this dissertation, it was found that severe restrictions are placed on the installation of wind turbines in most North Carolina counties. For example in most counties the wind turbine cannot be sited closer than 100 to 130 percent of the wind turbine's height. This restriction prevents the installation of many wind turbines on land less than 2 acres. Other restrictions include outright bans on the installation of wind turbines in some counties or communities because they are considered unsightly or noisy. Still other counties forbid their installation due to environmental concerns such as avian impacts. These severe restrictions have discouraged many homeowners or small business owners from considering the installation of wind energy systems or wind turbines. For these reasons the data (or lack of data) shows that wind energy systems are not a viable candidate for this dissertation research.

Heating ventilating and air conditioning (HVAC) contractors were consulted as to the reason that nobody has installed direct solar heating systems in their existing home. It was determined by discussing this subject with these contractors that installing a direct solar heating system in an existing home is totally cost ineffective. For example, a direct solar heating system was installed in a new home of about 6000 ft^2. The installation cost was about $80,000. An equivalent atmospheric heat pump system or gas pack could have been installed for about one fourth of that cost. Feedback from contractors suggests that people who install direct solar heating systems are doing it for other reasons than economics. For these reasons direct solar heating systems do not fall within the intent of this dissertation.

Twenty-seven subjects were selected and surveyed in the atmospheric heat pump systems category. More subjects could have been surveyed but it was determined that this was a sufficient number to achieve a 90% confidence of survey accuracy. This should be expected because atmospheric heat pumps have been a standard form of heating ventilating and air-conditioning systems for many years. They were included in the survey and model as a benchmark for the model.

Ten subjects were found and surveyed in the ground source heat pump system category. This number was significant enough to indicate that ground source heat pumps can be economically viable.

Five subjects were found and surveyed in the photovoltaic energy systems category. This number was significantly less than the ten desired and is not a large enough number to successfully test the model. This number suggests that photovoltaic systems are marginal in terms of their economic viability.

The next step in the evaluation of the economic viability model developed in Chapter four is to perform a statistical analysis of the data collected in each of the three categories where data was found. Each category will be evaluated individually. Winter and summer utility bill cost data was collected for one year prior to and after installation of the green energy equipment. The cost data after installation was subtracted from the cost data before installation to calculate actual cost savings from installing the green energy equipment. If any of these cost figures was negative, a loss would be indicated instead of savings. In all cases for all categories, no loss data was found. This savings data may be found in column 2 of Tables 2, 4, and 7. Technical and cost information such as the home size and equipment specifications, equipment cost and tax credits obtained from the survey data are used by the model to calculate predicted cost savings, present value, rate of return and payback period to be used by prospective buyers of such green energy products to aid them in making a credible decision about the purchase. The model predicted cost savings is shown in column 3 of Tables 2, 4, and 7. Columns 4 and 5 of these tables show model error and percent error. Internal Rates of Return and payback periods are found in Tables 2, 5, and 6.

The statistical analysis of the model's ability to predict the economic viability of purchasing green energy products in one of the three categories where the population is large enough to make the model test practical begins with a null hypothesis H_0: It is possible to predict cost savings from installing alternative energy products in a family dwelling, and an alternate hypothesis H_a: It is not possible to predict cost savings from installing alternative energy products in a family dwelling. This hypothesis must then be tested in each of the three green energy categories.

Summary of Results for Photovoltaic Equipment

Table 2 summarizes the statistical analysis of the model's economic viability predictive ability with Photovoltaic energy production equipment.

Table 2: Statistical analysis of model response to photovoltaic equipment

	Actual savings	Predicted savings	Model error	% error
Client 1	$1,872.00	$1,585.48	($286.52)	15.31%
Client 2	$564.00	$447.36	($116.64)	20.68%
Client 3	$984.00	$1,166.11	$182.11	18.51%
Client 4	$1,524.00	$1,578.51	$54.51	3.58%
Client 5	$1585.92	$1836.98	$51.06	3.22%
Mean	$1,305.98	$1,282.89	-$23.10	12.26%
std. dev.	$469.14	$450.79	$162.34	7.43%

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	1305.984	1282.888
Variance	275120.8	254019.9
Observations	5	5
Hypothesized Mean Difference	0	
df	8	
t Stat	0.0709964	
P(T<=t) one-tail	0.4725717	
t Critical one-tail	1.859548	
P(T<=t) two-tail	0.9451434	
t Critical two-tail	2.3060041	

The t-test from Table 2 confirms the null hypothesis that it is possible to predict cost savings from installing alternative energy products in a family dwelling. However, the mean percent error of 12.26% with a standard deviation of 7.43% suggests that more samples are needed to give more precision (repeatability) to the result.

