

2007

## Residential energy efficiency: socioeconomic importance, net-zero design, and existing building retrofits

Gregory Sullivan Raffio  
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Residential Energy Efficiency: Socioeconomic Importance, Net-Zero Design, and  
Existing Building Retrofits

Thesis

Submitted to

School of Engineering

UNIVERSITY OF DAYTON

In partial fulfillment of the requirements for

The degree

Master of Science in Mechanical Engineering

By

Gregory Sullivan Raffio

UNIVERSITY OF DAYTON

Dayton, Ohio

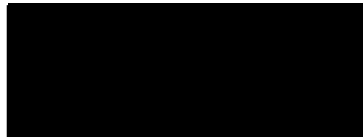
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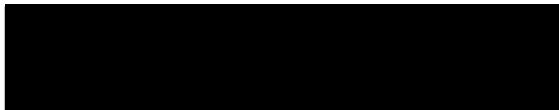
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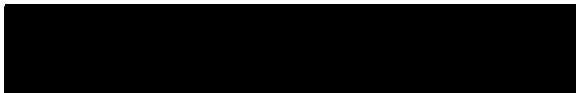
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## Acknowledgements

George Mertz: George was my design partner throughout the entire Eco-house project and is my partner in crime in other aspects of life. George is the lead author on two of the papers used in this work and a significant amount of the design, analysis, and writing is his. This thesis deserves his name on it as much as it does mine.

Dr. Kelly Kissock: I thank my advisor/mentor/friend Dr. Kelly Kissock for the countless hours that he helps his graduate students revise, re-write and develop their papers, projects, and abilities as energy engineers. He has been a priceless part of the development of the UD Eco-house project and without him; we would have never come so far.

Drs. Kevin Hallinan and David Herrelko: Drs. Hallinan and Herrelko have been some of my closest mentors throughout my undergraduate and graduate careers and have provided me with support in countless areas of my education.

Dr. Dan Fouke: Dr Fouke has helped me to formulate the philosophical arguments used in the introduction of this work.

Aubrien King and Kevin Pattera: These two fine engineers were our partners in the initial design of the UD Eco-house project and provided a semester of their time performing great design and research.

John "Grandpa" Seryak: As a second year undergraduate in mechanical engineering, I met John, the founder of the UD Sustainability Club. His graduate thesis, his enthusiasm, and his crazy stories sparked my interest in energy efficiency in buildings and he is the reason that I am involved in this field today.

Carl W. Eger III, Charlie Schreier, Ovelio Isambert, Jacob Janczak, Kevin Carpenter, Rizwan Syed, Peter Kleinhenz, Daniel Trombley, Kazim Mirza and the entire past and present University of Dayton Industrial Assessment Center and Building Energy Center: The IAC and BEC staff have been influential in supporting the philosophy of sustainability at the University of Dayton and have blazed the trail that I have followed for many years. Their emotional and technical support has been an endless source of help in my day to day life.

Bruce Bullman and Brian Rudduck: Over the course of many years, Bruce and Brian have helped members of the UD-BEC to obtain information on and access to the entire university neighborhood. Without their help, most of our research would have been impossible.

Jim Blevins: As campus energy manager, Jim has been an extremely valuable tool for accessing data within the university system and has provided many great ideas during the formulation of projects.

Carol Wilbanks: Without Carol, the entire UD MEE department would not move, no one would know what to do, and nothing would get accomplished.

Frank and Fran Swift: The Eco-house design is dedicated to this amazing couple who proved to be the only initial monetary donors of the Eco-house throughout its entire design and optimization effort. We would like to thank the Swifts for their inspiring enthusiasm for our project. Frank continues to help spread the message of sustainability and environmental stewardship in memory of Fran, who has passed away. If and when the house is built, it will be dedicated to her.

I would also like to thank my loving parents Marie and Michael, my inspiring brother Timothy, my best friend and girlfriend Alicia DiMarco, and the rest of my family, and friends not mentioned here for helping to make me the person that I am today. I am deeply thankful for their loving support, thoughtful discussion, and presence in my life.

## **ABSTRACT**

Residential Energy Efficiency: Socioeconomic Importance, Net-Zero Design, and Existing Building Retrofits

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University of Dayton, 2007

Advisor: Dr. Kelly Kissock

Resource constraints and environmental problems are major challenges facing the modern world. The natural limits of fossil fuels, clean water and land hinder the continued exponential growth of human population and economic activity. Global warming, deforestation, degradation of pristine wilderness, and the ever growing silence of extinct species are but a few of the woes of a wounded environment. If humanity truly desires to continue inhabiting its only planet, these problems must be met with creative solutions.

This thesis begins by discussing the socioeconomic advantages of residential energy-efficiency. This argument is followed by detailed descriptions of methods for reducing energy use in new and existing buildings. The potential for low-energy new buildings is demonstrated by two chapters describing the design of the net-zero energy University of Dayton Eco-house. The potential for improving the energy efficiency of



existing buildings is demonstrated in the next two chapters. First, a four-step method to analyze utility bills and weather data from multiple residences to target existing buildings for specific energy conservation retrofits is described. Finally, a residential building audit and its recommendations are shown to demonstrate the effectiveness of energy assessments at reducing energy use in existing buildings.

# Chapter 1

## Introduction

Kant's theory of deontological ethics poses guidelines for human ethical behavior. Kant claims that persons have rights and that they all have categorical duties to avoid actions that would deprive persons of the full exercise of their rational autonomy and to do those things which promote it. Kant also emphasized that these are not *contingent duties*, which only need to be carried out under certain empirical circumstances, but *categorical duties*, which always need to be carried out, because they are based on a priori reasoning about the general nature of things, and thus apply no matter what the circumstances are. Kant thought of the duty to promote human freedom and rationality as the only truly categorical duty [1-1].

Humans need not scrutinize Kant to understand ethics if they just look at world-wide commonly accepted moral consensus. Kant's ethics and similar theories of rights and duties have widely influenced law and moral thinking. The function of government and government policy is to enable collective action to solve problems and enable cooperation. For example, financial incentives such as low-interest loans, block-grants, subsidies, taxes and establishing market-tradable permits are tools of government to encourage socially beneficial behavior. In regards to sustainability, Kant would argue that local, federal, and global policy must be developed to encourage sustainability in many ways.

In contrast, in a speech On April 30, 2001 before the Associated Press in Toronto, Ontario, Vice President Dick Cheney said that “conservation may be a sign of personal virtue, but it is not a sufficient basis all by itself for a sound, comprehensive energy policy”. Kant would argue that conservation is, in fact, a categorical duty of justice not to infringe on the rights of future persons. According to Kant, we have a strict duty not to deprive them of the resources required for lives at least as meaningful and fulfilling as our own. This thesis adopts the Kantian viewpoint that sustainability ought to be a driving force for human decision making.

This thesis discusses residential energy efficiency as a first and important step to help achieve sustainability. Chapter 2 explains the socioeconomic importance of residential energy efficiency, describes sustainability and why we should care about it, and shows ways that residential energy efficiency can help move society toward sustainability. Chapters 3 and 4 discuss the University of Dayton Eco-house from its conceptual design, through cost-benefit analysis, and pending construction<sup>1</sup> [1-2, 1-3].

These chapters demonstrate that new buildings can be designed to use little or no net energy. The cost-effectiveness and energy-effectiveness of energy retrofits of existing buildings are the topics of Chapters 5 and 6. Chapter 5 discusses a method to effectively target existing structures for retrofit to significantly reduce their energy use. Chapter 6 contains a case study example of the energy assessment on a residential

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<sup>1</sup> The Eco-house improves upon the E/3 design, developed at UD in 2002, to attain a true net-zero energy home. Once the conceptual design was presented to UD officials, they began to work with the design team to bring the house to life. Over the course of two years, the design process went through a full fledged design process and contractual bidding. Since February of 2006, the house design and construction process went into bureaucratic limbo during which the parties involved quarreled about budget, design, and contractor issues. As of February 2007, the UD has begun a new bid process with the intent of constructing the Eco-house on campus during the summer of 2007.

building. The full documentation of other case studies by the University of Dayton Building Energy Center (UD-BEC) may be found on the UD-BEC website [1-4]. Previous work is discussed within the various chapters.

## **Chapter 2**

### **The Socioeconomic Advantage of Residential Energy-Efficiency**

Resource constraints and environmental problems are major challenges facing the modern world. The natural limits of fossil fuels, clean water and land hinder the continued growth of human population and economic activity. Global warming, deforestation, degradation of pristine wilderness, and the ever-growing silence of extinct species are but a few of the woes of a wounded environment. If humanity truly desires to continue inhabiting its only planet, these problems must be met with creative solutions.

A prominent example of a global resource constraint is the peak of production of worldwide crude oil. In 1956, M. King Hubbert predicted that the United States would peak in oil production between 1965 and 1970. The actual peak occurred in 1971 [2-1]. Hubbert then predicted that the world would experience a similar peak in 2005 [2-2]. Modern scientists bracket the world oil peak between 2005 and 2040 [2-3, 2-4]. Calculations following Hubbert's method, done in a University of Dayton "Renewable Energy Systems" class place the world natural gas peak in 2025. The existence of these peaks, rather than the exact dates, is an extraordinarily important concept for people to understand. We live in a finite world.

Similarly, the capacity of the environment to absorb human activity is also limited. In February of 2007, the Intergovernmental Panel on Climate Change (IPCC) stated that, "global atmospheric concentrations of carbon dioxide, methane and nitrous

oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land-use change, while those of methane and nitrous oxide are primarily due to agriculture” [2-5]. The IPCC continues to show with a 90% certainty that human activity is impacting the environment in a way that threatens to affect species and ecosystems on a global level.

According to the Global Footprint Network, “humanity's ecological footprint is over 23% larger than what the planet can regenerate”. The GFN measures ecological footprint numbers in terms of global hectares (gha) per capita or in terms of how many “earths” it would take to support human lifestyles as they currently are. “For example, the average ‘earthshare’ available to each human citizen is approximately 1.9 gha per capita. The US average footprint is 9.5 gha per capita, and that of Switzerland 4 gha, while China's is circa 1.5 gha per head” [2-6]. Humanity is taxing the earth at an alarming rate.

If present modes of consumption and production continue, future generations may not have the raw natural resources, pristine land and seascapes, or natural ecological and biological services that people enjoy, appreciate, and require for our survival today. The biosphere cleans water, irrigates the land, balances oxygen and CO<sub>2</sub>, provides protection from ultraviolet rays, and keeps the earth between the freezing point and boiling point of water (a necessity for life). In Natural Capitalism, Amory Lovins states that “several recent assessments have estimated that biological services flowing directly into society from the stock of natural capital are worth at least \$36 trillion annually” [2-7]. When

compared to worldwide GDP of \$65 trillion annually, it can be concluded that natural services are incorrectly ignored in economic theory as externalities [2-8]. If economies actually took these services into account, countries would be buying, producing, and using everything differently.

Based on these observations, it is evident that modern lifestyles are inherently unsustainable. According to a report presented to the UN General Assembly, sustainability is development that meets the needs of the present without compromising the ability of future generations to meet their own needs [2-9]. In a purely deontological sense, one who does not act to promote sustainability is at fault of denying future generations of people their ability to be free and rational (mainly because they wouldn't be alive, or have sufficient resources to meaningfully exercise their rational autonomy).

A key stepping stone toward sustainability is to concentrate initial efforts on reducing energy use in buildings, which is important for many reasons. First, energy used in buildings makes up a significant portion of total energy use; thus, significant reductions in building energy use would also mean significant reductions in total energy use. Second humanity's historic construction of low-energy structures through intelligence in design and understanding local climates, shows that it is very possible. Third, reducing energy used in buildings is the first step in a highly effective inside-out approach to overall energy use reduction. Finally, research at the University of Dayton has shown that energy use in existing buildings can be significantly reduced and that net energy use in new buildings can be reduced to zero; both economically and through current technological means. These themes are further developed in the paragraphs that follow.

The largest use of energy is in buildings. According to the 2005 US Energy Information Administration (EIA) Annual Energy Review, the nation's energy use by sector was: Industrial (32%), Transportation (28%), Residential (22%), and Commercial (18%) [2-10]. Almost all energy used in residential facilities and over 75% of commercial energy use is directly used for space conditioning, water heating, lighting, appliances, and other building-related applications [2-11]. A large reduction in these areas of energy use would have a significant impact on national and international energy use. After such a reduction, the utilization of renewable energy sources becomes much more feasible.

The current approach to reducing energy use focuses on improving the energy efficiency of heating and cooling equipment. This approach is practical and important, but is even more effective when coupled with intelligent building design. In 400 BC Aristotle said, "In houses with a south aspect, the sun's rays penetrate into the porticos in winter, but in summer the path of the sun is right over our heads and above the roofs so there is shade. For well being and health... the homesteads should be airy in summer and sunny in winter. A homestead promising these qualities would be longer than it is deep and the main front would face south". Native peoples on America's plains understood the use of passive ventilation control and radiant heat. Entire cultures have survived the heat of southern Tunisia by constructing structures underground to make use of the thermal properties of the earth [2-12]. All these examples show that intelligent, energy-efficient design can be done throughout the world.

As humans began to exploit abundant, cheap sources of energy, such as natural gas and electricity, buildings began to incorporate fewer intelligent design characteristics.



Modern houses are constructed without enough windows, passive solar design is all but ignored, heating and cooling come from extensive fossil fuel use, and insulation thicknesses have decreased to but a few inches. The design process must be given more effort if humans seek to provide a sustainable future for generations to come.

The inside-out approach is a sequential method of analyzing opportunities for energy-efficiency improvements that begins by focusing on the eventual end use of the energy and proceeds outward to the distribution system and energy conversion equipment. Application of the inside out-approach has been shown to maximize savings while minimizing first cost [2-13]. The main reason for the success of the inside-out approach is the multiplicative effect of losses as energy is converted, distributed and used. It is most effective to begin at these end-use applications. For example, the combined efficiency of electricity generation and distribution from coal is around 33%. For every one unit of energy used in a building, three units of energy must be generated at the coal power plant to make sure that unit of energy gets to the house. An inside out analysis of energy systems defines the path for greatest overall energy and pollution reductions.

Research at the University of Dayton, which is described in this thesis, shows that significant energy reductions in residential buildings are possible. Moreover, they are also economically feasible. The American Housing Survey found that the median age of houses in the U.S. was 30 years, 25% of all U.S. houses are over fifty years old and 9% are more than 80 years old [2-14]. Because buildings have long lifetimes, long-term investments in residential buildings to reduce lifetime energy use can still be

economically advantageous. For example, the UD Eco-house will use no net energy while paying for itself over a 35 year investment lifetime [2-15].

Similarly, in regards to existing housing, the University of Dayton Building Energy Center conducted energy assessments for two houses; each over 60 years old. Combined retrofits for these two houses would provide over a 45% reduction in energy use with an 85% rate of return on the investment [2-16, 2-17]. In addition, previous work at the University of Dayton has shown that occupant behavior, not technical changes, can reduce natural gas use by up to 35% and electricity use by up to 29%, depending on the degree of occupant participation and house potential [2-18]. Thus, reducing energy use in residential buildings is economically advantageous.

In summary, improving building energy efficiency is an important and effective strategy for attaining sustainability. This thesis concretely demonstrates how to do so using intelligent design and state-of the art engineering. The following two chapters discuss the University of Dayton Eco-house from its conceptual design, through cost-benefit analysis, and pending construction. Chapter 5 discusses a method to effectively target existing structures for retrofit to significantly reduce their energy use. Chapter 6 contains a case study example of the energy assessment on a residential building.

## **Chapter 3**

# **Conceptual Design of Net Zero Energy Campus Residence**

### ***Introduction***

Much of the student housing for upperclassmen at the University of Dayton (UD) was built in the early 1900s as housing for factory workers. These houses have minimal insulation and high infiltration rates. Many units are in need of replacement. Currently UD spends over \$1 million per year on gas and electricity for the 400 houses in the student neighborhood. A significant portion of this cost is due to irresponsible energy practices. For example, students leave lights and computers on even when no one is home and leave doors and windows open even while heating or air conditioning [3-1].

In response to these global and local challenges, the University of Dayton is committed to building a net-zero energy student residence, called the Eco-house. Across the United States, different college campuses, businesses, and private citizens have built cutting-edge environmentally-focused buildings. Examples include the College of Law at the University of Denver, The Lewis Center for Environmental Studies at Oberlin College, the Rose House in Portland, Oregon, and the Zero Energy Habitat House in Loudon County, Tennessee. A neighborhood in Vista Montaña, California, developed in conjunction with the US Department of Energy (DOE) Building America research program, is successfully incorporating Zero-Energy Homes into a residential community.

DOE's goal is that a large number of new U.S. houses will be true net zero-energy homes by 2020 [3-2].

A common link between these buildings, besides meeting green or LEED building standards, is that they are principally designed by experienced builders and architects. In contrast, the design of the UD Eco-house is student driven. In accordance with UD's mission, interdisciplinary student teams from mechanical engineering, civil engineering and the humanities are leading the design effort. In addition, the completed Eco-house will be an environment for students to learn and live together in a positive, environmentally and socially conscious community. The Eco-house will also be a bridge between UD and several community partners, serving as a regional showcase of energy efficiency and green building practices for the community. The house will be extensively instrumented and monitored by students, and serve as a living experiment to guide the design of future generations of UD Eco-houses.

To achieve net-zero energy use, the Eco-house will be highly insulated and use high-efficiency appliances. Incorporation of geothermal and solar photovoltaic energy sources will result in zero net off-site energy use. Rain water will be collected and used to reduce municipal water consumption. The Eco-house will be constructed from environmentally-friendly materials.

This paper discusses the conceptual design of a net-zero energy use campus residence, and the analysis completed thus far. Energy use of current student houses is analyzed to provide a baseline and to identify energy saving opportunities. The use of the whole-system inside-out approach to guide the overall design is discussed. Using the inside-out method as a guide, the energy impacts of occupant behavior, appliances and

lights, building envelope, energy distribution systems and primary energy conversion equipment are designed to be radically smaller than those in a typical house. As a result, renewable energy or lower entropy generating sources can be utilized. The design of solar thermal and solar photovoltaic systems to meet the hot water and electricity requirements of the house is described. Eco-house energy use is simulated and compared to the energy use of the existing houses. Finally, conclusions are drawn and future work is noted. Detailed cost analysis and cost optimization have not been performed but are critical aspects of the UD Eco-house project, which will be performed in the future.

### ***Baseline: Current UD Housing***

In order to quantify savings from building an Eco-house, the energy use of current student houses must be understood. Most upperclassmen at the University of Dayton live in houses owned by the university. The houses fall into two categories. About 90% of the houses were constructed during the early 1900s. These older homes are wood-framed, with single-pane windows, no perimeter insulation, and little insulation in the walls and ceilings. As the university replaces these older units, new houses are being constructed with wood-frames, double pane windows, and fiberglass insulation in walls and ceilings. Both old and new houses will be used for comparison with the Eco-house.

The building practices described below are for the new houses. Walls consist of wood siding, 0.75-inch OSB sheathing, 2" x 4" wood stud frames built 16 inches on center with 4-inch fiberglass batt insulation, and ½-inch drywall on the interior surface. Assuming, winter convection coefficients, the R-value of the walls is about 13 hr-ft<sup>2</sup>-F/Btu. The double-hung windows are double-pane, with vinyl frames. The windows have an R-value of about 2 (hr-ft<sup>2</sup>-°F/ Btu) and an average solar heat gain coefficient

(SHGC) of about 0.531 [3-3]. The roof and ceiling consist of asphalt shingles, 0.75-inch OSB sheathing, attic space, 4-inch of fiberglass batt insulation, and drywall on the interior surface. The combined R-value of the roof and ceiling is about 16 hr-ft<sup>2</sup>-F/Btu [3-4]. A blower door test measured the rate of infiltration to be 0.62 air changes per hour [3-5]. The houses use 80% efficient natural gas furnaces and natural gas hot water heaters with an average efficiency of about 55%. The air conditioners have a SEER of 10 (Btu/Wh).

Monthly electricity use for four new five-person houses is shown in Figure 3-1. The electricity use patterns are highly variable due to irregular occupancy. After adjusting for occupancy, average annual electricity use in a regularly occupied, un-air conditioned house is about 11,400 kWh.

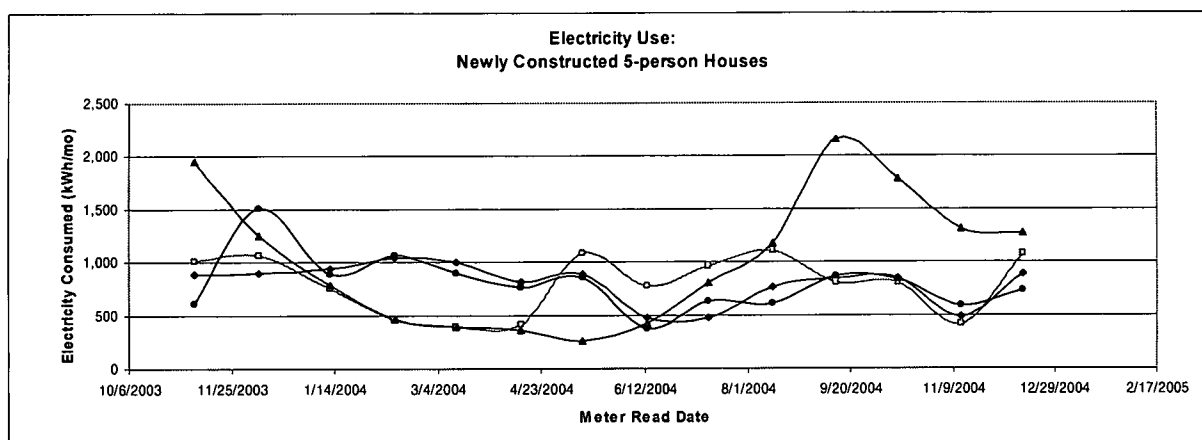


Figure 3-1. Electricity Use in Newly Constructed 5-person Houses.

Electrical appliances and lighting in the houses were inventoried and approximate operating hours were observed. The power draw of each type of electrical equipment was determined from nameplates and manufacturers data. Using this data, electricity use was broken down by equipment use and calibrated to match the 11,400 kWh measured

annual electricity use (Table 3-1). Summary characteristics of the new baseline houses are shown in Table 3-2.

Table 3-1: Equipment Electricity Use in Baseline House

Item	Unit Power (Watts)	Qty	Total Power (W)	Hours Operated (hrs/dy)	Operating Schedule (dys/yr)	Annual Energy Use (kWh/yr)
<b>Lighting</b>						
60 W Incandescent	60	17	1020	8	365	2,978
34 W T 12 4-foot 2-lamp flourescent	68	1	68	10	365	248
40 W Incandescent	40	5	200	5	365	365
<b>Total Lighting</b>						<b>3,592</b>
<b>Appliances</b>						
Electric Range	4100	1	4100	0.25	365	374
Dishwasher	1300	1	1300	0.25	365	119
Refrigerator	160	1	160	16.75	365	978
Washer	500	1	500	0.5	365	91
Dryer	5000	1	5000	0.5	365	913
Microwave	1300	1	1300	0.25	365	119
Toaster	1100	1	1100	0.1	365	40
George Foreman Grill	760	1	760	0.5	365	139
1/3-hp Fan	281	1	281	8	365	822
<b>Total Appliances</b>					365	<b>3,594</b>
<b>Electronics</b>						
Televisions	110	4	440	5	365	803
Stereos	30	4	120	1.5	365	66
Clocks	5	7	35	24	365	307
Computers	100	5	500	15.75	365	2,874
DVD Player/VCR	40	2	80	1.5	365	44
Gaming System	100	3	300	1	365	110
<b>Total Electronics</b>						<b>4,203</b>
<b>Total Electricity Use</b>						<b>11,389</b>

Annual and peak building energy use in a typical baseline house were simulated using the ESim building energy simulation software [3-6]. ESim simulates building energy use on an hour-by-hour basis using typical meteorological data [3-7]. ESim's building load calculations consider heat exchange through the building envelope, solar loads, internal sources of heat and humidity, and air exchange. ESim is appropriate for passive-solar, single-zone and large multi-zone buildings with sophisticated HVAC systems and controls. The computational algorithms are based on fundamental thermodynamic, psychrometric and heat-transfer calculations. Solar radiation on each

building surface is computed using the HDKR anisotropic sky model [3-8]. Energy-storage effects are considered using transfer-function and finite-difference algorithms. Primary equipment efficiencies take into account part loading and ambient conditions. The performance of important HVAC control systems such as night-setback thermostats, economizer cycles, hot-deck reset schedules and VAV controls can be simulated.