Table 3 shows the model predictions for the surveyed clients. These predicted internal rates of return and payback periods suggest that economic viability of photovoltaic energy equipment is marginal even with a 65% tax rebate. When tax rebates are removed, photovoltaic energy equipment at the current installation prices will not be economically viable. Comments received from the survey subjects of this research indicate that most people who do invest in photovoltaic energy equipment are not doing so for economic viability (cost savings) alone. Most have their own personal reasons for investing in photovoltaic energy equipment. For example, one client used the tax rebate money to pay off high interest credit card debt and continues to pay the tax deductible low interest for the PV equipment.

Table 3: Model outputs from PV survey subjects

Survey Subject	Internal Rate of Return	Payback Period
Client 1	13.00%	7.25 yrs.
Client 2	4.00%	15.63 yrs.
Client 3	9.00%	10.13 yrs.
Client 4	9.00%	9.87 yrs.
Client 5	4.00%	15.45 yrs.

Summary of Results for Ground Source Heat pump Equipment

Table 4 summarizes the statistical analysis of the model's economic viability predictive ability with Ground Source heat pump equipment.

Table 4: Statistical analysis of model response to ground source heat pump equipment

	Actual Savings	Predicted savings	Model error	% error
Client 1	$240.00	$250.73	$10.73	4.47%
Client 2	$420.00	$344.72	($75.28)	17.92%
Client 3	$210.00	$169.73	($40.27)	19.18%
Client 4	$336.00	$299.97	($36.03)	10.72%
Client 5	$132.00	$130.99	($1.01)	0.77%
Client 6	$330.00	$270.98	($59.02)	17.88%
Client 7	$432.00	$344.15	($87.85)	20.34%
Client 8	$240.00	$204.53	($35.47)	14.78%
Client 9	$228.00	$215.59	($12.41)	5.44%
Client 10	$276.00	$268.55	($7.45)	2.70%
Mean	$162.28	$146.06	($15.76)	11.93%
Standard Deviation	$89.93	$67.06	$30.88	7.14%

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	284.4	249.994
Variance	8985.6	4997.347
Observations	10	10
Hypothesized Mean Difference	0	
df	17	
t Stat	0.9201	
P(T<=t) one-tail	0.185197	
t Critical one-tail	1.739607	
P(T<=t) two-tail	0.370393	
t Critical two-tail	2.109816	

The t-test from Table 4 confirms the null hypothesis that it is possible to predict cost savings from installing alternative energy products in a family dwelling. However, the mean percent error of 11.93% with a standard deviation of 7.14% suggests that more samples are needed to give more precision (repeatability) to the result. It is also worth noting that 10 samples were taken in this category. This is five more than in the photovoltaic category, yet the standard deviation only improved by about .3. This was investigated to see if other factors could be influencing the utility bill costs besides the change from standard equipment to more energy efficient “green energy” equipment. A number of factors were found that could influence the difference in utility bill cost between before the installation of the ground source heat pump and after the installation. There are three factors that stand out as probable causes:

1. Many ground source heat pumps have an extra feature available allowing the energy recovered from the ground to also heat water, thus saving on electricity used to heat water in the home.
2. Weather – extremes in weather such as an extremely cold winter or hot summer can influence the utility bill cost.
3. Home population change – often, if the home population includes high school age people leaving the home, utility bill costs will reduce after they have left.

These factors were not taken into account during the survey process.

Table 5 shows the model predictions for the surveyed clients. The surveyed equipment yielded an 18.6% average rate of return which is 8.6% better than the accepted stock market long term rate of return. The average payback period predicted by the model is 6.64 yrs. These figures show that with 65% tax rebates, ground source heat pump equipment is very cost effective and economically viable. It also showed a wide variation of rates of return from 5% to 38% largely due to the significant 65% tax rebate nearly offsetting the difference between the ground source heat pump cost and the cost of replacing existing HVAC equipment. Just to illustrate this tax rebate effect, the model was exercised without tax rebate. These figures are shown in Table 6.

Table 5: Model outputs from Ground source Heat pump survey subjects

Survey Subject	Internal Rate of Return	Payback Period
Client 1	12.00%	7.26 yrs.
Client 2	30.00%	3.84 yrs.
Client 3	5.00%	12.88 yrs.
Client 4	13.00%	7.00 yrs.
Client 5	5.00%	12.08 yrs.
Client 6	11.00%	8.03 yrs.
Client 7	38.00%	2.64 yrs.
Client 8	18.00%	5.27 yrs.
Client 9	25.00%	3.94 yrs.
Client 10	29.00%	3.41 yrs.

Table 6: Model outputs from Ground source heat pump survey subjects without the 65% tax rebate included

Survey Subject	Internal Rate of Return	Payback Period
Client 1	-7.00%	45 yrs.
Client 2	-6.00%	42.21 yrs.
Client 3	-13.00%	122.38 yrs.
Client 4	-7.00%	48.15 yrs.
Client 5	-13.00%	121.97 yrs.
Client 6	-7.00%	45.32 yrs.
Client 7	-6.00%	42.89 yrs.
Client 8	-7.00%	44.78 yrs.
Client 9	-6.00%	39.47 yrs.
Client 10	-6.00%	41.20 yrs.

It may be easily noticed from Table 6 that without the 65% tax rebate, investing in ground source heat pump technology is not economically viable. Worse yet, the negative rates of return indicate that investing in ground source heat pump technology is a losing investment. The significant cost that renders this form of green energy not economically viable is the high cost of drilling the well or digging the trench for the heat exchange pipe. If these costs were to drop considerably and even more significant gains in efficiency are realized, these devices may be able to stand on their own as economically viable HVAC equipment. But as of the time of this research, they cannot and must be judged not economically viable without the 65% tax rebates currently allowed by the state of North Carolina and the federal government.

Summary of Results for Atmospheric Heat pump Equipment

Table 7 summarizes the statistical analysis of the model's economic viability predictive ability with atmospheric heat pump equipment. This analysis was performed as a baseline for comparing other less popular alternative (green) energy sources. As with the photovoltaic energy equipment and ground source heat pump equipment category, the t-test from Table 7 confirms the null hypothesis that it is possible to predict cost savings from installing alternative energy products in a family dwelling. It should also be noted that the mean percent error in all categories ranges from 11.93% to 13.91% which is fairly consistent. The standard deviation of the percent error is considerably lower for the atmospheric heat pump category than it is for the photovoltaic and the ground source heat pump equipment. This may be attributable to the larger sample size for the atmospheric heat pump category.

Table 8 shows the model predictions of rates of return and payback periods for the atmospheric heat pump category. It is important to note that these predictions are without tax incentives since no tax incentives are given to purchasers of atmospheric heat pumps. The average rate of return for this category is 22.3%. Clearly, the upgrading of atmospheric heat pumps is economically viable even if tax rebates are not offered.

Table 7: Statistical analysis of model response to atmospheric heat pump equipment

	Actual Savings	Predicted Savings	Model error	% error
Client 1	$126.00	$115.84	-$10.16	8.06%
Client 2	$30.00	$29.37	-$0.63	2.10%
Client 3	$180.00	$160.34	-$19.66	10.92%
Client 4	$48.00	$53.14	$5.14	10.71%
Client 5	$42.00	$60.43	$18.43	43.88%
Client 6	$66.00	$65.41	-$0.59	0.89%
Client 7	$96.00	$85.68	-$10.32	10.75%
Client 8	$66.00	$75.43	$9.43	14.29%
Client 9	$60.00	$82.38	$22.38	37.30%
Client 10	$72.00	$82.38	$10.38	14.42%
Client 11	$66.00	$52.89	-$13.11	19.86%
Client 12	$48.00	$52.89	$4.89	10.19%
Client 13	$54.00	$52.89	-$1.11	2.06%
Client 14	$72.00	$54.07	-$17.93	24.90%
Client 15	$130.86	$124.82	-$6.04	4.62%
Client 16	$90.00	$64.51	-$25.49	28.32%
Client 17	$60.00	$64.92	$4.92	8.20%
Client 18	$44.52	$68.99	$24.47	54.96%
Client 19	$84.00	$64.51	-$19.49	23.20%
Client 20	$78.00	$78.40	$0.40	0.51%
Client 21	$60.00	$62.25	$2.25	3.75%
Client 22	$84.00	$87.17	$3.17	3.77%
Client 23	$102.00	$93.67	-$8.33	8.17%
Client 24	$108.00	$89.41	-$18.59	17.21%
Client 25	$78.00	$75.31	-$2.69	3.45%
Client 26	$90.00	$87.70	-$2.30	2.56%
Client 27	$108.00	$100.91	-$7.09	6.56%
Mean	$79.38	$77.25	-$2.14	13.91%
Standard Deviation	$16.35	$11.78	$6.88	4.74%