Table 3-2. Summary of Baseline House Characteristics

Awalls (ft <sup>2</sup> )	2,002
Awindows (ft <sup>2</sup> )	78
Aceiling (ft <sup>2</sup> )	938
Number of occupants	5
Conditioned Floor Area (ft <sup>2</sup> )	1600
Perimeter length (ft)	104
Rwalls (hr-ft <sup>2</sup> -F/Btu)	13
Rwindows (hr-ft <sup>2</sup> -F/Btu)	2
SHGC	0.531
Rperimeter_insulation (hr-ft <sup>2</sup> -F/Btu)	0
Rceiling_roof (hr-ft <sup>2</sup> -F/Btu)	16
Infiltration (air changes per hour)	0.62
Internal Loads (kWh/mo)	950
Temperature Setbacks	None
Furnace Efficiency	0.8
SEER Air Conditioner (Btu/Wh)	10

Figures 3-2 and 3-3 show simulated and actual electricity and natural gas use of a newly constructed five-person university house. The actual electricity use data is from a house without air conditioning; however, the simulation includes air conditioning since many new houses will be occupied during the summer and air conditioning will be used. Except for summer air conditioning, the simulations are well calibrated to the actual energy use data. Simulated electricity consumption is 13,455 kWh per year with air conditioning and simulated natural gas consumption is 61.2 mmBtu per year including heating and hot water.



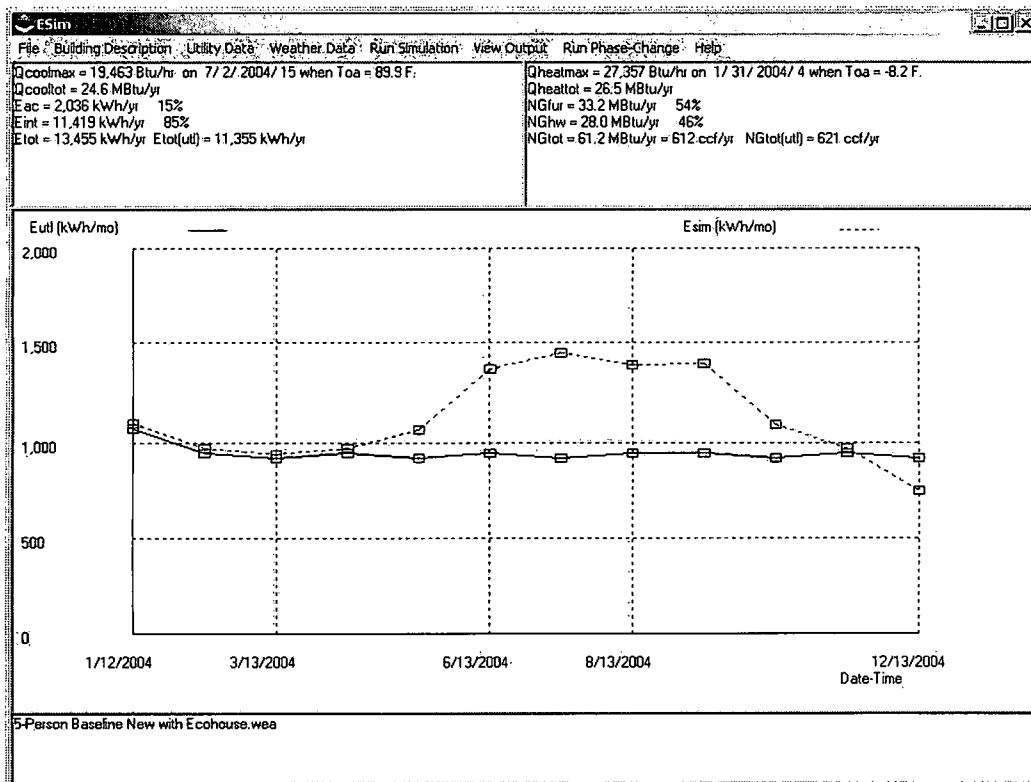


Figure 3-2. Baseline Electricity Use.

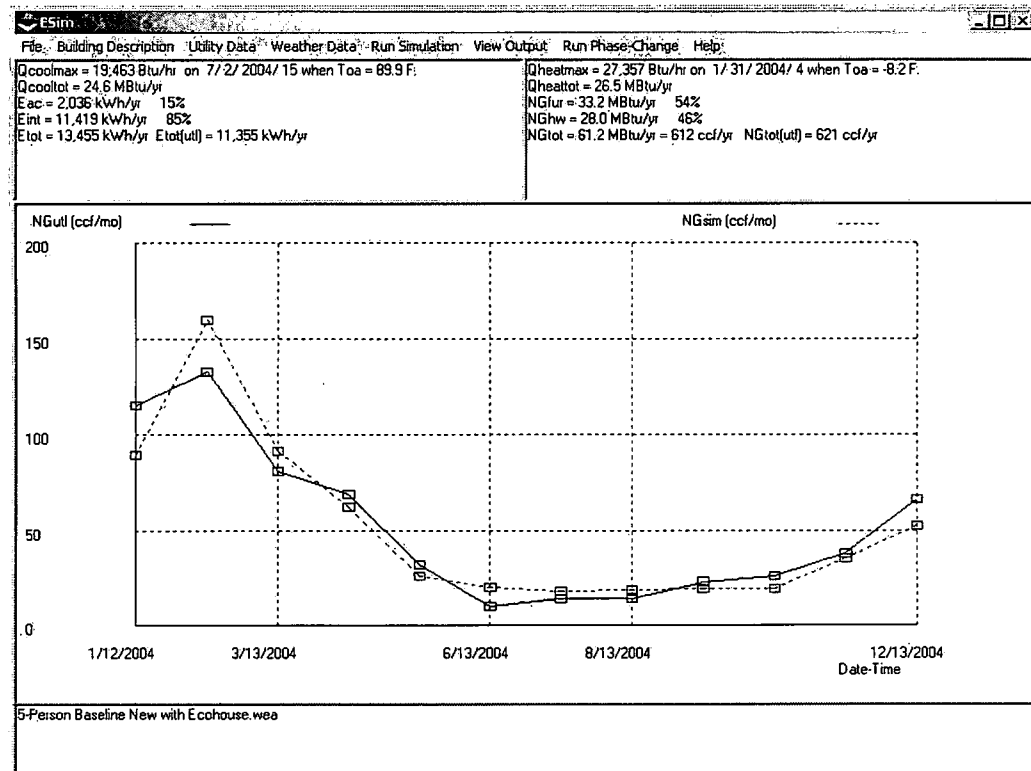


Figure 3-3. Baseline Natural Gas Use.

## ***Inside-Out Approach***

The inside-out approach is a structured method of analyzing opportunities for energy efficiency improvements that begins by focusing on the eventual end use of the energy and proceeds outward to the distribution system and energy conversion equipment. Application of the inside out-approach has been shown to maximize savings while minimizing first cost [3-9].

One reason for the success of the inside-out approach is the multiplicative effect of losses as energy is converted, distributed and used. For example, consider an electrical appliance that provides 1 kWh of useful work. If the appliance is 50% efficient, the electrical distribution system 93% efficient, and electrical power plant is 33% efficient, then, for every useful kWh provided by an appliance, the quantity of source energy consumed is:

$$1 \text{ kWh} / (50\% \times 93\% \times 33\%) = 6.5 \text{ kWh}$$

This means that reducing 1 kWh of energy at the end use (inside) results in 6.5 kWh of energy savings at the source (outside). Thus, minimizing end use energy, then distribution losses and finally improving the efficiency of the primary energy conversion equipment tends to multiply savings.

For the conceptual design of the Eco House, this means sequentially focusing on:

- Occupant behavior
- Appliances and lighting
- Building envelope (walls, ceiling, windows, infiltration)
- Energy distribution system (pumps, fans, radiant panels)
- Primary space conditioning equipment (ground-source heat pump, etc.)
- Solar heating and electricity systems

### ***Eco-house Occupant Behavior***

Previous research has documented that occupant behavior significantly affects energy use in campus housing. For example, energy contests sponsored by the UD Sustainability Club, which focused almost exclusively on occupant behavior, resulted in over \$26,000 in energy savings over the course of two years [3-10].

The Eco-house will be populated by students motivated to practice energy-conscious behavior. Students will reduce electricity consumption by using natural lighting, and turning off lights, computers and televisions when not needed. Table 3-3 shows estimated electricity use with reduced appliance and lighting operating hours. The results indicate that electricity consumption could be reduced by about 33% from 11,389 kWh per year to 7,654 kWh per year.

Table 3-3. Equipment Electricity Use in Baseline House with Improved Occupant Behavior

Item	Unit Power (Watts)	Qty	Total Power (W)	Hours Operated (hrs/dy)	Operating Schedule (dys/yr)	Annual Energy Use (kWh/yr)
<b>Lighting</b>						
60 W Incandescent	60	17	1020	6	365	2,234
34 W T 12 4-foot 2-lamp fluorescent	68	1	68	8	365	199
40 W Incandescent	40	5	200	4	365	292
<b>Total Lighting</b>						<b>2,724</b>
<b>Appliances</b>						
Electric Range	4100	1	4100	0.25	365	374
Dishwasher	1300	1	1300	0.2	365	95
Refrigerator	500	1	500	2.5	365	456
Washer	500	1	500	0.5	365	91
Dryer	5000	1	5000	0.5	365	913
Microwave	1300	1	1300	0.2	365	95
Toaster	1100	1	1100	0.1	365	40
George Foreman Grill	760	1	760	0.5	365	139
1/3-hp Fan	281	1	281	8	365	822
<b>Total Appliances</b>					365	<b>3,025</b>
<b>Electronics</b>						
Televisions	110	4	440	2	365	321
Stereos	30	4	120	1	365	44
Clocks	5	7	35	24	365	307
Computers	100	5	500	6	365	1,095
DVD Player/VCR	40	2	80	1	365	29
Gaming System	100	3	300	1	365	110
<b>Total Electronics</b>						<b>1,905</b>
<b>Total Electricity Use</b>						<b>7,654</b>

### ***Eco-house Appliances and Lighting***

In the United States, residential electricity use makes up 35% of the total electricity use. Appliances account for about 60% of this; thus the use of energy efficient appliances can result in significant energy savings. For example, compact fluorescent lights save up to 73% of the energy consumed by incandescent bulbs. Laptop computers save 70% of the energy consumed by desktop computers [3-11]. Energy Star refrigerators save 50% of the energy consumed by low-end refrigerators [3-12]. Table 3-4 shows projected Eco-house electricity use from both reducing operating hours and using energy efficient appliances and lights. The results show that electricity consumption could be reduced to 4,997 kWh per year. This is 35% less than projected

electricity consumption from solely reducing operating hours and 56% less than baseline electricity use.

Table 3-4. Electricity Use with Energy Efficient Appliances and Improved Occupant Behavior

Item	Unit Power (Watts)	Qty	Total Power (W)	Hours Operated (hrs/dy)	Operating Schedule (dys/yr)	Annual Energy Use (kWh/yr)
Lighting						
18 W CF bulbs	18	17	306	6	365	670
34 W T 8 4-foot 2-lamp flourescent	58	1	58	8	365	169
13 W CF bulbs	13	5	65	4	365	95
Total Lighting						<b>934</b>
Appliances						
Electric Range	3750	1	3750	0.25	365	342
Dishwasher		1				181
Refrigerator		1				392
Washer		1				278
Dryer	1800	1	1800	1	365	710
Microwave	700	1	700	0.25	365	64
Toaster	1100	1	1100	0.1	365	40
George Foreman Grill	760	1	760	0.5	365	139
1/3-hp Fan	281	1	281	8	365	822
Total Appliances						<b>2,968</b>
Electronics						
Televisions	110	4	440	1.5	365	241
Stereos	30	4	120	1.5	365	66
Clocks	5	7	35	24	365	307
Computers	30	5	150	6	365	329
DVD Player/VCR	40	2	80	1.5	365	44
Gaming System	100	3	300	1	365	110
Total Electronics						<b>1,095</b>
Total Electricity Use						<b>4,997</b>

## ***Eco-house Building Envelope***

Following the inside-out method, the next area to consider is the building envelope. Residential natural gas use accounts for 21.1% of the total natural gas use in the US, and space heating accounts for 66% of residential gas use [3-13]. Thus, space heating is a major target for improvement. To reduce space conditioning energy use, this section focuses on reducing thermal loads. Subsequent sections will focus on improving the energy efficiency of the distribution and primary energy conversion components of the heating and cooling systems.

In order to reduce heating and cooling loads, Eco-house walls, ceiling, windows and perimeter insulation will have high thermal resistances. The walls and ceiling will be constructed with Structurally Insulated Panels (SIPs). SIPs are both tighter and more insulative than framed walls [3-14]. The proposed SIP wall structure, from exterior to interior, consists of exterior wood siding, ½-inch OSB, 8.5-inch polystyrene foam, ½-inch OSB and ½-inch drywall on the inside. Assuming winter wind conditions, the R-value for the proposed SIP walls is about 39 hr-ft<sup>2</sup>-F/Btu. The cathedral style roof/ceiling will be constructed of thicker SIPs. From outside to inside, the construction is light-colored asphalt shingles, felt paper backing, ½-inch OSB, 11.25-inch polystyrene foam, ½-inch OSB, ½-inch drywall. Assuming winter wind conditions, the R-value of the roof /ceiling is about 51 hr-ft<sup>2</sup>-F/Btu [3-4].

Significant winter heat loss and summer heat gain occurs through windows. In addition, poorly installed windows also increase air leakage into and from the house. The Eco-house will use low-emissivity, argon-filled Tripane SuperSpacer windows, which have a center-of-glass R-value of 4.76 and a solar heat gain coefficient of 0.65 [3-15].

Houses constructed with SIPs are far more airtight than typical frame houses, and require mechanical ventilation to maintain fresh indoor air. ASHRAE recommends a minimum ventilation rate of about 0.35 air changes per hour to prevent the build up of indoor air pollutants [3-16]. The Eco-house will have an air-to-air heat exchanger to pre-condition outside air by exchanging energy between the intake and exhaust air streams. To provide 0.35 air changes per hour, the heat exchanger will provide about 75 cfm with a heat exchanger effectiveness of 81% [3-4]. Perimeter insulation reduces heat transfer

from the basement to the ground. The Eco-house will have insulated, pre-cast basement walls with an overall R-value of 23 hr-ft<sup>2</sup>-F/Btu [3-17].

### ***Eco-house Heating and Cooling Distribution System***

Typical UD student houses are heated by furnaces and cooled by air conditioners. In these houses, an air distribution fan blows air over heating and cooling coils, through ducts to the conditioned space. This method of distributing heat requires large volumes of air since air has a relatively low density and specific heat. The air distribution fan motors in UD houses are typically about 0.3 hp. Assuming a 0.3 hp motor is 75% loaded and 80% efficient, the motor draws about 210 W. Total fan motor electricity consumption depends on how often the fan runs. Simulation results, which assume a pressure drop of 2-inwg, indicate that annual supply fan electricity use is about 1,000 kWh/yr, which amounts to about 10% of all household electricity use.

To reduce distribution energy use, heating and cooling in the Eco-house will be delivered by hot and cold water streams that flow through microtubing mats in the ceiling. To minimize friction losses, panels will be arranged in parallel whenever possible. The piping configuration will use indirect return to assure equal flow through each panel. A separate thermostat will control each zone. Preliminary calculations indicate that the house will require 75 panels, and pump energy requirements, assuming continuous flow, will be about 120 kWh per year. An example of installed microtubing is shown in Figure 3-4.

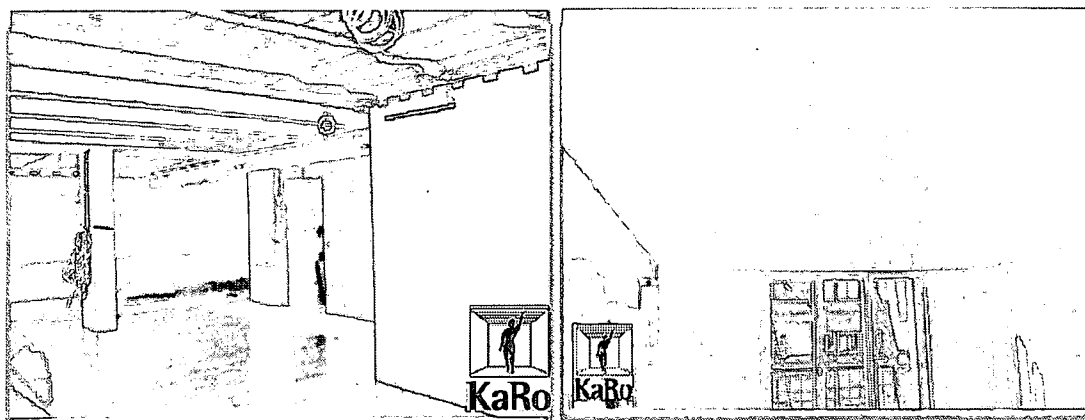


Figure 3-4. Microtubing mats during and after construction [3-18].

In addition to the pump, the air-to-air heat exchanger employs two 75 cfm fans. Assuming the fan motors are 80% efficient, the fans are 70% efficient and the pressure drop is 1 inwg, the motors will consume about 380 kWh per year in continuous operation. Thus, total distribution electricity use will be about 500 kWh per year, which is about half of the distribution energy use in a typical UD residence.

### ***Eco-house Primary Heating and Cooling***

The next step in the inside-out design approach is to consider the primary heating and cooling equipment. The Eco-house will use a geothermal, water-to-water heat pump to provide warm and cool water for the microtube panels. The heat pump will transfer heat to and from water circulated through a ground loop, which acts as a heat source during winter and a heat sink during summer. A schematic of the proposed design is shown in Figure 3-5.



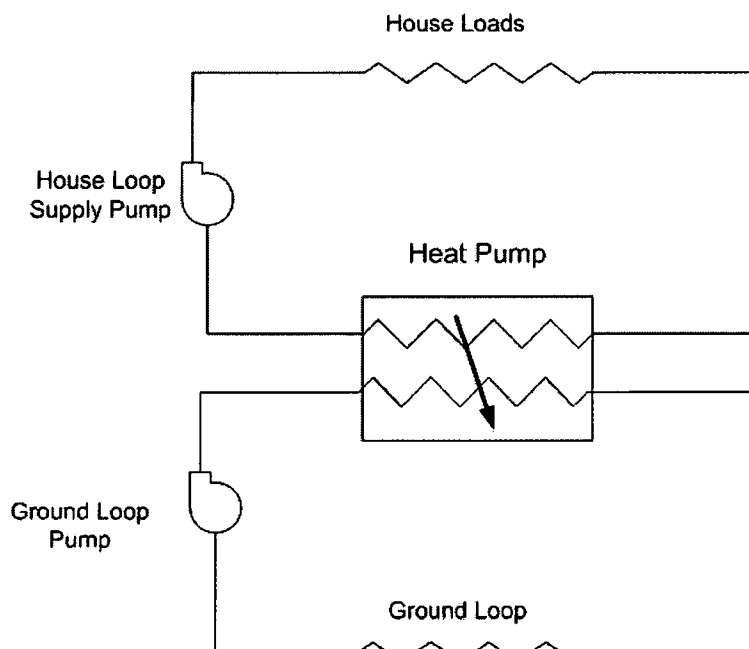


Figure 3-5. Geothermal heat pump schematic.

Preliminary calculations indicate that house-loop supply temperatures required for meeting peak heating and cooling loads are 84 F and 67 F, respectively [3-4]. The design volume flow rates through both the house and ground loops are 7 gpm. The average annual ground temperature for Dayton, Ohio is about 50 F. Assuming the ground loop supplies 42 F fluid to the heat pump during winter and 58 F fluid during summer, the heat pump will operate with an average heating COP of about 4.8 and an average cooling EER of about 24 (Btu/Wh) [3-19].

### ***Eco-house Solar Water Heating***

The inside-out approach was also applied to the hot water system. On the inside, energy and water-efficient dishwashers and clothes washers are assumed to reduce overall hot water use by 20%. In the distribution system, hot water supply temperature has been reduced from 60 C (140 F) in typical UD residences to 48.9 C (120 F). Finally,

a solar thermal hot water system will be the primary source of heat for hot water. Supplemental heat will be provided by electric resistance heaters.

Energy use for domestic hot water was simulated using SolarSim software [3-20]. SolarSim uses typical meteorological data [3-7] to simulate the hourly performance of photovoltaic and solar thermal systems. SolarSim uses the Hay, Davies, Klucher, Reindl (HDKR) model for calculating incident solar energy on a surface [3-8]. The computational algorithms are based on fundamental thermodynamic, psychrometric and heat-transfer calculations. Using SolarSim, a solar thermal system was designed with three 2-m<sup>2</sup> solar collectors facing due south at a tilt angle of 52 degrees from the horizon. Collector [3-21] and system specifications for the system are shown in Figure 3-6.

Collector Properties	
Collector slope from horz. (deg)	52
Collector azimuth from south (deg)	0
Reflectance of ground (.6 = for snow)	2
Area per collector (m2)	2
Number of collectors	3
Number of glazings per collector	1
F <sub>rit</sub> (y-intercept of coll perform curve)	832
F <sub>rit</sub> (kJ/hr m2 C slope of coll perform curve)	948

System Properties	
HX Effectiveness (0 to 1)	0.8
Mass Water Storage (kg)	1500
Aux Space Heater Efficiency (0 to 1)	1
Aux Water Heater Efficiency (0 to 1)	1

Building Data	
UA house (kJ/hr C)	637
Building Set Point Temp (C)	22.22
Hot Water Set Point Temp (C)	48.9
Cost of Aux Energy (\$/GJ)	27.7778

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Figure 3-6. SolarSim input screen for modeling space and water heating.

Simulation results indicate that 3,858 kWh per year of the 3,911 kWh per year of electricity necessary for water heating will be provided by the solar system (Figure 3-7). The overall Solar Load Ratio will be 99%. Electric resistance heaters will provide an additional 53 kWh per year in supplemental hot water heating.

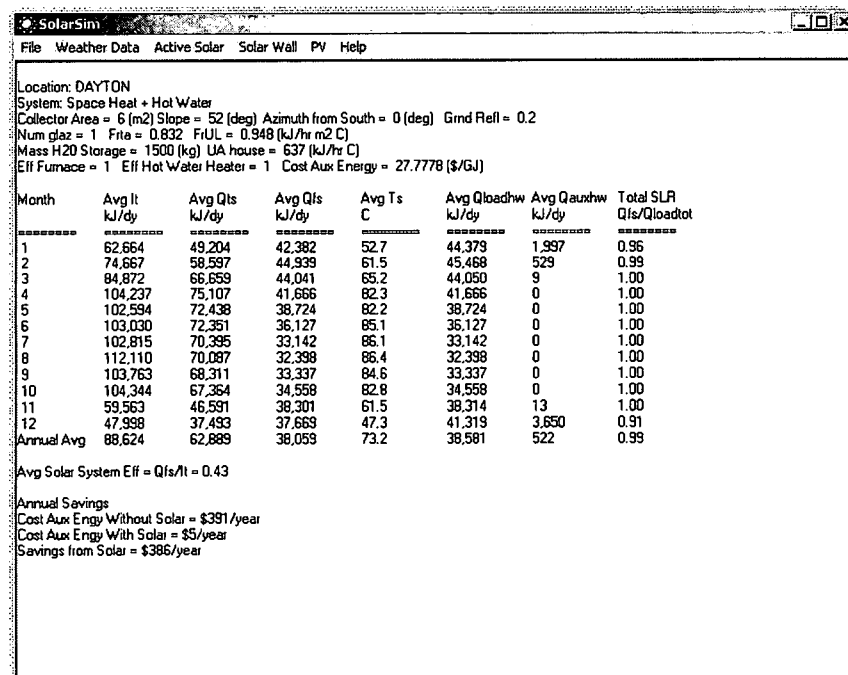


Figure 3-7. ESim Domestic Hot Water Results.

### ***Eco-house Simulated Electricity Use***

Annual building electricity use in the Eco-house was simulated using the software ESim [3-6]. The Eco-house building characteristics used in the simulation are summarized in Table 3-5. In the Eco-house Appliances and Lighting section of the report, it is estimated that annual appliance and lighting electricity use will be about 416 kWh/month. Preliminary calculations indicate that the house pump will consume about 10 kWh per month and the air-to-air heat exchanger fans will consume about 32 kWh per month. Based on the SolarSim simulation, auxiliary electricity use for hot water will be about 4 kWh per month. Thus, the total internal, non-space conditioning electricity use will be about 462 kWh/month.

Table 3-5. Summary of Eco-house Characteristics

Awalls (ft2)	2,002
Awindows (ft2)	78
Aceiling (ft2)	938
Number occupants	5
Conditioned floor area (ft2)	1,600
Basement perimeter (ft)	104
Rwalls (hr-ft2-F/Btu)	39
Rwindows (hr-ft2-F/Btu)	4.76
Window SHGC	0.65
Rbasement walls (hr-ft2-F/Btu)	23
Rceiling roof (hr-ft2-F/Btu)	49
Ventilation (air changes per hour)	0.35
Air-to-air heat exchanger effectiveness	0.81
Internal electricity use (kWh/mo)	462
Occupied temperature set point (F)	72
Temperature setbacks (10pm – 8am)	
Winter (F)	68
Summer (F)	76
Heat Pump Coefficient of Performance	4.8
Heat Pump EER (Btu/Wh)	24
Ground loop pressure drop (ft H2O)	5.5
Ground loop flow rate (gpm)	7

Using these input data and TMY2 weather data for Dayton, Ohio, simulated Eco-house electricity use is shown in Figure 3-8. ESim estimates that total Eco-house electricity use, including space conditioning and hot water heating, will be about 6,520 kWh per year.

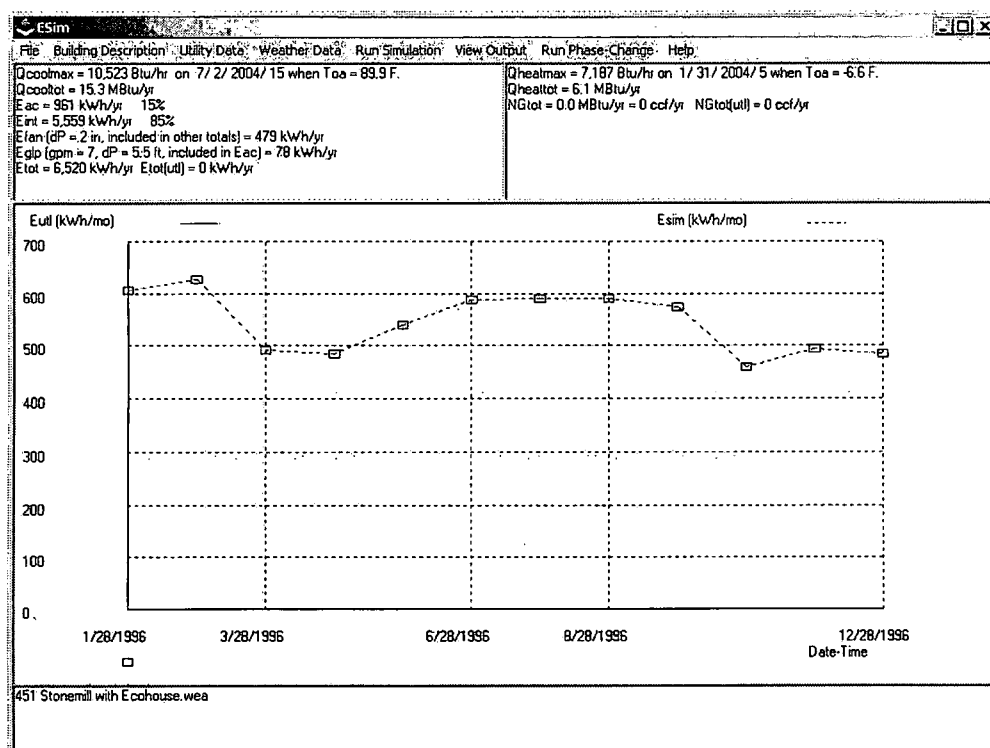


Figure 3-8. Simulated electricity use for the Eco-house.

The simulated electricity use of the Eco-house is compared to electricity use in older and newer baseline houses in Figure 3-9. Annual electricity use in the newer baseline house is 13,455 kWh per year, and annual electricity use in the older baseline house is 15,581 kWh per year. Thus, the Eco-house will use about 51% less electricity than the new baseline house, and about 58% less electricity than the old baseline house.

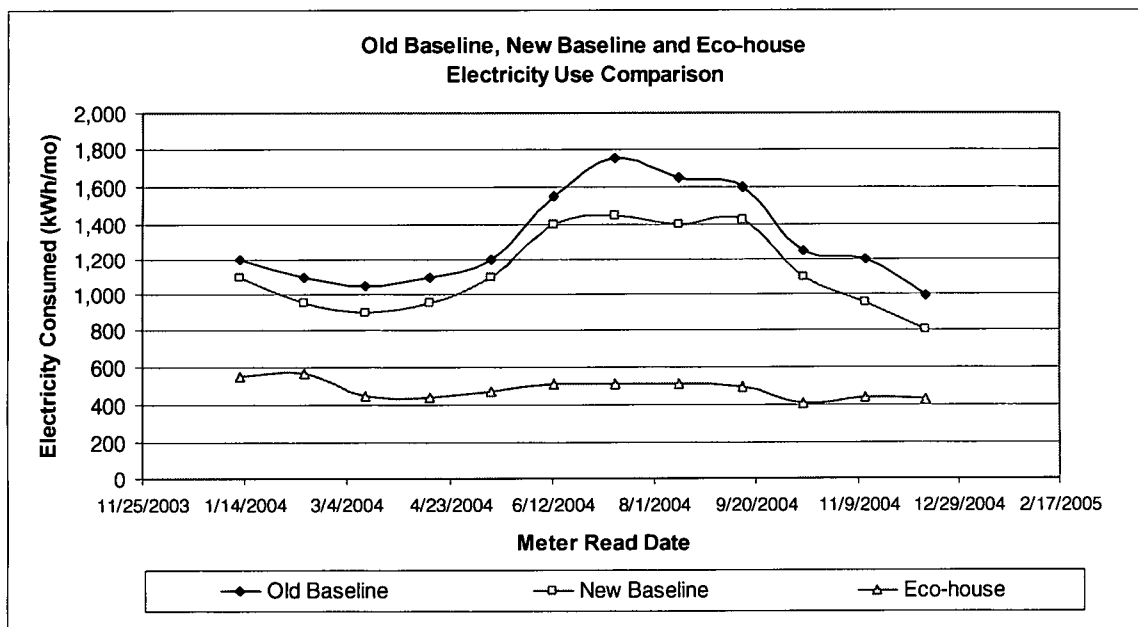


Figure 3-9. Comparison of electricity requirements for new baseline house and Eco-house.

Natural gas use in the older and newer baseline houses and the Eco-house are shown in Figure 3-10. The Eco-house will use no natural gas, compared to 61 mmBtu per year for the newer baseline house and 163 mmBtu per year for the older baseline house.

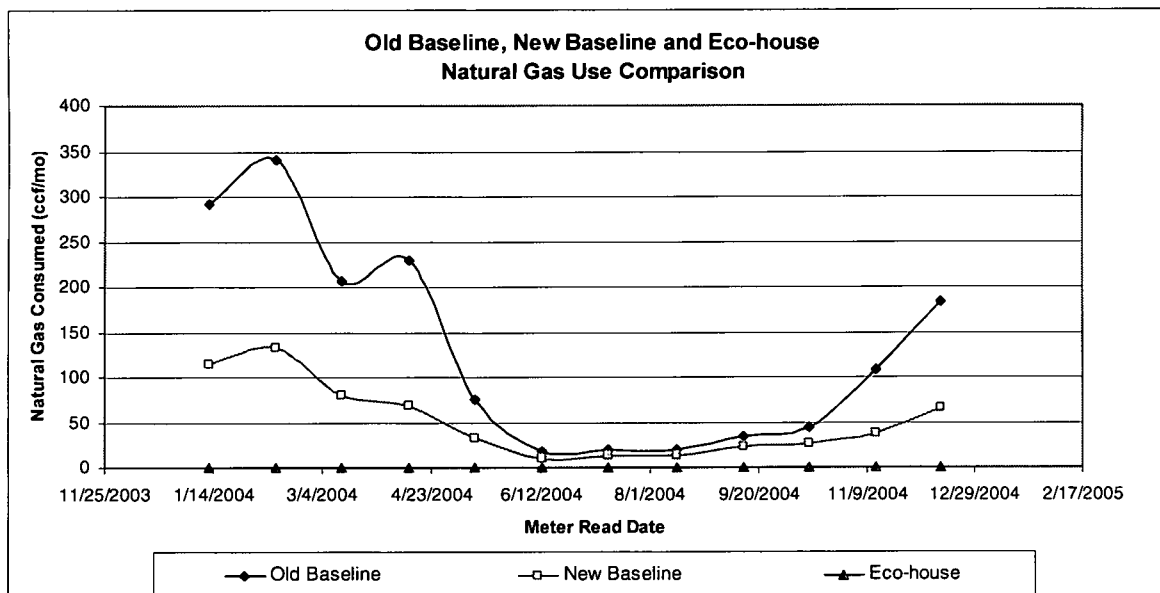
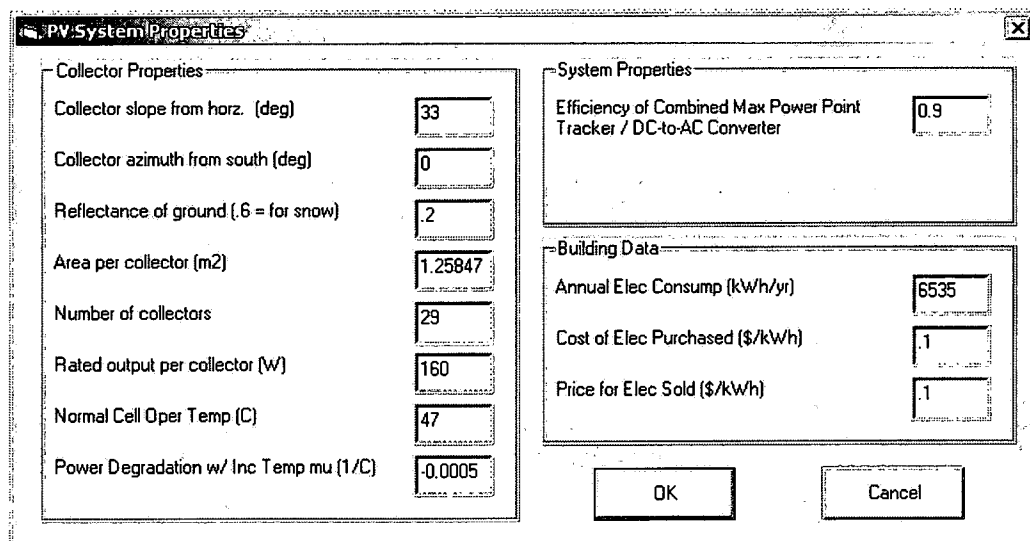


Figure 3-10. Comparison of older baseline, newer baseline and Eco-house natural gas use

## ***Eco-house Solar Electricity***

To achieve net-zero energy use, the Eco-house will employ a photovoltaic solar system (PV) sized to generate the total electricity requirements of the house. When the PV system output exceeds house electricity requirements, excess electricity will be put into the utility grid and the house electricity meter will run backward. When the PV system does not provide enough electricity for the house, the Eco-house will purchase the required electricity from the utility.

The PV system was designed using the SolarSim simulation software. Based on these simulations, a system with 29 1.26-m<sup>2</sup> collectors, facing due South at a tilt angle of 33 degrees from the horizon was selected. The properties of the PV collector [3-22] and system, as entered in SolarSim, are shown in Figure 3-11.



Collector Properties	
Collector slope from horz. (deg)	33
Collector azimuth from south (deg)	0
Reflectance of ground (.6 = for snow)	.2
Area per collector (m2)	1.25847
Number of collectors	29
Rated output per collector (W)	160
Normal Cell Oper Temp (C)	47
Power Degradation w/ Inc Temp mu (1/C)	-0.0005

System Properties	
Efficiency of Combined Max Power Point Tracker / DC-to-AC Converter	0.9

Building Data	
Annual Elec Consump (kWh/yr)	6535
Cost of Elec Purchased (\$/kWh)	.1
Price for Elec Sold (\$/kWh)	.1

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Figure 3-11. PV system inputs for SolarSim.

Based on this simulation, PV system output is estimated to be about 6,756 kWh per year (Figure 3-12). This will result in a net-positive cash flow of about \$22 from the electrical utility to the Eco-house.

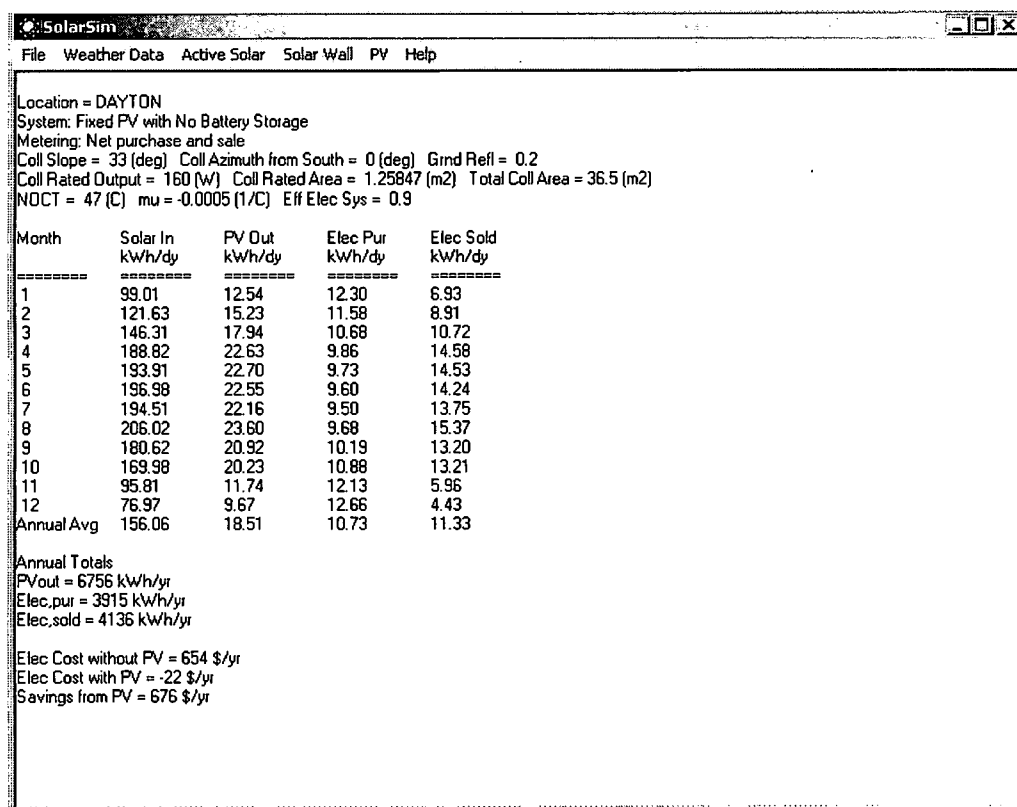


Figure 3-12. SolarSim Output.

### ***Annual Savings Summary***

According to these simulations, the Eco-house will save about 163 mmBtu per year in natural gas use and 15,581 kWh per year in electricity over the old baseline house, and 61.2 mmBtu per year in natural gas use and 13,455 kWh per year in electricity over the new baseline house. Assuming the total efficiency of the electrical generation and distribution is 30%, the total source energy savings from the Eco-house compared to the old baseline house and new baseline house will be about 340 mmBtu per year, and 214 mmBtu per year, respectively (Figure 3-13).

It is also appropriate to compare reductions in CO<sub>2</sub> emissions. The local utility generates about 2.3 lbs CO<sub>2</sub> for each kWh of electricity generated [3-23]. Assuming 10% excess air, about 113 lbs CO<sub>2</sub> are generated for each mmBtu of natural gas combusted. Using these numbers, the total CO<sub>2</sub> emission savings from the Eco-house compared to the



old baseline house and new baseline house will be about 53,713 lbs per year and 37,964 lbs CO<sub>2</sub> per year, respectively (Figure 3-14).

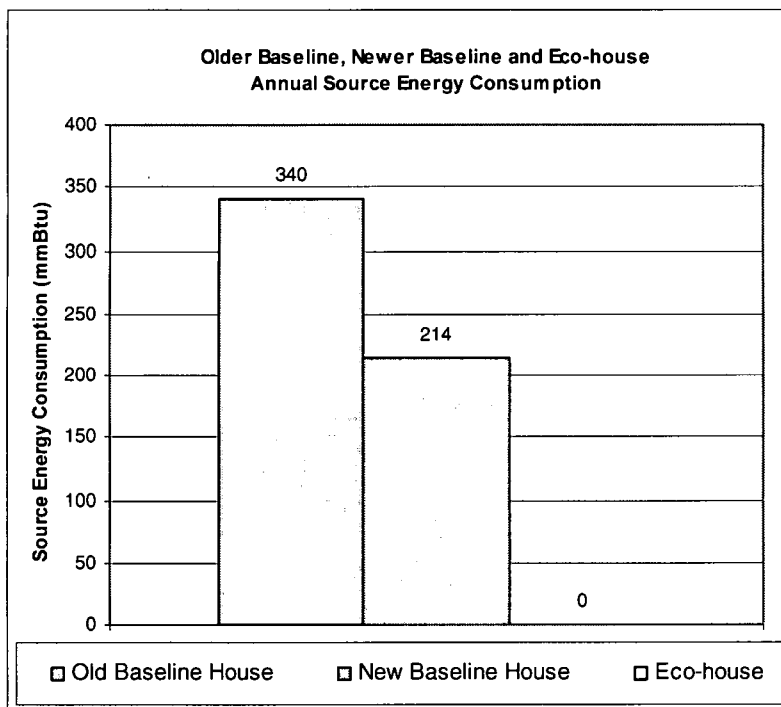


Figure 3-13. Source energy use of older baseline, newer baseline and Eco-house.

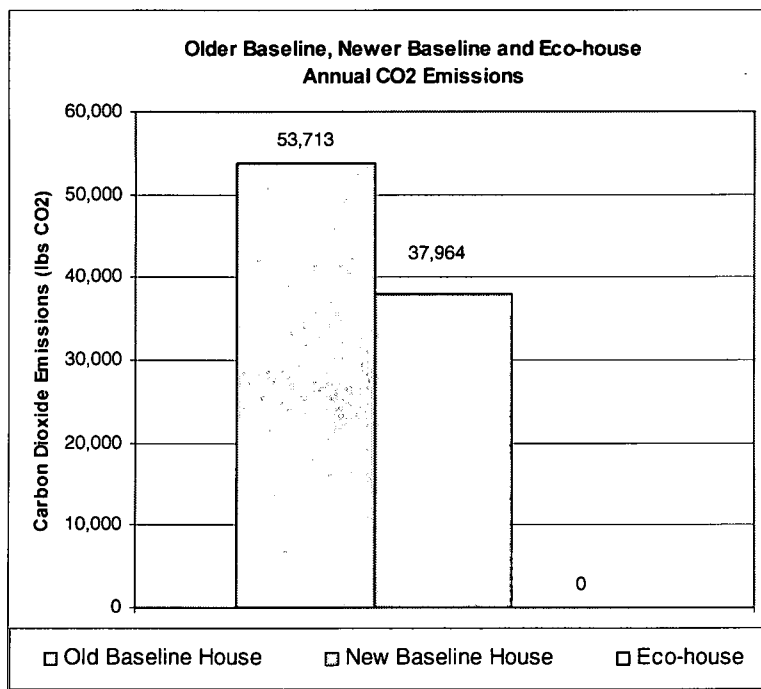


Figure 3-14. CO<sub>2</sub> emissions for older baseline, newer baseline and Eco-house.

The current cost of natural gas in the Dayton area is \$9.40 per mmBtu and the cost of electricity is about \$0.098 per kWh. Using these unit costs, the total energy cost savings from the Eco-house compared to the old baseline house and new baseline house will be \$3,009 per year and \$1,902 per year, respectively (Figure 3-15).

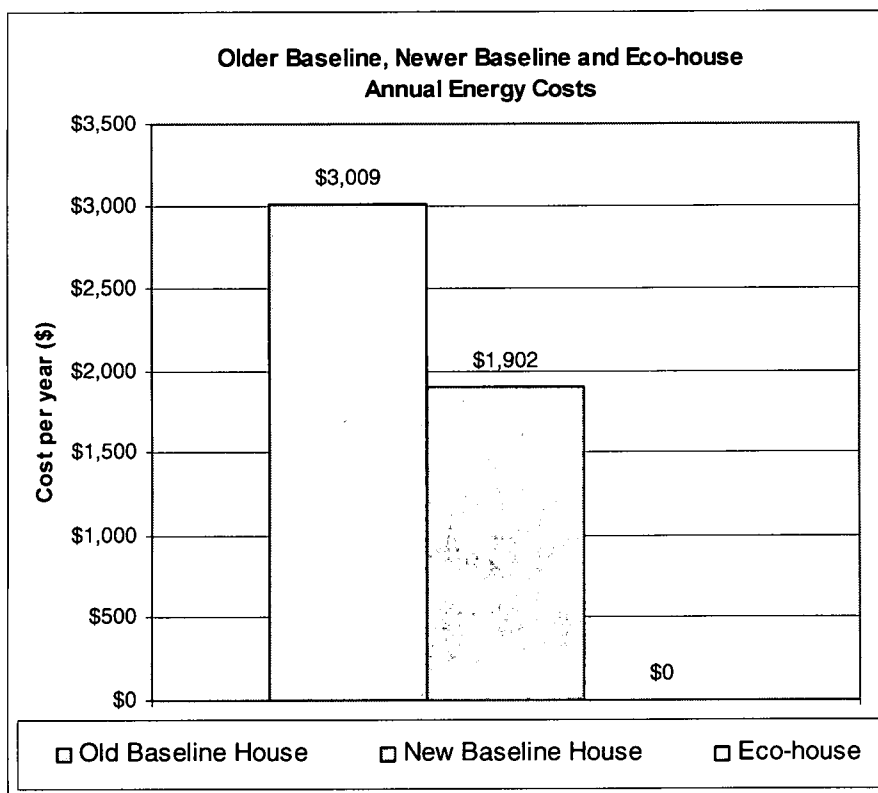


Figure 3-15. Energy costs of older baseline, newer baseline and Eco-house.

## **Chapter 4**

# **Cost-Benefit Analysis of Net Zero Energy Campus Residence**

### ***Introduction***

Much of the student housing for upperclassmen at the University of Dayton (UD) was built in the early 1900s as housing for factory workers. These houses have both minimal insulation and high rates of infiltration. Currently UD spends over \$1 million per year on gas and electricity for the student neighborhood. The University of Dayton is committed to building a net-zero energy student residence, called the Eco-house. The house will be extensively instrumented and monitored by students, and serve as a living experiment to guide the design of future generations of UD Eco-houses.

The motivation for the Eco-house along with its conceptual design is presented in full detail in the paper “Conceptual Design of a Net Zero Energy Campus Residence”. This design followed the inside-out method to analyze the energy impacts of residential occupant behavior, appliances and lights, building envelope, energy distribution systems and primary energy conversion equipment. Since publication of “Conceptual Design of a Net Zero Energy Campus Residence”, progress has been made on the design of the heating and cooling system, solar thermal system, and solar photovoltaic system. Design occupant behavior, lighting and appliances, walls and windows have remained unchanged.

This paper discusses in detail those house components which have been redesigned. Cost-benefit analysis of selected house components and the whole Eco-house design are presented. Conclusions are drawn from cost-benefit analysis of selected house components and synergistic benefits realized in the whole Eco-house design. Within the primary constraint of net-zero energy, we seek to design the Eco-house to be as economical as possible. In addition, we seek to use this experience to provide guidance for the design of future eco-houses and typical student housing. The cost-benefit analysis is performed using the real discount rate for the University and estimated fuel escalation rates. Lifetime owning and operating costs of current new construction and the Eco-house are brought back to present value and compared.

### ***Baseline Houses***

For our analysis, two types of baseline houses were considered. The older houses on campus were built in the early 1900s as housing for factory workers. These houses have minimal insulation, high infiltration rates, inefficient appliances and lighting, single pane windows (some with storm windows), older furnaces, and older hot water heaters [4-1].

The University of Dayton is slowly replacing these older houses with newer, to-code houses. The walls have an R-value of 13 hr-ft<sup>2</sup>-F/Btu, ceilings have an R-value of 16 hr-ft<sup>2</sup>-F/Btu, and the windows have an R-value of about 2 hr-ft<sup>2</sup>-°F/ Btu. The rate of infiltration is about 0.62 air changes per hour; the houses use 80% efficient natural gas furnaces and natural gas hot water heaters with an average efficiency of about 55%. The air conditioners have a SEER of 10 (Btu/Wh). A summary of baseline house characteristics may be found in Table 4-1.

Table 4-1. Summary of Baseline House Characteristics

House Characteristics	Old House	New House
Awalls (ft2)	2,002	2,002
Awindows (ft2)	78	78
Aceiling (ft2)	662	662
Number occupants	5	5
Floor area (ft2)	662	662
Perimeter length (ft)	104	104
Rwalls (hr-ft2-F/Btu)	4	13
Rwindows (hr-ft2-F/Btu)	0.90	2
SHGC	0.85	0.531
Rperimeter_insulation (hr-ft2-F/Btu)	0	10
Rceiling_roof (hr-ft2-F/Btu)	16	16
Infiltration (ACH)	1.21	0.62
Internal Loads (kWh/mo)	1108	949
Temperature Setbacks (10pm - 8am)	None	None
Winter (F)	72	72
Summer (F)	72	72
Furnace Efficiency	0.8	0.8
COP Air Conditioner	10	10
HSPF Heat Pump	None	None
SEER Heat Pump	None	None

Simulated electricity consumption in the newer baseline house is 13,455 kWh per year and 15,581 kWh per year in the older baseline houses. Simulated natural gas consumption in the newer baseline house is 61.2 mmBtu per year and 163 mmBtu per year in the older baseline houses. The current cost of natural gas in the Dayton area is \$12.50 per mmBtu and the cost of electricity is about \$0.088 per kWh. Using these unit costs, the total energy costs of the old baseline house and new baseline house are \$3,409 and \$1,949, respectively.