t-Test: Two-Sample Assuming Unequal Variances

	Variable 1	Variable 2
Mean	79.38444	77.24852
Variance	1041.667	706.0509
Observati	27	27
Hypothesi	0	
df	50	
t Stat	0.26548	
P(T<=t) on	0.395865	
t Critical o	1.675905	
P(T<=t) tw	0.791731	
t Critical t	2.008559	

Table 8: Model outputs from Atmospheric Heat pump survey subjects

Survey subject	Internal Rate of Return	Payback Period
Client 1	19.00%	5 yrs.
Client 2	5.00%	12.8 yrs.
Client 3	7.00%	10.8 yrs.
Client 4	13.00%	7.08 yrs.
Client 5	8.00%	9.58 yrs.
Client 6	14.00%	6.70 yrs.
Client 7	4.00%	11.56 yrs.
Client 8	37.00%	2.69 yrs
Client 9	41.00%	2.46 yrs.
Client 10	41.00%	2.46 yrs.
Client 11	5.00%	12.86 yrs.
Client 12	26.00%	3.84 yrs.
Client 13	13.00%	7.11 yrs.
Client 14	26.00%	3.75 yrs.
Client 15	2.00%	16.92 yrs.
Client 16	14.00%	6.79 yrs.
Client 17	32.00%	3.13 yrs.
Client 18	3.00%	15.31 yrs.
Client 19	16.00%	5.83 yrs.
Client 20	39.00%	2.59 yrs.
Client 21	16.00%	6.04 yrs.
Client 22	43.00%	2.33 yrs.
Client 23	9.00%	8.88 yrs.
Client 24	14.00%	6.48 yrs.
Client 25	19.00%	4.99 yrs.
Client 26	43.00%	2.31 yrs.
Client 27	94.00%	1.05 yrs.

Conclusions

A model was developed to assess the economic viability of installing green energy products in five different categories in a family dwelling. The model was statistically tested by surveying 42 survey subjects and performing a t-test to confirm or refute the null hypothesis that it is possible to predict cost savings from installing alternative energy products in a family dwelling. The t-test confirmed the null hypothesis. Five categories of alternative (green) energy products were targeted:

1. Wind energy production
2. Photovoltaic energy production
3. Direct solar heating
4. Ground source heat pumps
5. Upgrading Atmospheric heat pumps from 13 EER to 15 EER

Categories 1 and 3 were not evaluated due to the extremely small population. Categories 2, 4 and 5 were evaluated for economic feasibility. The economic feasibility of category 2 was found to be marginal at best with a 65% tax break and not feasible at all without the tax break. Category 4 was found to be economically feasible with a 65% tax break and not economically feasible without the 65% tax rebate. Category 5 was found to be economically viable even without the 65% tax rebate.

Much social and political pressure exists to transition to alternative energy products, to reduce the carbon footprint, be environmentally friendly and ‘go green’. Much research and development is currently being done in this area and the wisdom of continuing in this direction is well established. However, the economic viability of a wide spread consumer transition to these areas within the narrow scope of this research is not established. The atmospheric heat pump is the only form of alternative ‘green’ energy that demonstrated economic viability in this research. This result is consistent with the maturity of this technology since it has been in common use for at least 30 years and is therefore a proven technology. This was a compelling reason to use it as a benchmark in this research for the other categories of less mature technology.