### ***Inside-Out Design Approach and Component Economic Analysis***

The inside-out approach is a structured method of analyzing opportunities for energy efficiency improvements that begins by focusing on the eventual end use of the energy and proceeds outward to the distribution system and energy conversion equipment. Application of the inside out-approach has been shown to maximize savings while minimizing first cost [4-2]. One reason for the success of the inside-out approach

is the multiplicative effect of losses as energy is converted, distributed and used. For the design of the Eco House, this means sequentially focusing on occupant behavior, appliances and lighting, building envelope, energy distribution system, primary space conditioning equipment and finally solar heating and electricity systems.

## **Occupant Behavior**

The Eco-house will be populated by students motivated to practice energy-conscious behavior. Students will reduce electricity consumption by using natural lighting, and turning off lights, computers and electronics when not needed. These students will also keep the house at an efficient temperature and reduce their overall water use. Results indicate that electricity consumption could be reduced by about 32% from 11,399 kWh per year to 7,759 kWh per year [4-1].

## **Appliances and Lighting**

The Eco-house will incorporate compact fluorescent lights and Energy Star appliances. By improving occupant behavior and using energy efficient appliances and lights, electricity consumption could be reduced to 4,985 kWh per year. This is 36% less than projected electricity consumption from solely reducing operating hours and 56% less than baseline electricity use [4-1].

The EnergyStar dishwashers currently installed in baseline houses use 328 kWh per year and cost \$279. A more energy efficient model uses about 278 kWh per year and costs \$780. An even more energy efficient model uses 231 kWh per year costs \$1,100. For subsequent cost-benefit analysis on house components will use a real discount rate of 5%, a fuel escalation rate of 4%, and a present natural gas and electricity costs of \$12.50 per mmBtu and \$0.088 per kWh. The net-present value of owning and operating each

system for 13 years is summarized in Table 4-2. Considering the net present value of owning and operating dishwashers, the energy efficient model was chosen for the Eco-house design.

Table 4-2. Dishwasher Net-Present Value

	Baseline	Energy Efficient	Super Efficient
First Cost (\$)	\$279	\$780	\$1,100
Annual Energy Cost (\$/yr)	\$29	\$24	\$20
Net Present Value Total Cost (\$)	\$630	\$1,078	\$1,347

The refrigerators currently installed in baseline houses use 479 kWh per year and cost \$449. A more energy efficient model uses about 409 kWh per year and costs \$679. Despite the apparent cost-ineffectiveness of choosing the energy efficient model, because the current refrigerators are not EnergyStar, the energy efficient model was chosen for the Eco-house design. The net-present value of owning and operating each refrigerator for 13 years is summarized in Table 4-3.

Table 4-3. Refrigerator Net-Present Value

	Baseline	Energy Efficient
First Cost (\$)	\$449	\$679
Annual Energy Cost	\$42	\$36
Net Present Value Total Cost	\$962	\$1,117

## Building Envelope

Space conditioning is a major target for improvement. To reduce space conditioning energy use, this section focuses on reducing thermal loads. Subsequent sections will focus on improving the energy efficiency of the distribution and primary energy conversion components of the heating and cooling systems.

In order to reduce heating and cooling loads, Eco-house walls, ceiling, windows and perimeter insulation will have high thermal resistances. The walls and ceiling will be constructed with Structurally Insulated Panels (SIPs) from R-Control Systems. SIPs are

both tighter and more insulative than framed walls [4-3]. The R-value for the proposed SIP walls is about 39 hr-ft<sup>2</sup>-F/Btu. The cathedral style roof/ceiling will be constructed of thicker SIPs. The R-value of the roof /ceiling is about 51 hr-ft<sup>2</sup>-F/Btu [4-4].

Significant winter heat loss and summer heat gain occurs through windows. In addition, poorly installed windows also increase air leakage into and from the house. The North, East, and West facing windows will be low-emissivity, triple-pane windows with a center of glass U-value below 0.2 Btu/hr-ft<sup>2</sup>-F and SHGC below 0.3. On the South side, the windows will be low-emissivity, triple-pane windows with a center of glass U-value below 0.35 Btu/hr-ft<sup>2</sup>-F and SHGC above 0.4.

Houses constructed with SIPs are far more airtight than typical frame houses, and require mechanical ventilation to maintain fresh indoor air. ASHRAE recommends a minimum ventilation rate of about 0.35 air changes per hour to prevent the build up of indoor air pollutants (ASHRAE, 1989). The Eco-house will have an energy recovery ventilator (ERV) to pre-condition outside air by exchanging energy between the intake and exhaust air streams. To provide 0.35 air changes per hour, the energy recovery ventilator will provide about 75 cfm with an effectiveness of 52% [4-4].

Perimeter insulation reduces heat transfer from the basement to the ground. The Eco-house will have insulated, pre-cast basement walls with an overall R-value of 23 hr-ft<sup>2</sup>-F/Btu [4-5]. The current walls in newly constructed 5-person homes at UD have an R-value of about 13 hr-ft<sup>2</sup>-F/Btu, and a cost of construction of about \$25,200. Natural gas and electricity for space conditioning with the current walls is about 33.2 mmBtu and 2,036 kWh per year. Six inch SIP panels could be installed with an R-value of about 26 hr-ft<sup>2</sup>-F/Btu, and a cost of construction of about \$28,300. Natural gas and electricity for



space conditioning with 6-inch SIPs would be about 3.5 mmBtu and 2,025 kWh per year. Ten-inch SIP panels could be installed with an R-value of about 41 hr-ft<sup>2</sup>-F/Btu, and a cost of construction of about \$34,300. Natural gas and electricity for space conditioning with 10-inch SIPs would be about 1.4 mmBtu and 2,016 kWh per year. The net-present value of owning and operating each system for 35 years is summarized in Table 4-4. The 6-inch SIP wall has the lowest present value of owning and operating costs, however the 10-inch SIP wall was chosen for the design of the Eco-house in order to ensure the net-zero energy design requirement with a limited roof space for solar photovoltaic collectors.

Table 4-4. SIP Net-Present Value

	Baseline	SIP 6"	SIP 10"
First Cost (\$)	\$25,200	\$28,300	\$34,300
Annual Energy Cost	\$594	\$226	\$195
Net Present Value Total Cost	\$42,787	\$34,981	\$37,598

## Heating and Cooling System

Typical UD student houses are heated by furnaces and cooled by air conditioners. In these houses, a constant air volume distribution fan blows air over heating and cooling coils, through ducts to the conditioned space. Simulation results, which assume a pressure drop of 2-inwg, indicate that annual supply fan electricity use is about 1,000 kWh/yr [4-1]. Eco-house heating, cooling and ventilation will also be supplied through ductwork. The Eco-house will use an air-to-air heat pump with a variable speed fan to distribute heating and cooling. According to ESim, the peak heating and cooling loads for the Eco-house are 9,260 Btu/hr and 9,851 Btu/hr. The heat pump is rated at 2 tons and has the capability to independently control air temperature and humidity. Additionally, the heat pump has internal electric resistance heating elements that supply

heat when the outdoor air temperature is too low. Heat pumps are usually more efficient than electric resistance heating. However, when the outdoor air temperature falls below a certain temperature, air-to-air heat pumps become less efficient than electric resistance heating. According to system specifications, the heat pump will operate with an average COP of about 9.4 and an average cooling SEER of about 14.5 (Btu/Wh) [4-6]. Calculations indicate that the ½ hp variable speed fan on the air-to-air heat pump will use about 188 kWh per year in electrical energy.

The natural gas furnace which is currently installed in newly constructed 5-person homes at UD has an AFUE of 0.94, a lifetime of about 18 years and a cost of \$1,978. The air conditioner has a SEER of 10.2, a lifetime of 13 years and a cost of \$650 [4-7]. Natural gas and electricity for space conditioning is about 33.2 mmBtu and 2,036 kWh per year. A more efficient natural gas furnace could be installed with an AFUE of .966, a lifetime of about 18 years and a cost of \$2,400. A more efficient air conditioner could be installed with an SEER of 16, a lifetime of about 18 years and a cost of \$1,850. Natural gas and electricity for space conditioning would be about 32.4 mmBtu and 1,272 kWh per year. A highly efficient heat pump could be installed with an HSPF of 8.85 and SEER of 14.7, a lifetime of about 18 years and a cost of \$2,775. Electricity for space conditioning would be about 5,313 kWh per year. The net-present value of owning and operating each system for 13 years is summarized in Table 4-5. The highly efficient heat pump was chosen for the Eco-house design. It is also the most cost-effective of the three options.

Table 4-5. Space Conditioning Net-Present Value

	Baseline	Energy Efficient	Heat Pump
First Cost (\$)	\$2,628	\$4,250	\$2,775
Annual Energy Cost (\$/yr)	\$594	\$517	\$468
Net Present Value Total Cost (\$)	\$9,856	\$10,539	\$8,463

## Solar Water Heating

The inside-out approach was also applied to the hot water system. On the inside, energy and water-efficient dishwashers and clothes washers are assumed to reduce overall hot water use by 20%. In the distribution system, hot water supply temperature has been reduced from 60 C (140 F) in typical UD residences to 48.9 C (120 F). Finally, a solar thermal hot water system will be the primary source of heat for hot water. Supplemental heat will be provided by a traditional high-efficiency, electric hot water heater. A schematic of the hot water system is shown in Figure 4-1.

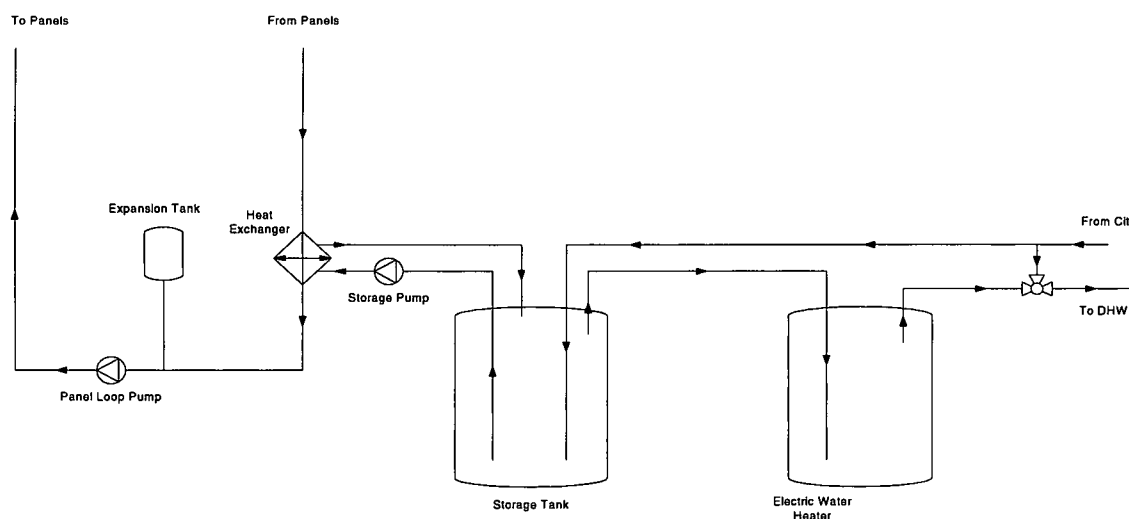


Figure 4-1: Solar Hot Water System

Energy use for domestic hot water was simulated using SolarSim software [4-8]. SolarSim uses typical meteorological data [4-9] to simulate the hourly performance of photovoltaic and solar thermal systems. Using SolarSim, a solar thermal system was designed with two 3.74 m<sup>2</sup> solar collectors facing due south at a tilt angle of 44 degrees

from the horizon. The FrTa (y-intercept of collector performance curve) is 0.74 and the FrUI (slope of performance curve) is 1.527 [4-10]. The heat exchanger is 80% effective and the system has 120 gallons of storage. Simulation results indicate that 97% of the solar hot water heating load will be provided by the solar system. The electric hot water heater will provide an additional 122 kWh per year in supplemental hot water heating.

The water heaters which are currently installed in newly constructed 5-person homes at UD have an energy factor of 0.58, an average life expectancy of about 13 years and a cost of \$480 [4-7]. Natural gas for hot water in these homes is about 28.0 mmBtu per year. A more efficient water heater could be installed with an energy factor of 0.63 an average life expectancy of 13 and a cost of \$580. Natural gas use for this hot water heater would be about 23.6 mmBtu per year. A solar water heating system including three 1.71 m<sup>2</sup> collectors, dedicated PV pump, and hot water tank could be installed for about \$3,735. The solar water heating system has an estimated lifetime of 15 years. The net-present value of owning and operating each system for 13 years is summarized in Table 4-6. The solar water heating system was chosen for the Eco-house design to supporting the design constraint of net-zero energy. It is also the most cost-effective.

Table 4-6. Hot Water Net-Present Value

	Baseline	Energy Efficient	Solar Water Heater
First Cost (\$)	\$480	\$580	\$3,735
Annual Energy Cost (\$/yr)	\$365	\$307	\$0
Net Present Value Lifetime Cost (\$)	\$4,918	\$4,315	\$3,735

## Electricity Use

Annual building electricity use in the Eco-house was simulated using the software ESim [4-11]. The Eco-house building characteristics used in the simulation are summarized in Table 7. In the Eco-house Appliances and Lighting section of the report,

it is estimated that annual appliance and lighting electricity use will be about 416 kWh/month (4,997 kWh/year). Preliminary calculations indicate that the air-to-air heat exchanger fans will consume about 32 kWh per month. Based on the SolarSim simulation, auxiliary electricity use for hot water will be about 16 kWh per month. Thus, the total internal, non-space conditioning electricity use will be about 464 kWh/month.

ESim estimates that total Eco-house electricity use, including space conditioning and hot water heating, will be about 6,500 kWh per year. Annual electricity use in the newer baseline house is 13,455 kWh per year, and annual electricity use in the older baseline house is 15,581 kWh per year. Thus, the Eco-house will use about 52% less electricity than the new baseline house, and about 58% less electricity than the old baseline house. The Eco-house will use no natural gas, compared to 61 mmBtu per year for the newer baseline house and 163 mmBtu per year for the older baseline house. Monthly electricity and natural gas use of all three houses are shown in Figures 9 and 10 in "Conceptual Design of a Net Zero Energy Campus Residence" [4-1].

Table 4-7. Summary of Eco-house Characteristics

House Characteristics	Old House	New House	Eco-House
Awalls (ft <sup>2</sup> )	2,002	2,002	2,170
Awindows (ft <sup>2</sup> )	78	78	150
Aceiling (ft <sup>2</sup> )	662	662	698
Number occupants	5	5	5
Floor area (ft <sup>2</sup> )	662	662	698
Perimeter length (ft)	104	104	109
Rwalls (hr-ft <sup>2</sup> -F/Btu)	4	13	39
Rwindows (hr-ft <sup>2</sup> -F/Btu)	0.90	2	5
SHGC	0.85	0.531	0.3
Rperimeter_insulation (hr-ft <sup>2</sup> -F/Btu)	0	10	23
Rceiling_roof (hr-ft <sup>2</sup> -F/Btu)	16	16	49
Infiltration (ACH)	1.21	0.62	0.35
Internal Loads (kWh/mo)	1108	949	416
Temperature Setbacks (10pm - 8am)	None	None	Yes
Winter (F)	72	72	66
Summer (F)	72	72	78
Furnace Efficiency	0.8	0.8	None
COP Air Conditioner	10	10	None
HSPF Heat Pump	None	None	9.4
SEER Heat Pump	None	None	14.5

### Onsite Electricity Generation

To achieve net-zero energy use, the Eco-house will employ a photovoltaic solar system (PV) sized to generate the total annual electricity requirements of the house. The PV system was designed using the SolarSim simulation software. Based on these simulations, a system with 32 1.3-m<sup>2</sup> collectors, facing due South at a tilt angle of 33 degrees from the horizon was selected. The collectors have a 165 W rating at 47 C normal operating temperature [4-12]. Based on this simulation, PV system output is estimated to be about 6,577 kWh per year.

Figure 4-2 shows simulated monthly Eco-house PV production and simulated monthly energy use. One can see that the PV system will produce more electricity than the house needs during most of the year and drop off significantly in the winter.

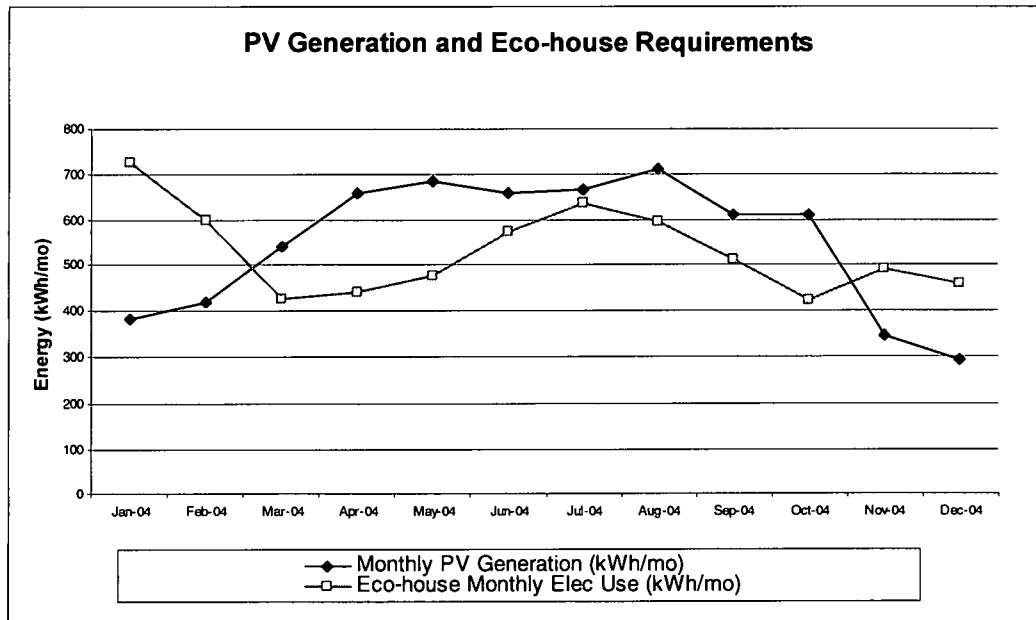


Figure 4-2: Eco-house PV Generation and Electricity Requirements

### **Whole House Cost-benefit Analysis**

So far, the design has shown that the Eco-house can be a net-zero energy house. In the following sections, economic analysis is presented to examine the cost-effectiveness of the Eco-house. The following analysis uses real historical fuel escalation rates for Dayton, Ohio and is bracketed by 1% and 4% annual fuel escalation rates as its upper and lower limits. The real interest rate and discount rate for the University of Dayton are used. Estimated additional costs for Eco-house construction are presented. Economic analysis is performed using the estimated first cost for construction and lifetime of the new baseline house and the Eco-house. Cost benefit analysis is performed using all costs as their net present value.

### **Eco-House Annual Electricity Cost**

Although the Eco House is designed to use no energy on a net basis over the year, the cost of energy for the house will not be zero. Current Ohio Law mandates that electric utilities install a single meter to measure the net amount of electricity used (or

generated) by the house each month. However, the law permits utilities to sell electricity for the standard residential rate and purchase electricity for their lowest avoided cost. According to DP&L's net-metering regulations, customers may generate excess electricity by solar, wind, biomass burning, hydro power, or fuel cells. The electricity can be fed into the electrical grid and the customer will be compensated according to their shopping credit tariff.

When billing, the utility generally breaks up the electricity tariff into three components, generation, transmission and distribution. The customer is further billed on additional riders, the excise tax surcharge rider, emission fee recovery rider, universal service fund rider, and the energy efficiency surcharge rider. In order to quickly calculate monthly bills, a customer could break these charges into a monthly service charge, which is typically fixed, and a monthly energy charge, based on the number of kWh consumed. According to the Dayton Power and Light Residential Electricity Tariff, the monthly service charge is \$4.25 and electrical energy charges are \$0.08844 per kWh for the first 750 kWh and \$0.07780 per kWh for all kWh over 750 kWh. Since both traditional homes and the Eco-house would be billed the same service charge, it will be ignored in the billing calculation. Homes in the student neighborhood never consume more than 750 kWh per month, so the price of electricity remains in the first block, at \$0.088 per kWh. Credits for electricity fed into the grid will be calculated on a net-monthly basis and will appear as credits on the next bill. For residential energy generation, credits will be \$0.05338 per kWh for first 750 kWh and \$0.04332 per kWh for all kWh over 750 kWh. The Eco-house solar system will never produce more than 750 kWh to sell back to the utility, so the electricity credit will always be \$0.05338 per kWh sold. So, using



current prices and rates, DP&L will sell electricity for about \$0.088 per kWh and purchases it for \$0.053 per kWh.

The electricity produced by the photovoltaic system is presented along with the electricity requirements of the Eco-house in Table 4-8. The monthly electricity charges, credits and annual utility costs are calculated.

Table 4-8: Monthly PV Generation, Electricity Use and Utility Charges

Month	Monthly PV Generation (kWh/mo)	Eco-house Monthly Elec Use (kWh/mo)	Monthly Elec Purchased (kWh/mo)	Electricity Cost
1/12/2004	379	725	373	\$32.87
2/12/2004	415	602	214	\$18.80
3/13/2004	542	425	-89	-\$4.74
4/13/2004	661	439	-195	-\$10.32
5/13/2004	685	477	-181	-\$9.61
6/13/2004	659	574	-58	-\$3.07
7/13/2004	669	638	-4	-\$0.19
8/13/2004	712	598	-88	-\$4.67
9/13/2004	611	512	-72	-\$3.82
10/13/2004	611	420	-164	-\$8.71
11/13/2004	343	490	174	\$15.33
12/13/2004	292	459	194	\$17.04
Total:		6,360	103	\$38.90

### Fuel Escalation Rate

DPL reports that at least 95% of its electrical power is produced from coal-fired power plants. We believe that future electricity cost escalation will be caused by increasing concerns about the carbon dioxide emissions from coal fired power plants, and the requirement that DPL and other utilities diversify their generation capacity. Despite aggressive drilling in the Rocky Mountain West, virtually no study projects that domestic gas production will increase substantially in the coming years, even as demand will continue to rise. In the long term, the U.S. will build ports to import LPG from Africa. However, we believe that natural gas prices will continue to increase in the future.

In order to predict the energy cost escalation, we examine local historical energy costs. The costs are adjusted with the implicit price deflator to reflect their real cost in 2000 \$US [4-13]. Historical electricity prices from the Dayton area were obtained from actual bills for a resident of Dayton. Readings were selected from the same time of year to minimize seasonal fluctuations in energy prices. Fuel escalation rate was calculated using the following formula, where F is the future value, P is the present value, n is the number of years in the period, and e is the fuel escalation rate.  $F = P \times (1 + e)^n$

Adjusted to 2000 \$US, the price of electricity in September, 1995 was \$0.101 per kWh. The price of electricity in September, 2005 was \$0.093 per kWh. Between 1995 and 2005, local electricity prices have decreased at a rate of 1.16% annually in the Dayton area. Unit costs of natural gas were read for winter months since the majority of natural gas use occurs during these months. Adjusted to 2000 dollars, the price of natural gas in January, 1996 was \$0.44 per ccf. The price of natural gas in January, 2005 was \$1.03 per ccf. Between 1996 and 2005, natural gas prices have increased at a rate of 7.97% annually in the Dayton area. In 2004, electricity and natural gas were 67% and 33% of all energy costs. Thus, locally, between 1995 and 2005, the weighted fuel escalation rate was 1.85%.

Since deregulation of electrical utility companies beginning in 2001, a fix has been placed on the residential cost of electricity for the next 5 years [4-14]. Beginning in 2006, it is expected that electricity rates will increase in a similar fashion to natural gas prices. Considering the fact that, locally, energy escalation rates have been about 1.85% between 1995 and 2005, we bracket the study with energy escalation rates between 1% and 4% annually over the 35 year economic lifetime of the Eco-house. The magnitude of

annual growth rates can be visualized by applying the rule of seventy, which states that the doubling time is approximately equal to the ratio of 70 and the annual rate of increase. Thus, a 1% annual increase corresponds to a doubling of the real cost of energy every 70 years. A 4% increase corresponds to a doubling every 18 years. In addition, the possibility of increasing energy supply disruptions is very real [4-15]. Although the economic consequences of supply disruption may be large, they are not considered here.

### **Baseline and Eco-house Energy Costs**

Annual energy costs for the old baseline, new baseline and Eco-house are calculated for the bracketed annual fuel escalation rates of 1% and 4% over the 35 year lifetime that the University allots to a house. As seen in Figure 4-3, the cost of operating the old baseline and new baseline houses varies significantly more than the cost of operating the Eco-house. This is seen in the flatness of the annual energy costs for the Eco-house and the steepness of the annual energy costs for new construction. Energy costs are subject to a high degree of variability and cannot be determined by the university. An additional benefit of the Eco-house is that it eliminates the risk of energy shortages or sharply increasing prices.