Limitations of the Study

The survey population in this research was limited to North Carolina. This resulted in a sample size of 42. Although this sample size was adequate to test the model and confirm the hypothesis that the model can make reasonable economic viability predictions, it was not sufficient to thoroughly test the model in a variety of conditions and individual sample sizes of specific ‘green’ equipment were not large enough to make the most precise predictions the model proved to be capable of. Additionally, other factors such as weather anomalies like colder than normal winters and hotter than normal summers cannot be smoothed out by only looking at one year of data before and after the installation of the equipment.

The hot water heating capability of some ground source heat pumps was not taken into account by the model and also limited the model’s effectiveness. Other features are being added to green energy products every year to enhance their efficiency and improve the equipment’s overall performance. Such improvements are not taken into account in the model developed in this research and will limit this model’s future effectiveness.

It was also apparent that cultural bias existed from the limited geographical population. This was clear with the wind energy system category resulting in a sample size of zero in that category.

Recommendations and Future Research

Future research in this area should expand the sample population to include all 50 states in the country. A larger population will produce larger sample sizes in a wider variety of climactic conditions that will test the model more thoroughly. Sampling in the bright cloudless intense heat of Arizona and by contrast, sampling in the pacific northwest in Washington state will test the model in climate extremes as well as moderate climate.

Weather anomalies may be smoothed out by extending the utility bill survey time from one year before and one year after to five years before and five years after installation of the alternative energy products. It may not hold true that the longer the time frame for surveying utility bills the more accurate the model test. The lifetime of equipment and other changing factors may conclude that a sweet spot exists for the length of time to survey utility bills. This may be investigated in future research.

Cultural bias such as that encountered with wind energy systems in North Carolina should also be mitigated since other states may not have the same cultural biases against the implementation of wind energy devices as North Carolina. This will open up the entire green energy research field and broaden green energy modeling capability.

The effects of more robust model testing will no doubt lead to more robust green energy models that will serve to more accurately guide the development of more cost effective as well as more efficient green energy products. This can only help to reduce barriers and contribute to expanding the availability of energy to all of us to meet our present and future energy needs.

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APPENDIX A: Restrictions on installing a wind turbine in Tyrell County, NC

Permitting Process: All new wind energy facilities, or expansions of existing facilities must receive a permit from the County Planning Board prior to construction. A permit application must include a narrative describing the facility; approximate generating capacity; the proposed number and height of all wind turbines to be built; location of the proposed site and names and addresses of all adjoining property owners; a detailed site plan; certification of compliance with Federal Aviation Administration (FAA) regulations; decommissioning plans; and financial assurance that the owner can pay for decommissioning.

Height Requirements: The total height of a wind turbine is determined by the height above grade to the tip of the turbine blade as it reaches its highest elevation. Small wind systems are restricted to a 120-foot height limit, whereas medium and large systems are restricted to a 250-foot height limit, and utility scale systems are restricted to a 500-foot limit.

Setbacks: The setback is calculated by multiplying the required setback number by the wind turbine height and measured from the center of the wind turbine base to the property line, building or road. Setbacks are generally determined by the following table:

Wind Energy Facility Type	Occupied Buildings on System Owner's Property	Occupied Buildings on Adjacent Property	Property Lines and Right-of-Ways	Highway 64
Small Facility	0.0	1.5	1.1	1.5
Medium Facility	1.1	2.0	1.5	1.5
Large System	1.1	2.5	1.5	1.5
Utility Scale	1.1	2.5	1.5	1.5

Noise and Shadow Flicker: Noise and shadow flicker issues for small and medium wind energy facilities are addressed by setbacks, or will be addressed by existing noise ordinances. Audible sound from a large or utility scale wind energy facility should not exceed fifty-five dBA, as measured at any occupied building of a non-participating landowner. Shadow flicker at any occupied building on an adjacent property caused by a large or utility scale wind energy facility located within 2,500 ft of the building shall not exceed thirty hours per year. These restrictions may be waived under certain conditions.

Installation and Design: The installation of wind energy facilities must conform to all applicable industrial standards, including those of the American National Standards Institute. All structural, electrical and mechanical components for the facility must conform to relevant local, state and federal codes. Towers and rotor blades must be of a non-obtrusive color approved by the County Planning Board. Wind energy facilities must also remain free from advertising, including flags, streamers and other decorative items, as well as artificial lighting, except that which is required by the Federal Aviation Administration (FAA). Any on-site transmission or power lines must, to the extent possible, be placed underground.