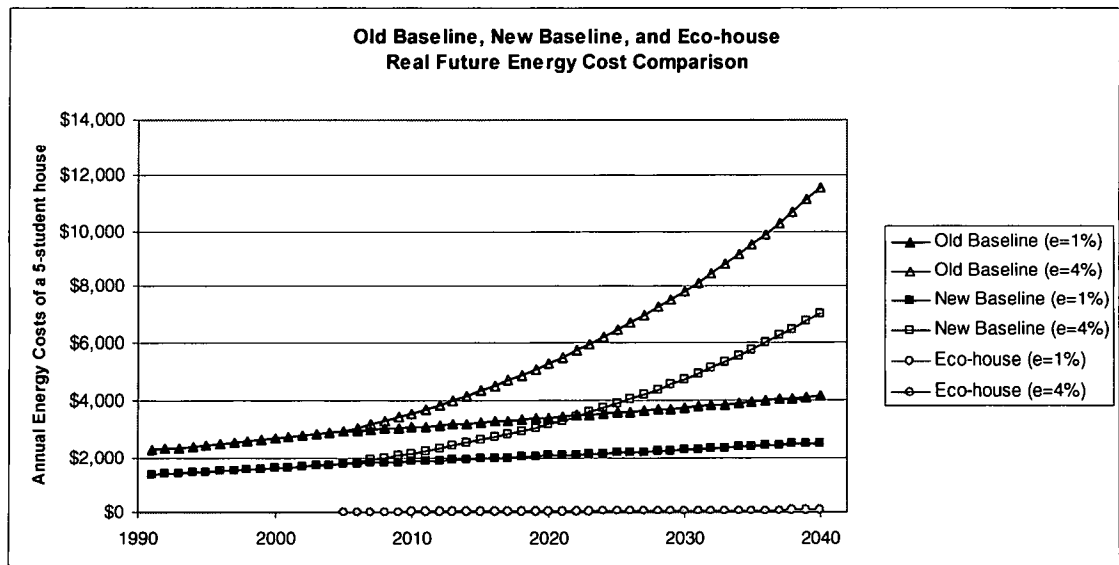


Figure 4-3: Old Baseline, New Baseline, and Eco-house Real Future Energy Cost Comparison

### **Baseline and Eco-house Owning and Energy Costs**

In order to compare owning and operating costs of the new baseline and Eco-house, present values of owning and energy costs are calculated. A schematic of the owning and energy costs for a residence over the lifetime of the residence is shown in Figure 4-4.

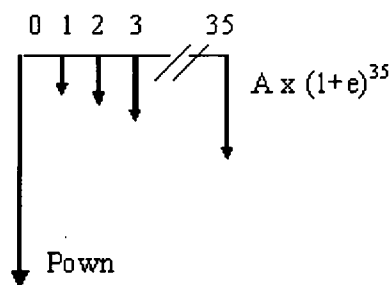


Figure 4: Owning and Energy Cost Schematic.

The present value of the owning and energy costs,  $P_{own,eng}$  is the sum of the present values of the owning,  $P_{own}$ , and energy,  $P_{eng}$ , costs.

$$\begin{aligned} \text{Pengy} &= A \times \text{ESPWF}(i,e,n) \\ &= A \frac{1}{(i-e)} \left[ 1 - \left( \frac{1+e}{1+i} \right)^n \right] \end{aligned}$$

$$\text{Pown,engy} = \text{Pown} + \text{Pengy}$$

where ESPWF(i,e,n) is the escalating series present worth factor.

### **Owning and Energy costs for New Baseline**

In 2005, a typical new 5-student house costs \$225,000 fully-furnished with appliances, painting and carpeting. To finance the house, the University of Dayton typically borrows \$225,000 at a 5% interest rate over a 20 year period. The economic lifetime of the house is 35 years. The largest single operating cost associated with student housing is the cost of energy. The annual energy cost for new baseline houses is \$1,940.

### **Owning and Energy Costs for Eco-house**

The Eco-house design is similar in size and layout to the new baseline houses currently constructed at UD. Thus, the cost of construction of the Eco-house is the added cost of Eco-house components and cost of construction of the baseline house. The additional costs of constructing the UD Eco-house are summarized in Table 4-9. Significant additional costs are solar PV, solar hot water systems, and data monitoring. The predicted net additional cost is \$46,657. Not every change in the design of the new baseline house is more expensive. Some changes eliminate traditional systems and save on the construction cost. For example, in the replacement of a traditional furnace and air conditioner, with an air to air heat pump, the costs of the furnace and air conditioner are eliminated. Also, the sole use of electricity eliminates the need for a natural gas hookup.

Table 4-9: Summary of Eco-House Net Additional Costs

Components	Baseline	Eco-house	Net Addition
Walls / Roof	\$25,200	\$31,300	\$6,100
Windows	\$3,684	\$4,254	\$570
Furnace	\$1,978	\$0	-\$1,978
Air Conditioner	\$650	\$0	-\$650
Heat Pump	\$0	\$2,775	\$2,775
Heat Exchanger	\$0	\$561	\$561
Hot Water	\$480	\$3,735	\$3,255
Clothes Washer/Dryer	\$648	\$988	\$340
Refrigerator	\$449	\$679	\$230
Dish Washer	\$279	\$780	\$501
Solar PV	\$0	\$34,953	\$34,953
Data monitoring	\$0	\$3,000	\$3,000
Natural Gas hookup	\$3,000	\$0	-\$3,000
Total	\$33,368	\$83,025	\$46,657

The present value of owning costs of the Eco-house would be about \$271,657.

Current annual energy costs of the UD Eco-house will be \$29 per year. The present value of the owning and energy costs is shown in the Table 4-10.

Table 4-10. Present Value of Owning and Energy Costs for New Baseline and Eco-house

	New Construction		Eco-house	
Fuel Escalation Rate 2005 to Future	0.01	0.04	0.01	0.04
Real Discount Rate	0.05	0.05	0.05	0.05
Annual Energy Cost (\$/yr)	\$1,949	\$1,949	\$29	\$29
Lifetime (yrs)	35	35	35	35
Escalating Series Present Worth Factor	18.6	28.5	18.6	28.5
Lifetime Owning Cost (\$)	\$225,000	\$225,000	\$271,657	\$271,657
Lifetime Energy Cost (\$)	\$36,212	\$55,471	\$539	\$825
Lifetime Owning and Operating Cost (\$)	\$261,212	\$280,471	\$272,196	\$272,482

At an annual fuel escalation rate of 1%, the present values of owning and energy costs are \$261,212 and \$272,196 for the new baseline and Eco-house, respectively. At an annual fuel escalation rate of 4%, the present values of owning and energy costs are

\$280,471 and \$272,482 for the new baseline and Eco-house, respectively. At an annual fuel escalation rate of 1%, the Eco-house is less cost-effective than the new baseline. However, at an annual fuel escalation rate of 4%, the Eco-house is more cost-effective than the new baseline.

In addition to supporting the university's commitment to sustainability and environmental stewardship, the Eco-house would be cost-effective to build and operate over a life-cycle of 35 years. If the Eco-house is operated for more than 35 years, additional energy savings will be accrued. Additional externalities such as publicity for the University and attraction of new students could easily add to the cost effectiveness of the Eco-house. Further, the Eco-house will provide a living-learning community where students will be encouraged to study the effect of technological improvements and occupant behavior on energy consumption. The Eco-house will begin construction in March, 2006. It will be finished by August, 2006, when students will move in. Occupants will monitor building performance through instantaneous monitoring equipment. Thermocouples, humidity sensors and power meters will be installed to enable monitoring.

### **Summary**

At an annual fuel escalation rate of 4%, the present values of owning and energy costs are \$280,471 and \$272,482 for the new baseline and Eco-house, respectively. The current cost of natural gas in the Dayton area is \$12.50 per mmBtu and the cost of electricity is about \$0.088 per kWh. Using these unit costs, the energy cost savings from the Eco-house compared to the old baseline house and new baseline house will be \$3,340 and \$1,910 in the first year, respectively. The Eco-house will save about 163 mmBtu per

year in natural gas use and 15,581 kWh per year in electricity over the old baseline house, and 61.2 mmBtu per year in natural gas use and 13,455 kWh per year in electricity over the new baseline house.

Assuming the total efficiency of the electrical generation and distribution is 30%, the total source energy savings from the Eco-house compared to the old baseline house and new baseline house will be about 340 mmBtu per year, and 214 mmBtu per year, respectively. Assuming 2.3 lbs CO<sub>2</sub> per kWh of electricity (NRDC, 1998) and 113 lbs CO<sub>2</sub> per mmBtu of natural gas, total CO<sub>2</sub> emissions for the old and new baseline houses are about 53,713 lbs per year and 37,964 lbs CO<sub>2</sub> per year, respectively. The Eco-house will generate no net CO<sub>2</sub> emissions.

### ***Eco-house Project Continuation***

Another paper about the UD Eco-house will be published, as its two predecessors, at the ASME International Solar Energy Conference by George Mertz, Greg Raffio, and Dr. Kelly Kissock.



## **Chapter 5**

# **Targeting Residential Energy Assistance with Multi-site Analysis**

### ***Abstract***

This chapter describes a four-step method to analyze the utility bills and weather data from multiple residences to target buildings for specific energy conservation retrofits. The method is also useful for focusing energy assessments on the most promising opportunities. The first step of the method is to create a three-parameter change-point regression model of energy use versus weather for each building and fuel type. The three model parameters represent weather independent energy use, the building heating or cooling coefficient and the building balance-point temperature. The second step is to drive the models using typical TMY2 weather data to determine Normalized Annual Consumption (NAC) for each fuel type. The third step is to create a sliding NAC with each set of 12 sequential months of utility data. The final step is to benchmark the NACs and coefficients of multiple buildings to identify average, best and worst energy performers, and how the performance of each building has changed over time. The method identifies billing errors, normalizes energy use for changing weather, prioritizes sites for specific energy-efficiency retrofits and tracks weather-normalized changes in energy use. This chapter describes the method, then demonstrates the method through a case study of about 300 low-income residences. After applying the method, targeted

buildings were visited to determine the accuracy of the method at identifying energy efficiency opportunities. The case study shows that over 80% of the targeted buildings presented at least one of the expected problems from each type of retrofit.

## ***Introduction***

Today, companies, governments, and individuals are reducing their energy use for both environmental and economic reasons. This paper describes a four-step method to analyze the utility bills and weather data from multiple residences to target buildings for specific energy conservation retrofits. It enables analysts to identify buildings with the greatest energy saving opportunities from a broader group of buildings, prior to visiting the sites. Further, it clearly identifies the best type of retrofit, and how the buildings energy use performance changes over time. Thus, it is able to derive a significant quantity of actionable information from simple utility bills and readily available weather data.

The method of regressing utility billing data against weather data presented here is a derivation of the Princeton Scorekeeping Method, PRISM [5-1], with a few important differences. First, the method presented here uses change-point models [5-2, 5-3] instead of the variable-base degree-day models used by PRISM. Second, this method uses TMY2 data, rather than an average of 10 years of data, as 'typical' weather. The interpretation of regression coefficients, also builds on early work by Goldberg and Fels [5-4] and by Rabl [5-5], Rabl et al. [5-6] and Reddy, [5-7]. Principle differences between this work and the aforementioned papers are that this work seeks to use inverse modeling proactively to identify energy saving opportunities rather than retroactively to measure energy savings, this work tracks changes in building performance using sliding

analysis, and this work uses comparisons between multiple buildings to extract additional information.

### ***Overview of the Method***

The first step of the method is to create statistical three-parameter models of each building's electricity and fuel use as functions of outdoor air temperature using data from utility bills and actual weather data. These models represent the energy signatures of the building, and the three model coefficients represent weather-independent energy use, building balance temperature and the total heating/cooling coefficient. The building balance temperature is the outdoor air temperature below/above which space heating/cooling begins. The total heating/cooling coefficient is the quotient of the building heat gain coefficient, UA, and the efficiency of the space heating/cooling equipment. The weather-independent energy use is the base fuel and electricity use which is not affected by outdoor air temperature.

The second step is to drive the energy signature models with typical weather data from TMY2 files [5-8] to determine energy use in a 'normal' weather year. This is called the Normalized Annual Consumption (NAC). The NAC removes the noise associated with changing weather from the utility billing data.

The third step is to determine an energy-signature model and NAC for each set of 12 sequential months of utility billing data. The resulting 'sliding NACs' show how weather-independent energy use changes over time. In addition, the 'sliding coefficients' show how independent energy use, the balance temperature and the heating/cooling coefficient change over time.

The fourth step is to compare the NACs and coefficients of multiple buildings to identify average, best and worst energy performers. For example, buildings with high weather-independent fuel use are good targets for hot-water heater retrofits. Buildings with high balance temperature are good targets for programmable thermostats. Buildings with high heating/cooling coefficients are good targets for envelope or high-efficiency space conditioning equipment retrofits. This information is also useful when conducting energy assessments to identify problem areas even in advance of the site visit. Finally, the benchmarking process enables the user to quantify the 'average' performance of all the buildings, and to quantify how that 'average' changes over time.

### **Description of Data and Software Tools**

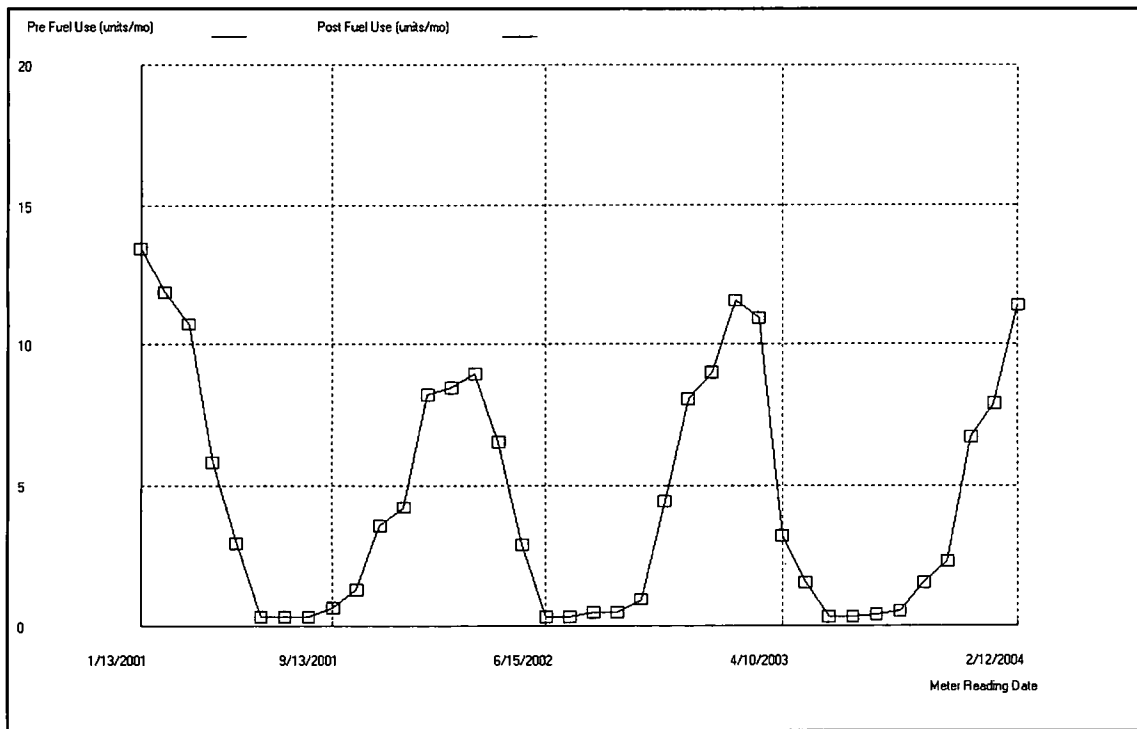
Utility bills are widely available and accurately describe the amount of fuel or electricity delivered to buildings. Thus, this method uses utility bills as the principle source of energy use data. In addition, it is sometimes useful to normalize building energy use by occupancy, floor area or other variables. If deemed useful, energy use from billing data should be normalized prior to further analysis.

The method uses both actual and typical weather data. Actual average daily temperatures for 157 U.S. and 167 international cities from January 1, 1995 to present are available free-of-charge over the internet from the University of Dayton Average Daily Temperature Archive [5-9]. Typical weather data is derived from TMY2 data files [5-8]. TMY2 files contain typical meteorological year (TMY) data sets derived from the 1961-1990 National Solar Radiation Data Base (NSRDB). These files include typical hourly values of solar radiation, ambient temperature, ambient humidity and wind speed over a 1-year period.

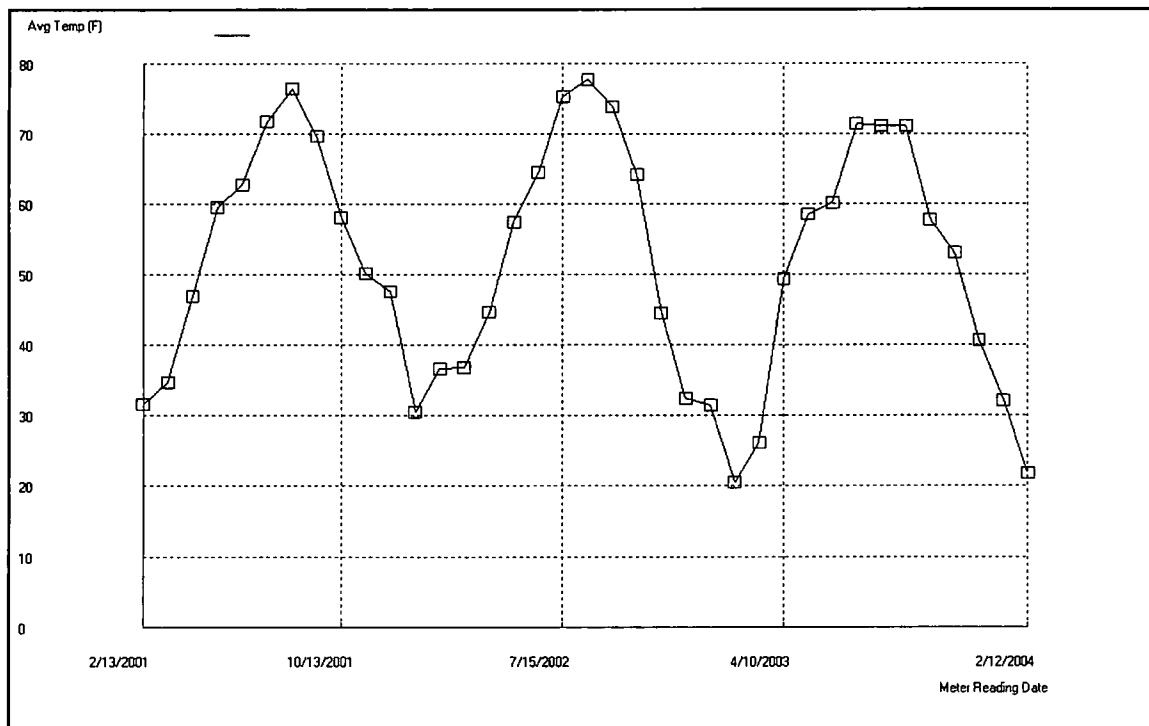
During the first step of this method, utility data is regressed with actual average daily temperature data to identify building energy signature models. These models describe the relationship between building energy use, outdoor air temperature, and other influential variables such as floor area and occupancy. Building energy signature models can be created with several statistical software tools. This work used the ETrackerC software [5-10]. ETrackerC is capable of performing the entire analysis described here on multiple sites.

### ***Step 1: Energy Signature Models***

The first step of the method is to combine utility data with average daily temperature data. It is recommended that at least three years of billing and daily temperature data are used in order to track building energy performance over time. Average daily temperatures should be combined to calculate the average outdoor air temperature during each billing period. Figure 5-1 shows three years of monthly natural gas use and the average outdoor air temperature during each billing period for an example residence.



**Figure 5-1a: Natural gas use for 3 years**



**Figure 5-1b: Average Temperatures for 3 years**

## Multi-Variable Change-Point Models

### Three Parameter Heating Model

The energy use and weather data are then regressed to identify energy signature model for each type of energy use. Figure 5-2 shows the three-parameter heating (3PH) model for the example residence. In this graph, the natural gas use is plotted on the vertical axis and outdoor air temperature is plotted on the horizontal axis. This model shows how natural gas use varies with outdoor air temperature.

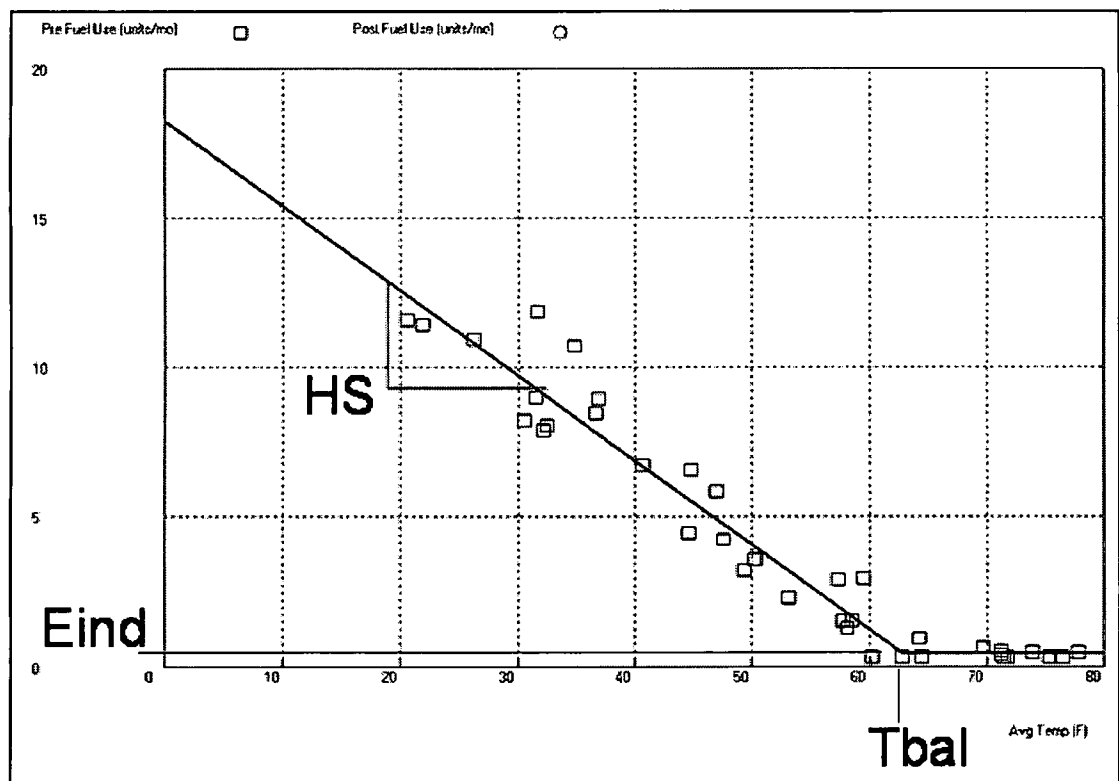


Figure 5-2: 3PH energy model

In a 3PH model, the coefficients represent the weather-independent natural gas use ( $E_{ind}$ ), the building balance temperature ( $T_{bal}$ ), and the total heating coefficient, or heating slope ( $HS$ ). The building balance temperature is the outdoor air temperature below which space heating begins. The total heating coefficient is the quotient of the

building heat gain coefficient (UA) and the efficiency of the space heating equipments (Eff). Thus, the heating coefficient is shown in Equation 5-1.

$$HS = UA/Eff \quad (\text{Equation 5-1})$$

The heating slope is negative because heating energy use increases with decreasing outdoor air temperature. Using this model, the natural gas use can be estimated using Equation 5-2. The superscript <sup>+</sup> indicates that the value of the parenthetic quantity is zero when it evaluates to a negative quantity.

$$\text{Gas Use} = E_{ind} - HS (T_{bal} - T_{oa})^+ \quad (\text{Equation 5-2})$$

### Three Parameter Cooling Model

Figure 5-3 shows an analogous model of electricity use versus outdoor air temperature. In this graph, the electricity use is plotted on the vertical axis and outdoor air temperature is plotted on the horizontal axis.

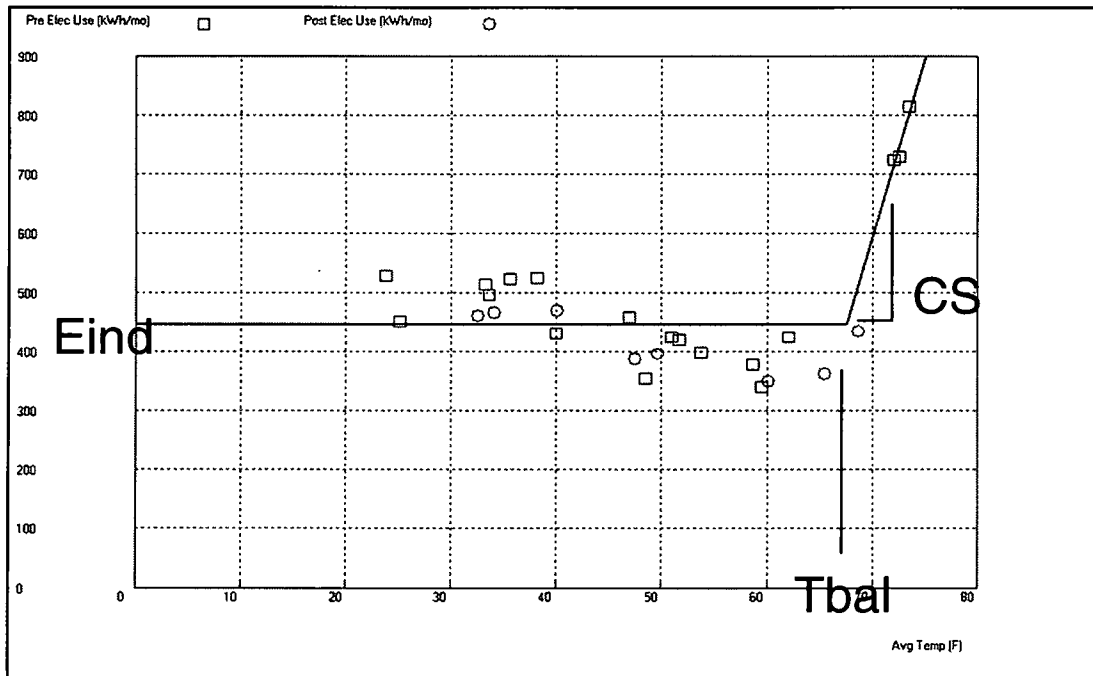


Figure 5-3: 3PC energy model



In a three-parameter cooling (3PC) model, the coefficients represent the weather-independent electricity use ( $E_{ind}$ ), the building balance temperature ( $T_{bal}$ ), and the total cooling coefficient, or cooling slope ( $HS$ ). The cooling slope is positive because electricity use for air conditioning increases with increasing outdoor air temperature. Using this model, electricity use can be estimated using Equation 5-3.

$$\text{Elec Use} = E_{ind} + CS (T_{oa} - T_{bal})^+ \quad (\text{Equation 5-3})$$

### Interpretation of Coefficients

A primary strength of this method is that the model coefficients have physical meaning. In a 3PH model,  $E_{ind}$  represents weather independent energy use. In 3PH models of gas use, this is often related to hot water heater efficiency and the hot water heater temperature set point. In 3PC models of electricity use,  $E_{ind}$  generally represents the general household electricity use from lights and electrical appliances. The balance temperature ( $T_{bal}$ ) represents the outdoor air temperature below or above which space conditioning begins.  $T_{bal}$  is a function of the thermostat setpoint temperature ( $T_{sp}$ ) the internal loads from electricity use, solar gain and people ( $Q_{int}$ ) and the building load coefficient  $UA$  (Equation 5-4).

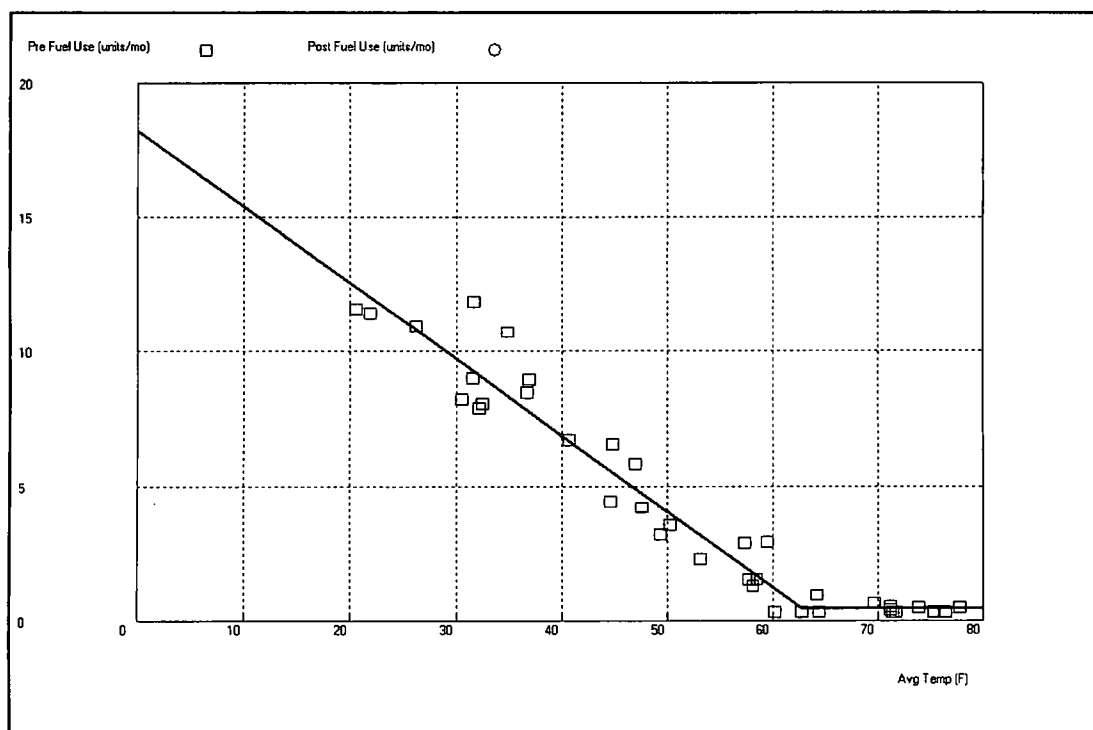
$$T_{bal} = T_{sp} - Q_{int}/UA \quad (\text{Equation 5-4})$$

The heating and cooling slope ( $HS$  and  $CS$ ) are the quotient of the building load coefficient and heating/cooling equipment efficiency. The building load coefficient is determined by envelope insulation and air infiltration through the envelope. The heating and cooling slopes are very important since they cause the most significant change in natural gas and electricity use with the outdoor air temperature.

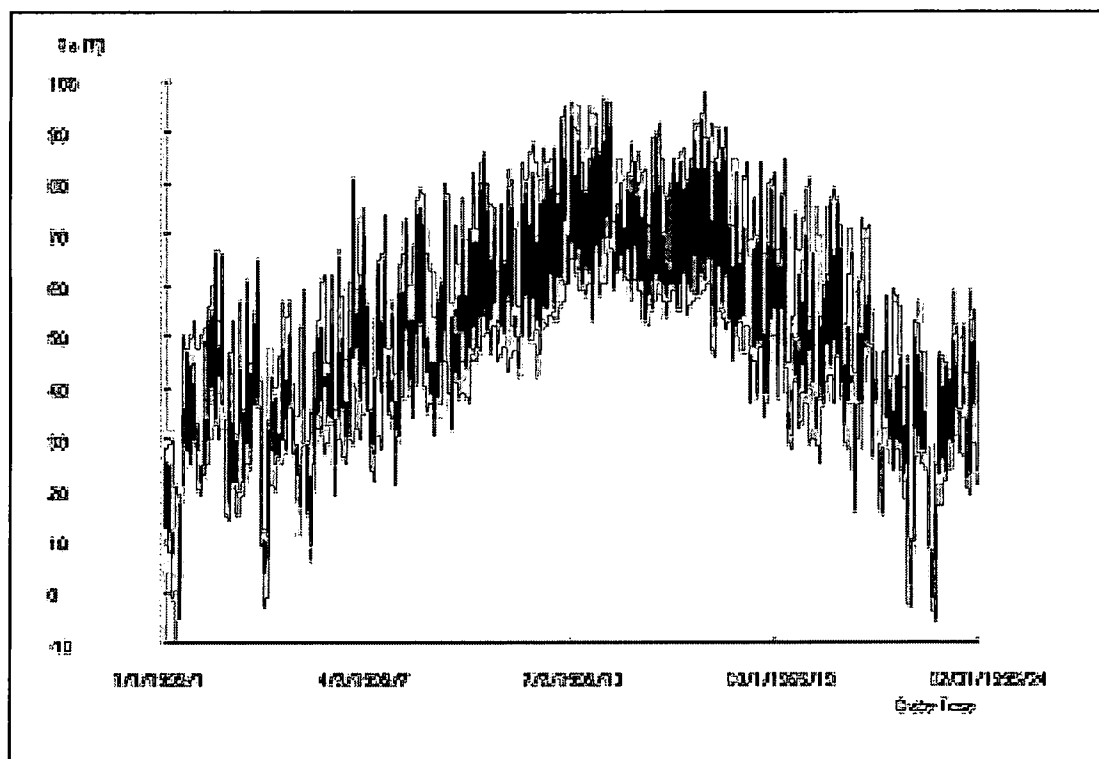
Analyzing the physical meaning of energy signature model coefficients and their relationship to building characteristics enables specific problems to be identified. For example, buildings with high weather-independent fuel use are targets for hot-water heater retrofits, such as reducing hot water set point temperature, fixing hot water leaks, and replacing inefficient water heaters. Buildings with high balance temperatures are targets for programmable thermostats. Buildings with high heating/cooling coefficients are targets for envelope or space conditioning equipment retrofits.

## ***Step 2: Normalize Annual Energy Consumption***

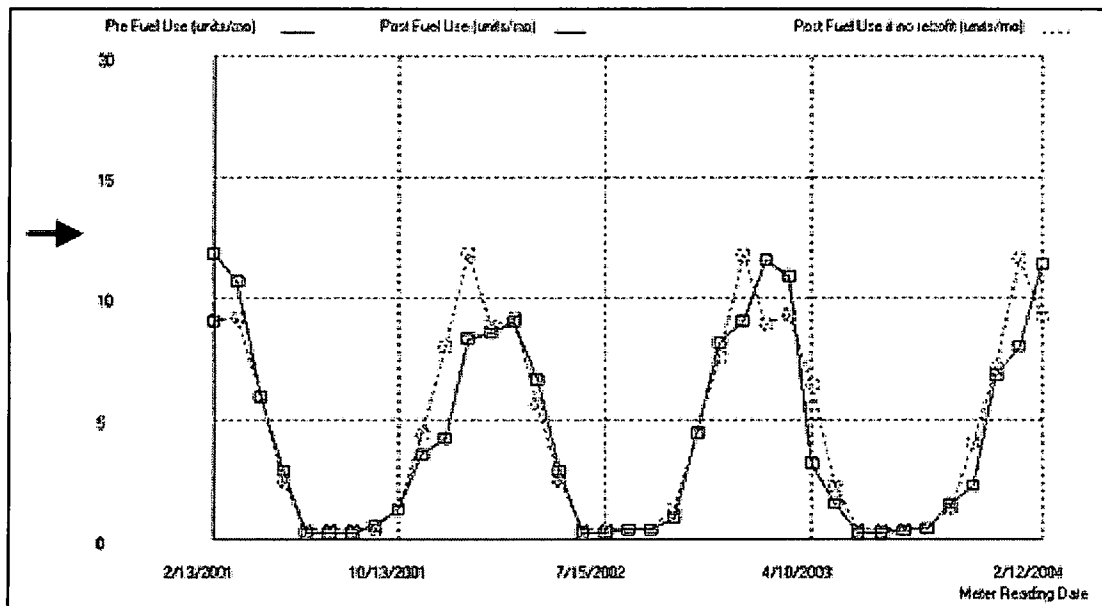
In order to compare or benchmark multiple buildings located in different sites, or to compare the energy use of a single building during different time periods energy signature models should be normalized for weather. Utility bills show the actual annual energy consumption during a billing period. However, that energy consumption might be affected by unusual weather, making it difficult to assess the building's energy performance. Similarly, it is difficult to compare the energy performance of buildings located in different climates. Both of these problems can be eliminated by driving the energy signature model with "typical" weather. The resulting annual energy use is called the Normalized Annual Consumption, (NAC). To calculate the NAC, the energy signature models developed in Step 1 are driven with typical weather data from TMY2 files. Figure 5-4 shows a graphical example of the steps required to calculate the NAC of the example building.



**Figure 5-4a: Energy signature model**



**Figure 5-4b: Typical weather data**



**Figure 5-4c: NAC**

**Figure 5-4: Combining 3PH energy model (a) with typical weather data (b) to derive NAC (c)**

Figure 5-4\_a shows the energy signature model. Figure 5-4\_b shows the one year of hourly outdoor air temperatures from a TMY2 data file. Figure 5-4\_c shows monthly actual consumption and normalized consumption over three years. The actual consumption is represented by the continuous line and the normalized consumption is characterized by the dashed line. The differences between actual and normalized consumption are caused by abnormally warm or cold weather.

Thus, NAC represents the noise-free energy use of a building after changes due to abnormal weather have been removed. As such, NAC reveals the true energy characteristics of buildings, and allows comparison of building energy use between buildings in different climates and over time.

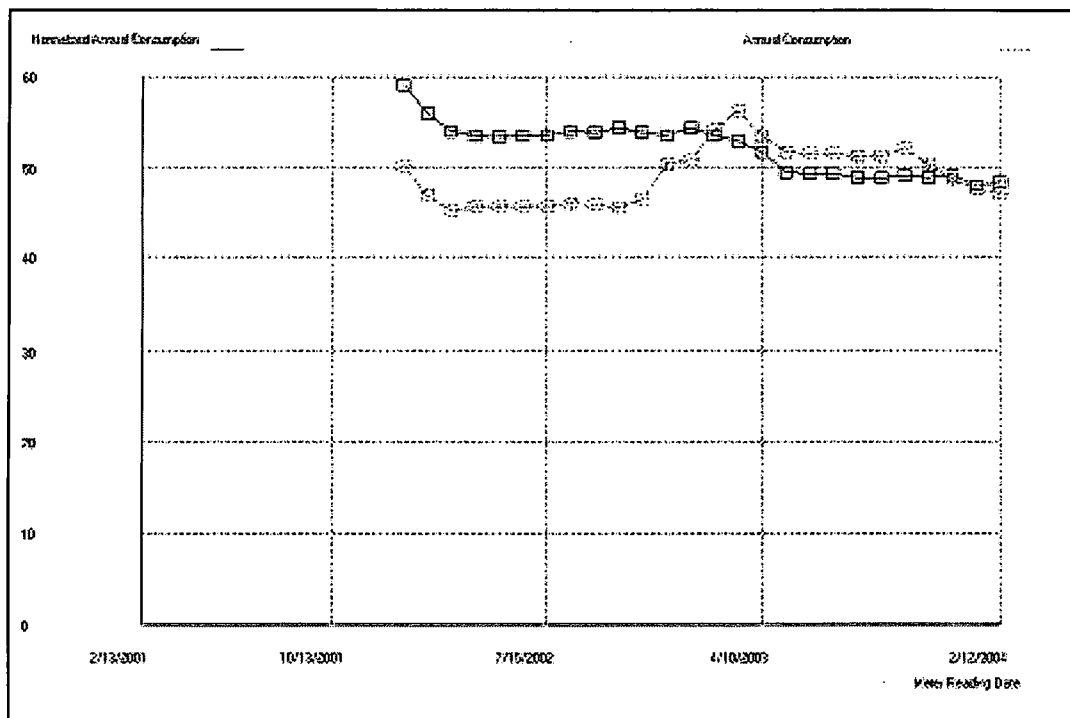
### Step 3: Sliding NAC Analysis

The best way to compare the change in energy characteristics of buildings is by comparing the buildings' NAC during sequential 12-month periods. This is called a 'sliding' NAC analysis. To do so, an energy-signature model is created for each set of 12 sequential months, and then driven with typical weather from a TMY2 file to create a sequence of NACs. Figure 5-5 shows how the building's energy signature model and NAC are computed for sequential 12-month data periods over two years. The sliding NAC analysis illustrates how the building's fundamental energy use characteristics change over time. When these changes are caused by energy conservation retrofits, this sliding analysis provides an accurate measurement of the energy savings. In addition, it can measure persistence of the savings.

Sliding NAC Analysis Data Set	Data set 1												Data set n											
Months	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Data set (Year)	Year 1												Year n											
Months	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Sliding NAC Analysis Data Set	Data set 2																							

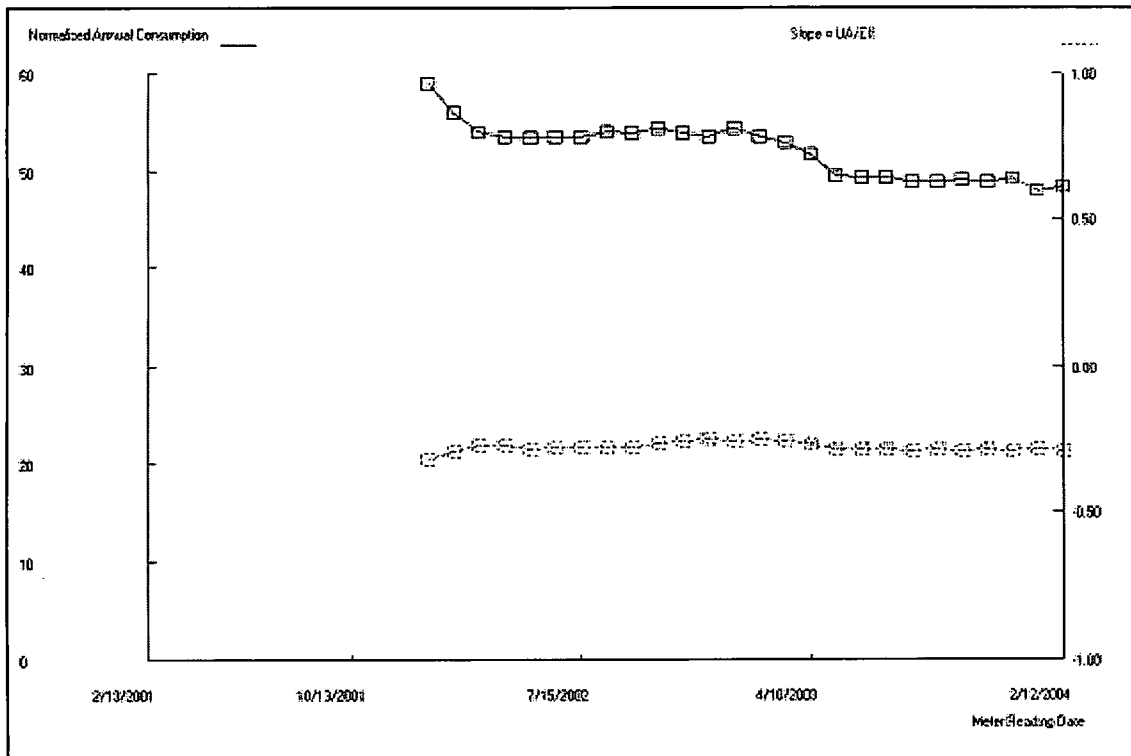
**Figure 5-5: Graphical representation of sliding NAC**

Figure 5-6 shows the sliding NAC over three years for the example residence. In this residence, a different set of occupants moved in every year. The dashed line is the actual annual consumption (AC); the solid line is the NAC. During the first year, both AC and NAC remain steady. The NAC is greater than the AC, which means that the weather was unusually mild. However, during the second year the AC increases, which appears to indicate that the building became noticeably *less* energy efficient. However, the NAC decreases, which shows that the building actually became *more* energy efficient during the second year. This example shows both the power and necessity of using NAC to understand building energy performance over time.



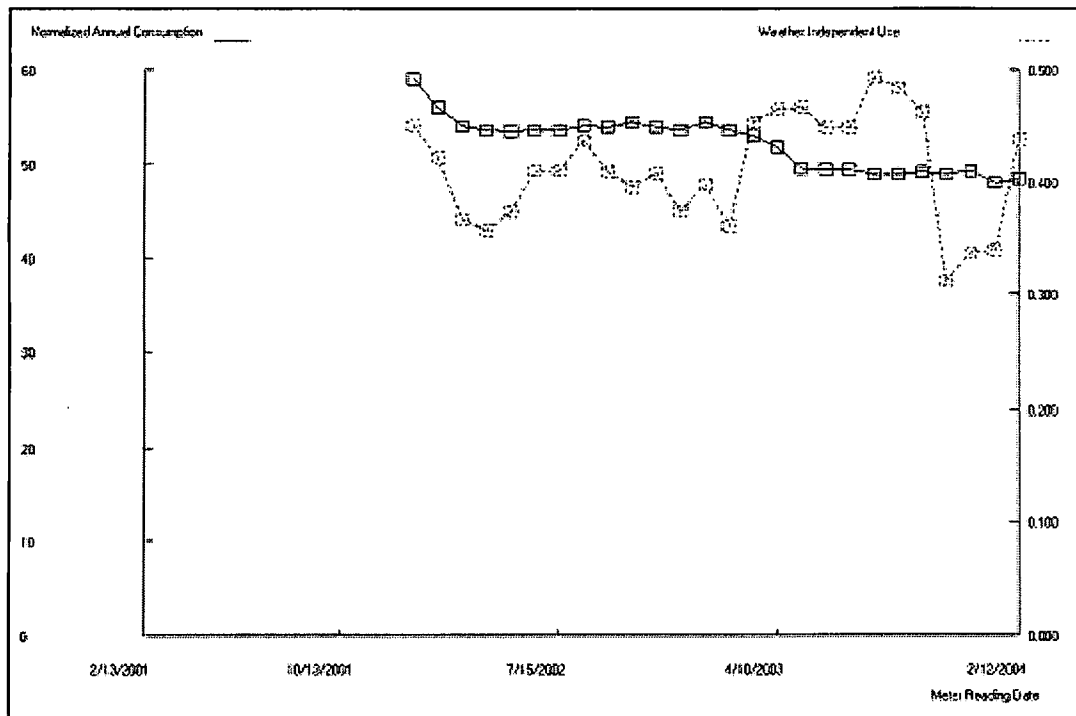
**Figure 5-6: Sliding NAC analysis of typical Dayton residence**

However, even more information can be extracted from this analysis by tracking the values of the model coefficients over time. Changes in NAC are caused by changes in model coefficients. Thus, a sliding analysis of model coefficients can identify the cause of a change in NAC. Figure 5-7 shows how heating slope (HS) and NAC vary over time. The dashed line is the heating slope and the solid line is the NAC. The HS remains steady over time. Thus, the reduction in NAC is not caused by an improvement to the building's envelope or space heating equipment.



**Figure 5-7: Sliding NAC analysis compared to heating slope**

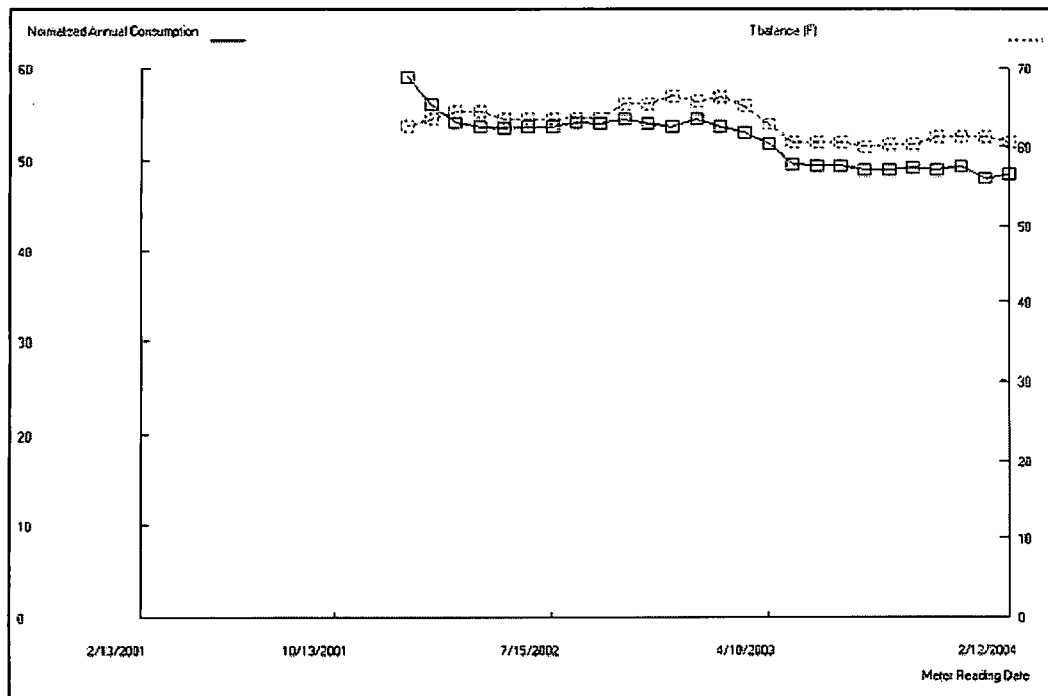
Figure 5-8 shows how weather-independent energy use ( $E_{ind}$ ) and NAC vary over time. The dashed line is  $E_{ind}$  and the solid line is NAC. Although  $E_{ind}$  varies over time, in this building  $E_{ind}$  is too small to have a significant effect on NAC. Thus, in this case, the reduction in NAC is not caused by the variations in  $E_{ind}$ .



**Figure 5-8: Sliding NAC analysis compared to independent energy use**

Figure 5-9 shows how the building's balance-point temperature ( $T_{bal}$ ) and NAC vary over time. The dashed line is  $T_{bal}$  and the solid line is NAC. The graph shows that after one year, the balance temperature was lowered, which caused the decrease in NAC. Thus, the reduction in NAC was caused either by a reduction in the thermostat set-point temperature or a dramatic increase in internal loads, which is unlikely. Thus, this analysis was able to identify how the building's fundamental energy use changed over time and the cause of this change.





**Figure 5-9: Sliding NAC analysis compared to balance point temperature**

Thus, sliding NAC and coefficient analysis provides a powerful lens through which a building's fundamental energy performance can be understood, and without which it is almost impossible to perceive what is happening. In addition, sliding analysis enables accurate measurement of changes and energy savings from energy conservation retrofits.

#### **Step 4: Benchmarking NAC and Coefficients**

In the fourth step of this method, the NAC and the model coefficients are benchmarked against other buildings to identify best and worst energy performers. In essence, benchmarking provides another dimension to the analysis, and reveals another type of actionable information.

One way to convey this information is to plot NAC and the change in NAC for multiple buildings on orthogonal coordinates. The change in NAC is shown in Equation 5-5.

$$(NAC\_1 - NAC\_n)/NAC\_1 \quad \text{(Equation 5-5)}$$

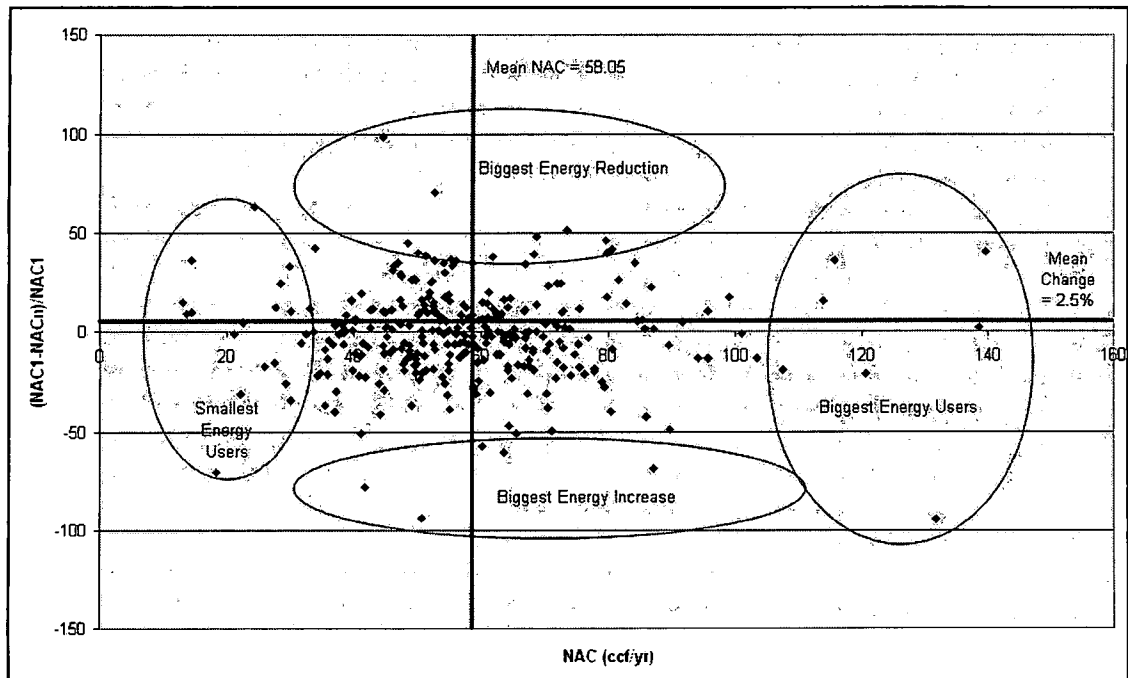
Figure 5-10 shows NAC on the horizontal axis and change in NAC on the vertical axis for 260 low income residences. Buildings on the right side of the chart are the biggest energy users and buildings on the left are the lowest. Buildings near the top of the chart have experienced the greatest reduction in NAC, while the normalized energy consumption of buildings near the bottom has increased. In addition, the mean NAC and change in NAC are shown as lines through the center of each distribution.

This graph conveys a wealth of actionable information for energy managers or analysts. For example, on the horizontal axis, high energy buildings are targets for energy assistance; while low energy buildings can serve as goals or examples of what can be achieved. Similarly, buildings with large energy increases may be experiencing equipment malfunctions or inadvertent changes in operations; while buildings with reducing energy use are examples of improving energy efficiency. The mean NAC defines the center of the distribution and provides a metric for defining “typical” performance and the distribution of performance across all buildings. The mean change

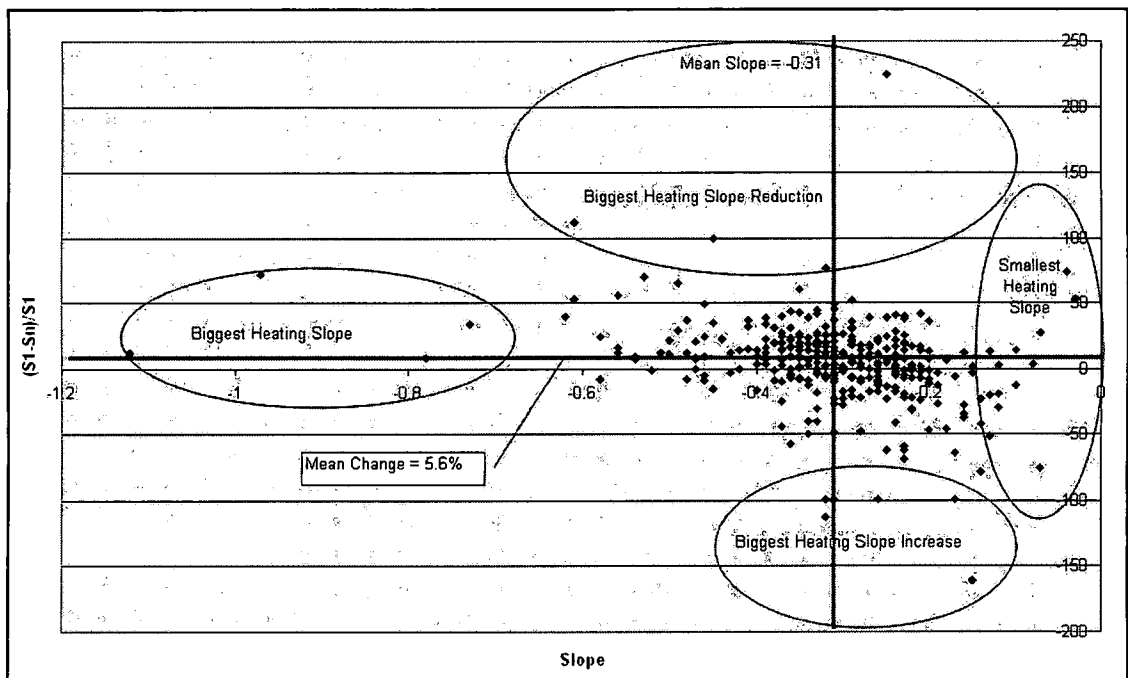
in NAC indicates the magnitude of change in the energy performance of the entire group of buildings, and can be a solid indicator of the success of energy efficiency efforts across large groups of buildings.

Similar plots can be constructed for the model coefficients. As in the case of a single building, analysis of the model coefficients shows why and how NAC has changed. Figure 5-11 shows HS on the horizontal axis and change in HS on the vertical axis for 260 low income residences. Buildings on the right have the largest heating slopes are targets for building envelope and space conditioning equipment retrofits, while buildings on the left demonstrate best practices. Similarly, buildings near the bottom have experienced significant deterioration in the building envelope or space conditioning equipment.

In summary, the fourth step is to compare the NACs and coefficients of multiple buildings to identify average, best, and worst energy performers. Buildings with high weather-independent fuel use are good targets for hot-water heater retrofits, or in the case of electricity, high efficiency lighting and appliances. Buildings with high balance temperature are good targets for programmable thermostats. Buildings with high heating/cooling coefficients are good targets for envelope or high-efficiency space conditioning equipment retrofits. The center and distribution of all of these indices of performance can be determined, as well as the change in these indices.



**Figure 5-10: NAC and change in NAC for 260 sites**



**Figure 5-11: Heating slope and change in heating slope for 260 buildings**

### ***Case Study: Sorted NAC and Model Coefficients***

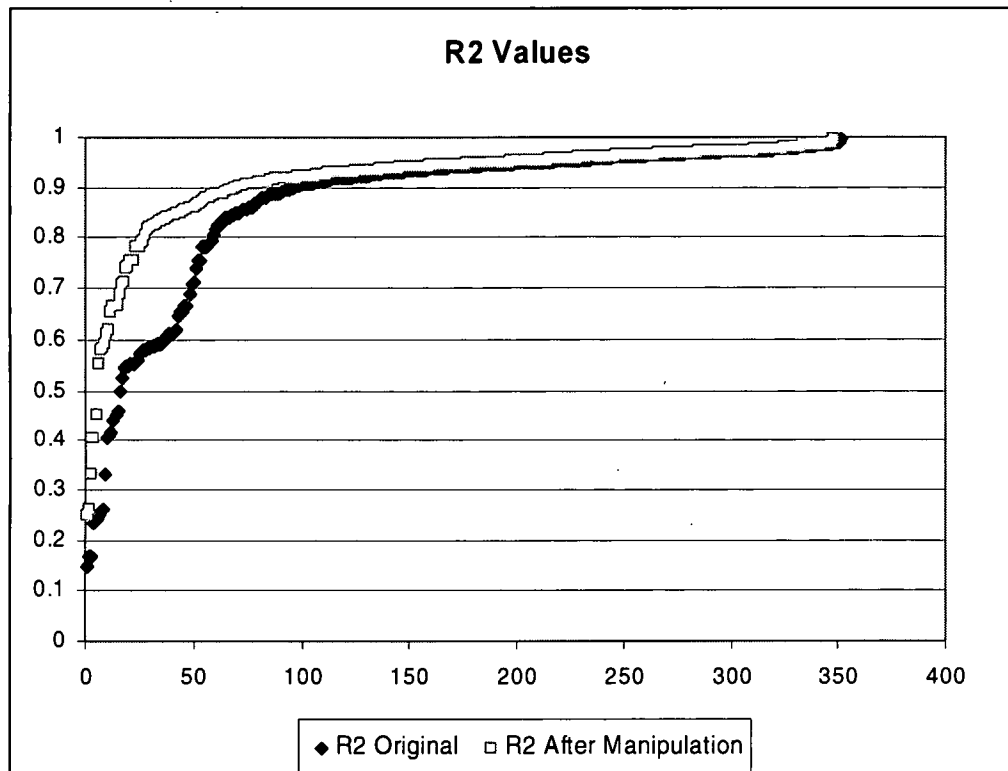
The method and selected results are demonstrated in the following case study of 260 student residences at the University of Dayton. Most of these houses were built in the

early 1900s as housing for factory workers. The houses have minimal insulation and high infiltration rates. Currently UD spends nearly \$1 million per year on gas and electricity for the student neighborhood. A significant portion of this cost is due to irresponsible energy practices [5-11]. These houses provide a good test for targeted residential energy assessment and the measuring the resulting savings

The base data were derived from utility bills between 2/12/2001 and 2/12/2004. Actual and typical weather data was taken from the Average Daily Temperature Archive [5-9] of the University of Dayton and from the TMY2 file for Dayton, Ohio. 3PC and 3PH energy signature models were developed for each of the 260 houses. In this particular case, only the 3PH results are presented.

### **Data and Model Screening**

The 3PH signature models were sorted by  $R^2$  values. Approximately 80% of the buildings had  $R^2$  values greater than 0.80. In many cases, low  $R^2$  were caused by one or more bad data points. It was found that of the original 20% of the houses with  $R^2$  values less than 0.80, half of these were due to data errors. This result shows the ability of the simple 3PH models to accurately characterize gas consumption, and the use of the method to identify billing data errors. Removing houses with errant data resulted in a set of 260 houses. Figure 5-12 shows a plot of the  $R^2$  values of each house model before and after data manipulation.



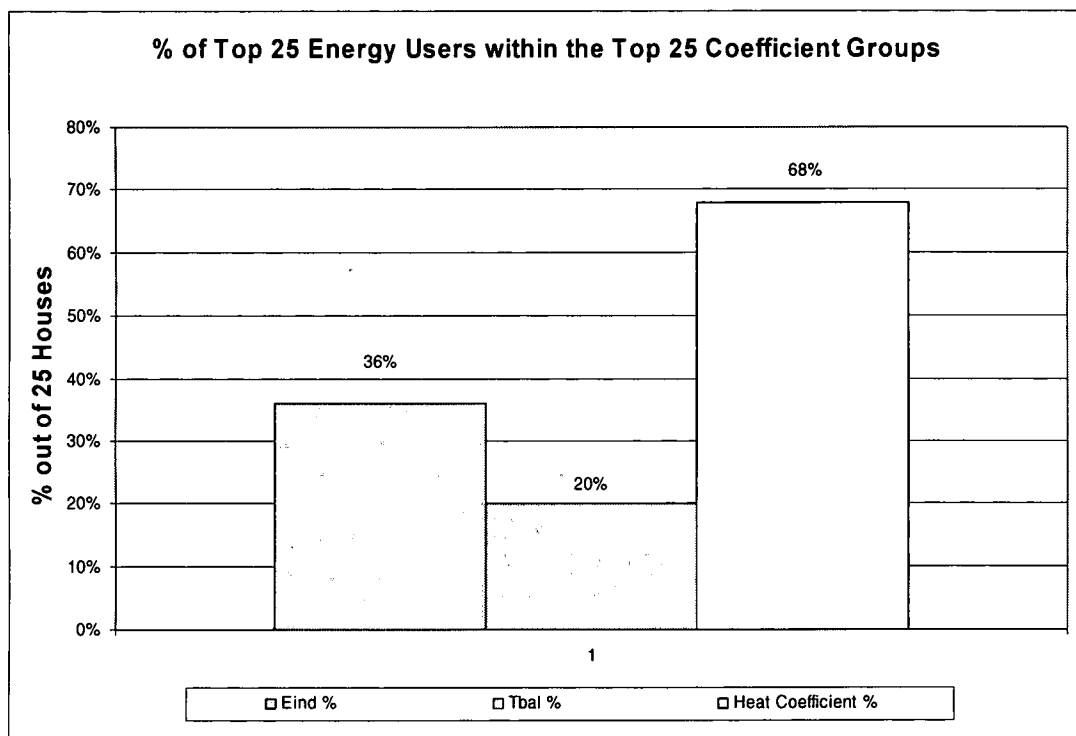
**Figure 5-12:  $R^2$  values before and after data manipulation**

### **Targeting Houses for Energy Efficiency Improvements**

Energy signature models and NACs were calculated for all houses, and the houses were sorted by NAC, HS, Eind and Tbal. In general, houses with the largest NACs are probably the most likely to benefit from energy efficiency improvements. However, sorting by HS, Eind and Tbal is a much more effective way to identify houses most likely to benefit from specific energy efficiency improvements.

For example, Figure 5-13 shows the fraction of the 25 houses with highest NAC that also show up in the top 25 houses sorted by each coefficient. About 80% of the 25 houses with highest NAC were also among the group with the top 25 heating slopes. This shows that poor insulation and low furnace efficiency are the two most significant problems identified in the case study. But perhaps more importantly, it shows that sorting by NAC alone would have missed 20% of the houses with poor building

envelopes or space conditioning equipment. Moreover, 60% of the houses with independent energy use and 80% of the houses with highest balance point temperatures would have also been missed. This underscores the importance of sorting by coefficients to target houses for specific energy efficiency assistance. Sorted coefficient analysis makes it possible to accurately identify what type of retrofit is to be expected, even before visiting the building. This enables houses to be sorted by retrofit type, and maximize the efficiency of energy assistance.



**Figure 5-13: % of top 25 energy users within the top 25 coefficient groups**

## ***Case Study: Site Visits***

### **Prioritization for Retrofits**

Based on the sorted coefficient analysis, the 10 houses with the highest independent gas use, heating slope and balance-point temperature were visited. Each

parameter suggests a different set of possibilities for what is happening in the house. The number of houses with the expected conditions were recorded.

### High Independent Gas Use

In the case of natural gas, weather independent energy use ( $E_{ind}$ ) is primarily for hot water since hot water is used all year. High  $E_{ind}$  generally indicates high water temperature set point, leaking hot water heater or pipes, or a low-efficiency water heater. Table 5-1 shows the frequency with which these issues were identified. Overall, 89% of the houses with high weather independent energy use presented at least one of the expected problems.

**Table 5-1: Summary of case study results ( $E_{ind}$ )**

SUGGESTED ISSUES DRIVING HIGH $E_{ind}$	% OF SIGNIFICANCE (OUT OF 10 HOUSES)
High water Temp. set point	67%
Low efficiency water heater	67%
Natural Gas stove (annual use will drive up the baseline and $Y_{cp}$ )	33%
Boiler (summer boiler instead of furnace)	22%
At least 1	89%

### High Balance Temperature

The balance point temperature, ( $T_{bal}$ ) is a function of thermostat set point temperature, heat from humans, solar radiation and electricity use. High balance point temperature generally indicates high temperature set-point, no night setbacks, and low solar and/or internal gains. Table 5-2 shows the frequency with which these issues were identified. Overall, 100% of the houses with high balance-point temperatures presented at least one of the expected problems.



**Table 5-2: Summary of case study results (Tbal)**

<b>SUGGESTED ISSUES DRIVING HIGH Tbal</b>	<b>% OF SIGNIFICANCE (OUT OF 10 HOUSES)</b>
No night set backs	100%
High UA values (Low Insulation)	70%
At least 1	100%

### **High Heating Slope**

The heating slope (HS) is the quotient of the building load coefficient and efficiency of the space conditioning equipment (Equation 5-1). In general, high HS indicates low furnace efficiency, poor insulation, and high infiltration rates. Table 5-3 shows the frequency with which these issues were identified. Overall, 80% of the houses with heating slopes presented at least one of the expected problems. Low furnace efficiency and high UA (low insulation) are the principal issues driving high HS values

**Table 5-3: Summary of case study results (HS)**

<b>SUGGESTED ISSUES DRIVING HIGH HS</b>	<b>% OF SIGNIFICANCE (OUT OF 10 HOUSES)</b>
Low furnace efficiency	70%
High UA value (Low R Value)	80%
At least 1	80%

This analysis shows that sorted coefficient analysis can effectively identify specific problems and energy saving opportunities.

### **Summary and Conclusions**

This paper describes a four-step method to analyze monthly utility billing and weather data to target residential buildings for energy assistance programs and assessments. The first step of the method is to create three-parameter energy use models. The second and third steps are driving the models using TMY2 data to determine Normalized Annual Consumption (NAC), and creating a sliding NAC with each set of 12 sequential months of utility data. The final step is to benchmark the NACs and coefficients of multiple buildings to identify average, best and worst energy

performers. This paper demonstrates the method through a case study of about 300 low-income residences.

After applying the four step method, targeted buildings were visited to determine the accuracy of the method. Of the houses visited, 89% of the high independent gas use houses, 100% of the high balance temperature houses, and 80% of the high heating slope houses had at least one significant issue as previously identified in the method. Of the high independent gas use houses, the most significant and frequent issues found were high hot water temperature setpoints (66%) and low efficiency hot water heaters (66%). Of the high balance temperature houses, the main issues found were no nighttime setbacks (100%) and high rate of infiltration (drafty houses) (70%). Finally, of the high heating slope houses, the issues were low furnace efficiency (70%) and high UA value (80%). The method is also helpful in identifying billing and transcription errors, which are significant problems for managers of multiple sites.

## **Chapter 6**

### **Energy Analysis and Savings Opportunities For UD Housing: 26 Chambers St.**

#### **Executive Summary**

On December 19, 2005 the University of Dayton Building Energy Analysis Center (UD BEAC) visited the UD owned residence at 26 Chambers St, Dayton, Ohio. With the help of the safety coordinator, we collected energy use, construction data, and occupancy information. The building's current electricity use is 11,578 kWh of electricity per year compared to 8,937 kWh per year for average Midwest homes. The building's current natural gas use is 3,305 ccf per year compared to 910 ccf per year for average Midwest homes. The residence uses about 30% more electricity and 265% more natural gas than typical Midwest homes. About 81% of natural gas use is for space heating and 19% is for water heating.

Using this information, the building's energy use was simulated using hour-by-hour building energy simulation software. Simulated energy use was then compared to actual energy use to calibrate the models. The process of simulating and calibrating energy use allows us to verify our understanding about how the building uses energy and provides a mechanism to estimate potential savings from potential changes. From the Statistical Analysis section of the report, the ratio of the building's UA to efficiency of

the heating plant is 5.7 ccf/dy-F. Its balance point temperature is 62.5 F, and hot water gas use is 17.5 ccf per day.

Based on information gathered, we identified and quantified 8 energy savings opportunities with a total potential savings of \$4,440 per year. The cost of implementation of the 8 recommendations would be about \$9,058. These savings opportunities are summarized in the table below. The body of the report contains more detailed descriptions of how energy is used in the residence, current practices that are already energy efficient, and the energy conservation opportunities identified.

Implementation of these recommendations would reduce electricity use by 3,761kWh per year. Predicted natural gas savings would be about 3,560 ccf per year, however current natural gas use is only 3,305 ccf per year. This is higher than the current annual utility costs and is a result of the fact that each recommendation was considered individually. Synergistic affects arise when multiple building components are changed at once. Together, retrofits will save less than the total of their individual savings. In order to account for the synergistic effects of modifying building characteristics, analysis is performed for all of the proposed building modifications.

Considering synergistic effects, natural gas savings would be about 2,290 ccf per year. Electricity savings would be about 3,761 kWh per year. Cost savings would be about \$3,151 per year. The rate of return on the investment is 49% annually. The simple payback on the investments is 24 months.

## Summary of Assessment Recommendations (ARs)

AR		Annual Savings			Cost	Rate of Return	Simple Payback (months)
		Electrical Energy (kWh)	Natural Gas (mmBtu)	Dollars			
1	Install Blown Cellulose Insulation in Wood Frame Walls	0	87	\$986	\$1,148	86%	14
2	Insulate Hot Water Supply and Return Pipes	0	68	\$770	\$764	101%	12
3	Install Weather Stripping and Caulk to Reduce Infiltration	0	61	\$700	\$100	700%	2
4	Decrease Excess Combustion Air to Hot Water Boiler	0	55	\$685	\$500	137%	9
5	Install Digital Thermostats and Implement Night Setbacks	0	51	\$585	\$96	609%	2
6	Install Compact Fluorescent Lights	3,761	0	\$314	\$0	N/A	Immediate
7	Install New Windows	0	25	\$284	\$5,250	5%	222
8	Replace Existing Water Heater with Tankless Water Heater	0	9	\$116	\$1,200	10%	124
<b>Totals</b>		5,519	356	\$4,440	\$9,058	49%	24

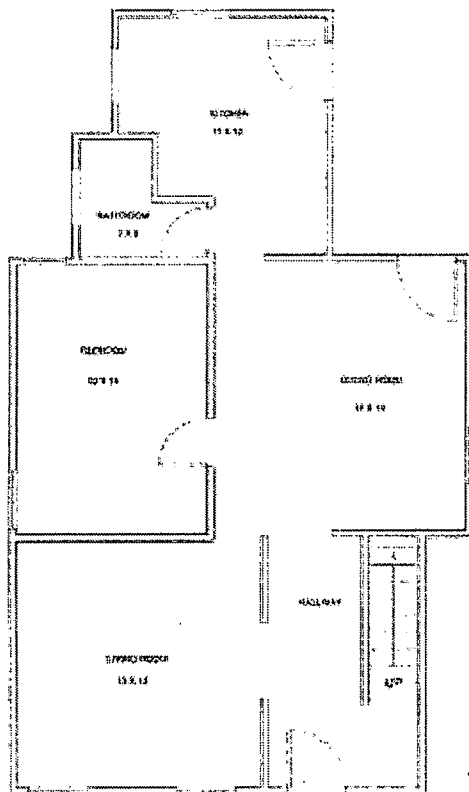
## 26 Chambers Street



### Building Description

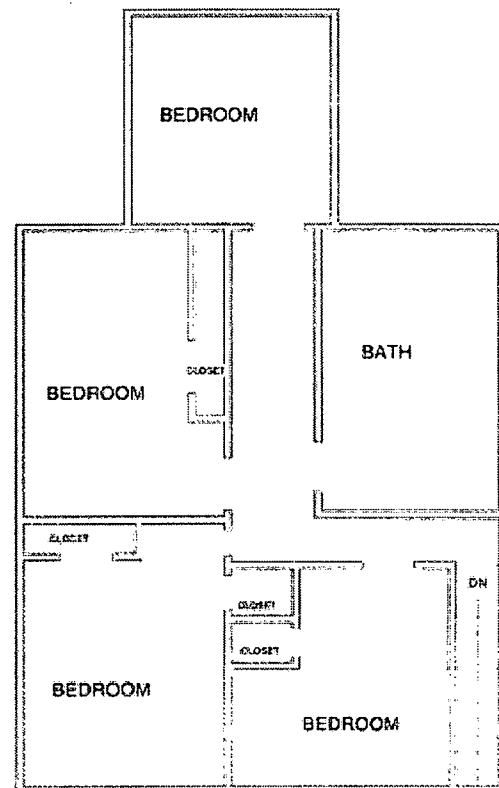
The house has two floors, an attic and a basement. Six residents live on the first and second floors, a total of 1,920 ft<sup>2</sup> conditioned floor space. In addition the attic and basement are about 960 ft<sup>2</sup> unconditioned floor space. The house is heated by a hot water boiler, located in the basement. Hot water is supplied by uninsulated pipes to cast-iron radiators located in the rooms. The supply of heat to the house is adjusted manually through opening and closing of valves on the radiators. No central air conditioning is installed. The house is equipped with single-pane windows. Walls are wood frame construction with no insulation installed. Lighting is provided by 60-W incandescent bulbs.

## House Layout



26 CHAMBERS

REF ID: A66883



26 CHAMBERS

290 PLOCH:

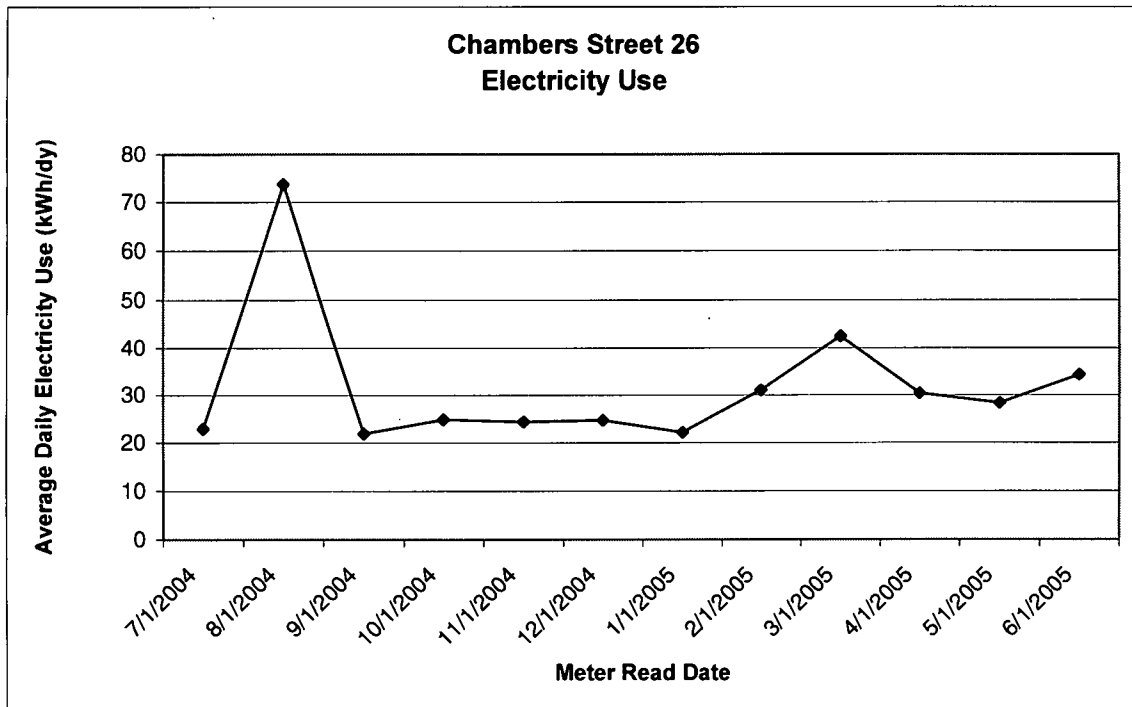
## Utility Summary

Floor Area: 1,920 ft<sup>2</sup>

Number of Occupants: 6

	Annual Usage	Annual Cost	Average Unit Cost	Cost / Area (\$/ft2-yr)	Cost / Occupant (\$/occ-yr)
Electricity	11,578 kWh	\$1,067	\$0.088 /kWh	\$0.56	\$178
Natural Gas	3,305 ccf	\$3,377	\$1.03 /ccf	\$1.76	\$563
Total		\$4,444		\$2.31	\$741

## Electricity



Electricity use for the month of August is significantly higher than other months of the year. This anomaly is typical of UD housing and is a consequence of students moving into an unoccupied space. Refrigerators and air conditioners are turned on and require large amounts of energy to bring about cool temperatures. It is also likely that much social activity takes place during the first month of school with added lighting, stereo and television usage.

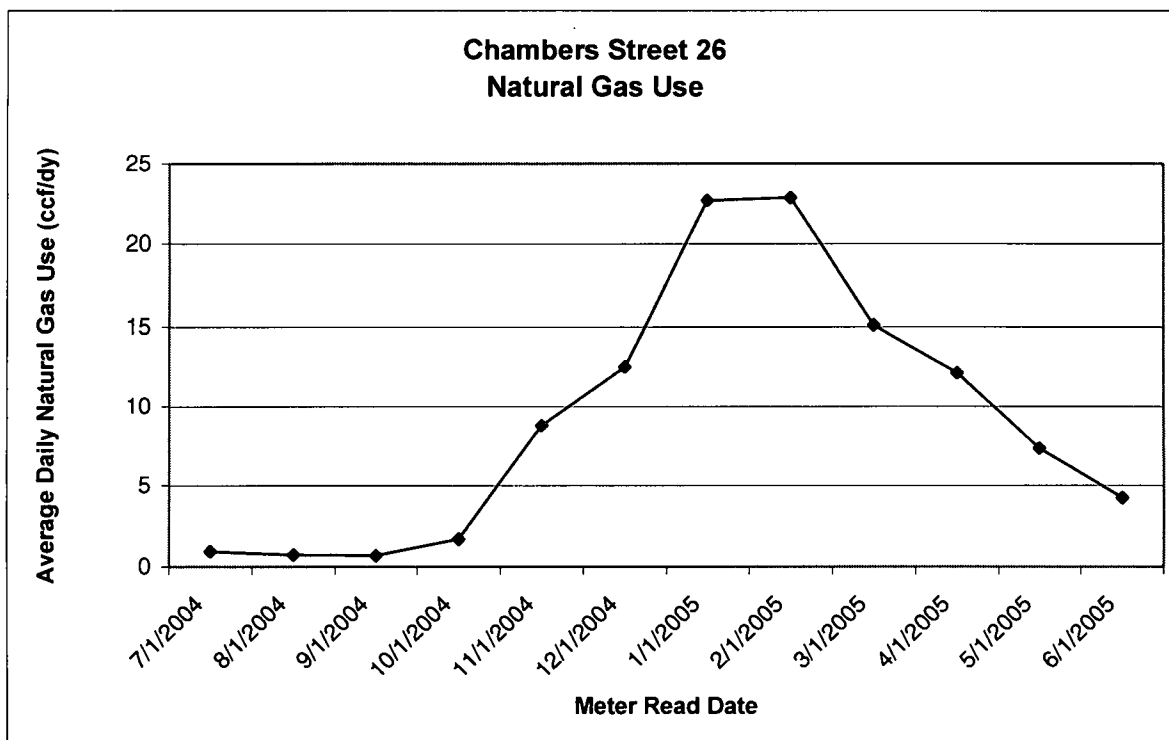


<b>Meter Read Date</b>	<b>Days Per Period</b>	<b>Utility Bill (\$/month)</b>	<b>Monthly Electricity Use (kWh/month)</b>	<b>Daily Electricity Use (kWh/dy)</b>
7/31/2004	30	\$65	688	23
8/31/2004	31	\$205	2,285	74
9/30/2004	30	\$62	655	22
10/31/2004	31	\$72	769	25
11/30/2004	30	\$68	731	24
12/31/2004	31	\$71	765	25
1/31/2005	31	\$64	685	22
2/28/2005	28	\$80	868	31
3/31/2005	31	\$120	1,316	42
4/30/2005	30	\$84	910	30
5/31/2005	31	\$81	879	28
6/30/2005	30	\$94	1,028	34
<b>Total/Average</b>	<b>364</b>	<b>\$1,067</b>	<b>11,578</b>	<b>32</b>

The residence at 26 Chambers St. used 11,578 kWh of electricity in one year.

The average annual electricity use for homes in the Midwest is 8,937 kWh per year. The residence used about 30% more electricity than typical Midwest homes.

## Natural Gas



Meter Read Date	Days Per Period	Utility Bill (\$/month)	Unit Cost (\$/ccf)	Monthly Natural Gas Use (ccf/month)	Daily Natural Gas Use (ccf/dy)
7/31/2004	30	\$30	\$1.05	28	1
8/31/2004	31	\$22	\$0.98	22	1
9/30/2004	30	\$21	\$0.98	22	1
10/31/2004	31	\$51	\$0.97	53	2
11/30/2004	30	\$261	\$0.99	263	9
12/31/2004	31	\$392	\$1.01	388	13
1/31/2005	31	\$693	\$0.99	702	23
2/28/2005	28	\$618	\$0.97	639	23
3/31/2005	31	\$464	\$0.99	469	15
4/30/2005	30	\$417	\$1.15	364	12
5/31/2005	31	\$264	\$1.16	227	7
6/30/2005	30	\$143	\$1.12	127	4
Total/Average	364	\$3,377	\$1.03	3,305	9

The residence at 26 Chambers St. used 3,305 ccf of natural gas in one year. The average annual natural gas use for homes in the Midwest is 910 ccf per year. The

residence used about 265% more natural gas than typical Midwest homes. This suggests that significant natural gas savings opportunities are present.

## Building Energy Simulation

Electricity and natural gas use of 26 Chambers Street was simulated using the hour-by-hour ESim building energy simulation program. To simulate energy use, building characteristics, operating schedules and energy using equipment data were entered into the building description file Chambers\_26.SZB shown below. Simulating current building energy use gives us confidence in our understanding of building characteristics. Through a process of calibration to actual utility data we can better understand the characteristics of the building. We are quickly able to spot errors in building operation, and target areas for improvement.

```

"Building ID"                "Chambers St 26"
"COOLING SET POINTS=====
"Cooling str month"          8
"Cooling end month"          8
"Cool set-point str hr - occ" 1
"Cool set-point end hr - occ" 24
"Cool set-point days/week - occ" 7
"Cool set-point temp - occ"    72
"Cool set-point temp - unocc"  72
"HEATING SET POINTS=====
"Heating str month"          11
"Heating end month"          4
"Heat set-point str hr - occ" 8
"Heat set-point end hr - occ" 22
"Heat set-point days/week - occ" 7
"Heat set-point temp - occ"    72
"Heat set-point temp - unocc"  72
"ROOF=====
"East-West ceil length (ft)"  40
"North-South ceil length (ft)" 24
"Max attic height (0 for flat roofs) (ft)" 9
"Ridgeline: EW, NS, none"      "NS"
"Solar absorptivity of roof: 0 to 1.0" .8
"Rroof+ceil (hr ft2 F / Btu)" 12
"Roof type: attic, steel, 2in-con, 6in-con" "attic"
"WALLS=====
"Rwall (hr ft2 F / Btu)"      4
"Solar absorptivity of walls: 0 to 1.0" 0.3
"Wall type: steel, frame, block, 12in-con" "frame"
"Awall n (ft2)"               348
"Awall s (ft2)"               384
"Awall e (ft2)"               648

```

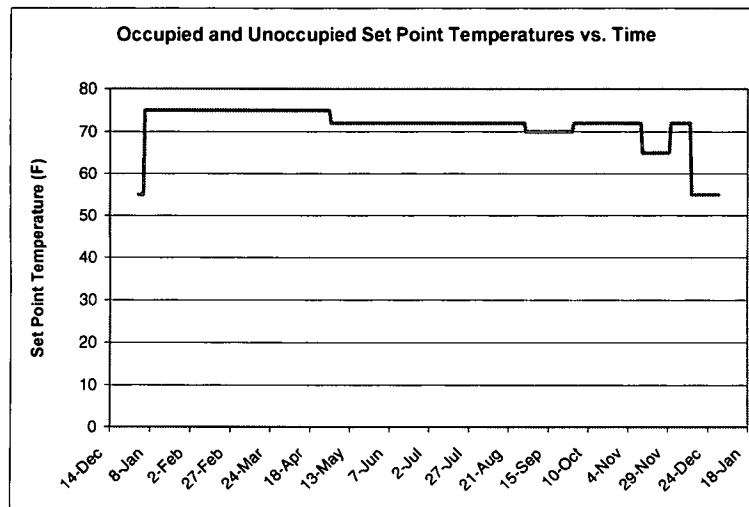
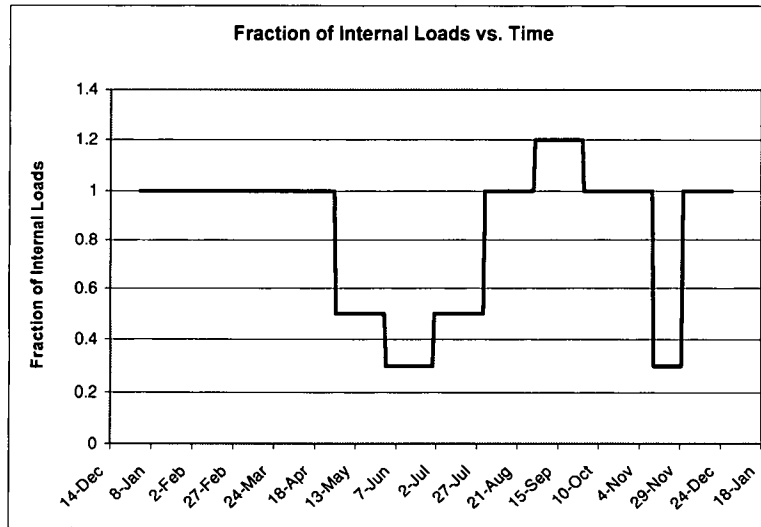
"Awall w (ft2) "	684
"DOORS=====	"
"Rdoors (hr ft2 F / Btu) "	2.5
"Adoors (ft2) "	54
"WINDOWS=====	"
"R center-of-glass (hr ft2 F / Btu) "	.9
"Area glass north (ft2) "	84
"Area glass south (ft2) "	48
"Area glass east (ft2) "	72
"Area glass west (ft2) "	36
"Solar heat gain coef(normal,beam): 0 to 1"	0.9
"Bldg's rotation from true NSEW (degrees) "	0
"Average ground reflectance (0 to 1.0) "	.2
"WINDOW OVERHANGS AND WINGS=====	"
"Protrusion of overhang (ft) "	0
"Gap between overhang and window (ft) "	1
"Height of window (ft) "	3
"Protrusion of wing (ft) "	0
"Gap between wing and window (ft) "	1
"Width of window (ft) "	3
"FLOOR=====	"
"Floor type: slab;hbase;unhbase"	"unhbase"
"Floor weight: wood;3in-con;8in-con"	"wood"
"Perim (ft) "	128
"Afloor (ft2) "	960
"Rfloor (hr ft2 F / Btu) "	5
"Rperim-insul (hr ft2 F / Btu) "	0
"INFILTRATION=====	"
"Infiltration (air changes per hour) "	1.2
"Volume conditioned area (ft3) "	17280
"HOT WATER=====	"
"Vol HW (gal/hr) "	3
"Temp HW (F) "	140
"Efficiency"	.55
"Fuel: elec; ng"	"ng"
"SZB INTERNAL LOADS AND ELEC USE=====	"
"Avg (non-AC) elec cons (kWh/mo) "	845
"Avg num people"	6
"Eoccupied / Eunoccupied"	1
"OTHER ENERGY CONSUMPTION=====	"
"Exterior elec cons (kWh/mo) "	25
"Other ng cons (ccf/mo) "	0
"SZB COOLING AND HEATING EQUIP=====	"
"System type: sd, sdcont, dd or hp"	"sd"
"SEER of air cond (Btu/hrW) "	8
"Efficiency of heating unit"	0.65
"HSPF of heatpump (Btu/W-hr) "	8.3
"Minimum fraction outdoor air"	0
"Economizer: none, temp, enthalpy"	"none"
"Temp of air leaving cooling coil (F) "	60
"Temp of air leaving heating coil (F) "	120
"Total supply air {about 1 cfm/ft2} (cfm) "	1920
"Cooling coil: on, off"	"on"
"Heating coil: on, off"	"on"
"END CODE=====	"
"End code"	-99

Daily occupancy data were entered in a file called UD.occ file. The first ten lines of UD.occ are shown below. The occupancy file is a way to account for changing occupancy and thermostat set points during holidays. The last two columns show zone

set point temperatures. For the University of Dayton, adjustments are typically made for summer occupancy and winter holiday occupancy. The University requires maintenance to turn down temperature set points to 60 F over the Christmas Holidays. Additionally, since students are gone during the summer, internal electricity use is reduced.

Month	Day	Fraction of Internal Loads	Occupied Temperature Set Point	Unoccupied Temperature Set Point
1	1	1	55	55
1	2	1	55	55
1	3	1	55	55
1	4	1	55	55
1	5	1	75	75
1	6	1	75	75
1	7	1	75	75
1	8	1	75	75
1	9	1	75	75
1	10	1	75	75

The fraction of internal loads and set point temperatures are shown in the charts below. Internal loads decrease during summer and increase when students first come back to school. They also decrease during unoccupied times such as thanksgiving and Christmas.

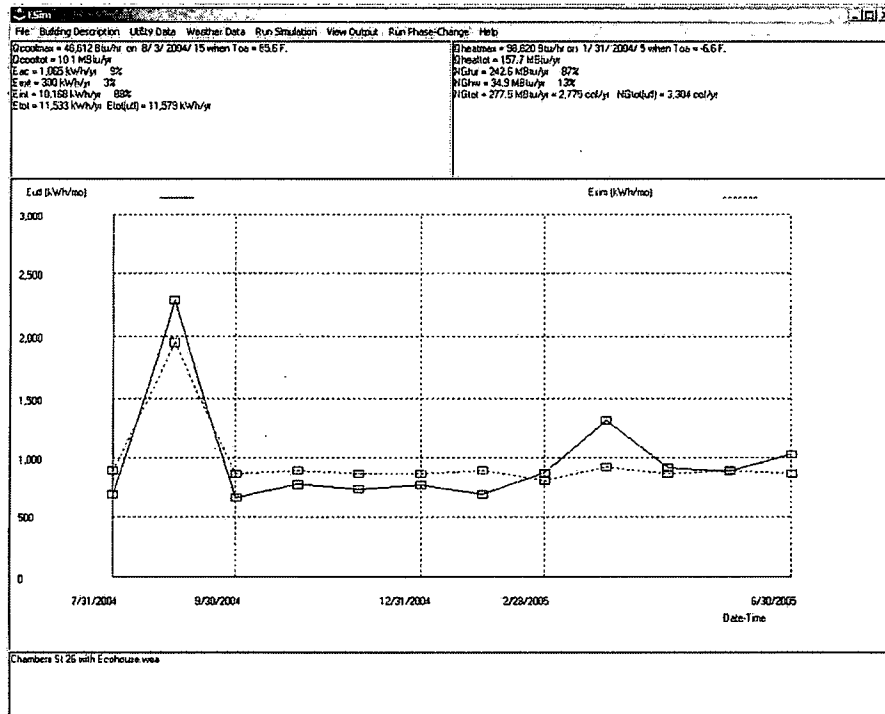


The actual monthly energy use data from May 2003 to March 2004 were entered in the Chambers\_26.UTL file shown below. The first three columns show meter reading month day and year. Column four is electricity use (kWh), and column six is natural gas use (ccf).

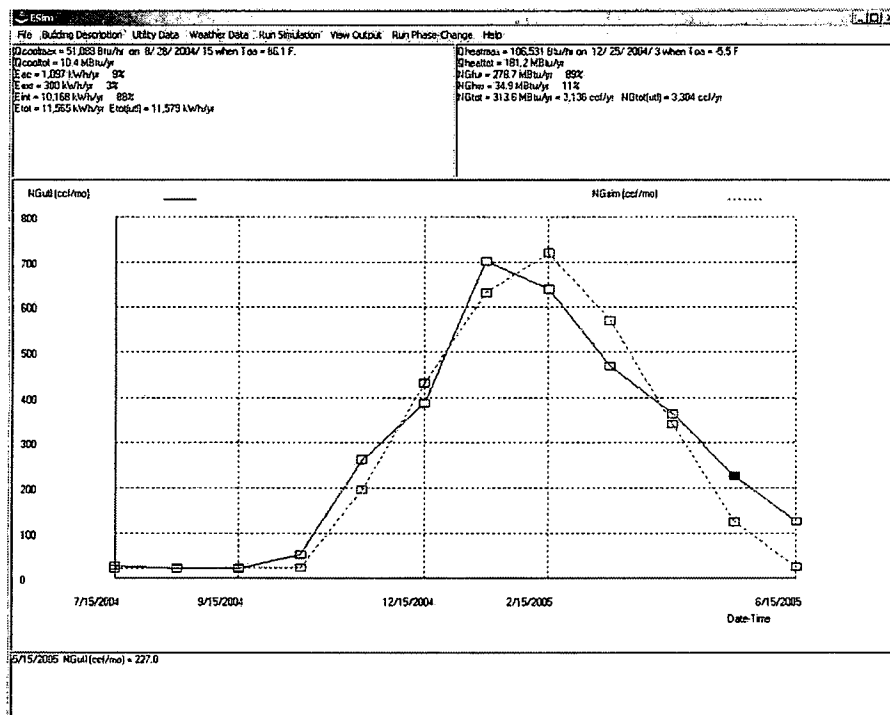
Month	Day	Year	Electricity Consumption (kWh/period)	Electrical Demand (kW)	Natural Gas Consumption (ccf/month)
6	30	2004	-99	-99	-99
7	31	2004	688	-99	28
8	31	2004	2285	-99	22
9	30	2004	655	-99	22
10	31	2004	769	-99	53
11	30	2004	731	-99	263
12	31	2004	765	-99	388
1	31	2005	685	-99	702
2	28	2005	868	-99	639
3	31	2005	1316	-99	469
4	30	2005	910	-99	364
5	31	2005	879	-99	227
6	30	2005	1028	-99	127

One year of hourly meteorological data from the same period as the energy use data were synthesized from actual average daily temperatures during this period and typical correlations between solar radiation, humidity and air temperature from nearby Dayton, OH. The actual average daily temperatures were from the UD/EPA Average Daily Temperature Archive at [www.engr.udayton.edu/weather](http://www.engr.udayton.edu/weather). The typical correlations between solar radiation, humidity and air temperature were derived from Typical Meteorological Year data from [http://rredc.nrel.gov/solar/old\\_data/nsrdb/tmy2/](http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/). The resulting hourly weather file was called UD\_2004\_2005.wea.

The figures below show simulated (dashed line) and actual (solid line) monthly electricity and natural gas use. The relatively good agreement between simulated and actual electricity and natural gas use increases confidence in the simulation model. By modifying the building characteristic file, building improvements can be modeled and savings predicted. ESim can predict savings for many retrofit measures. ESim can predict savings for temperature setbacks, higher insulation, reduced infiltration, and increasing furnace, water heater, or air conditioner efficiency.



Simulated Monthly Electricity Use



Simulated Monthly Natural Gas Use



## Statistical Analysis of Electricity and Natural Gas Use

Statistical Analysis offers a baseline characterization of energy use. These models can be used for budgeting purposes to predict future energy consumption based on predicted outdoor air temperature. As well, savings from implementation of energy-efficiency measures can be quantified using this facility model against future energy use.

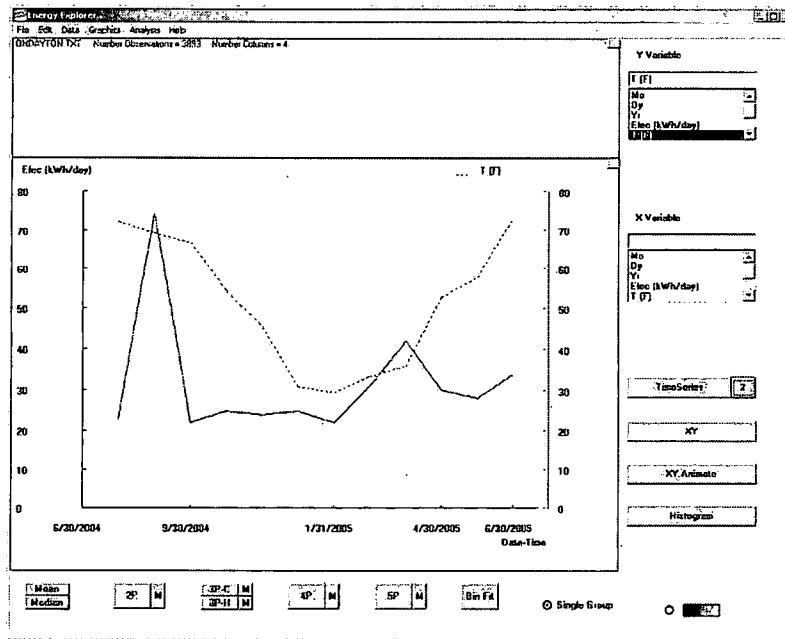
The following statistical analysis utilizes the computer software Energy Explorer (Kissock, 2004), available free-of-charge at <http://www.engr.udayton.edu/udiac/>. Electrical energy and natural gas use were provided by the University of Dayton. Temperature data for this analysis were taken from the Dayton, Ohio city file obtained in an archive maintained by the University of Dayton (<http://www.engr.udayton.edu/weather/>).

## Statistical Analysis of Electricity Use

Data used in this statistical lean energy analysis are shown below.

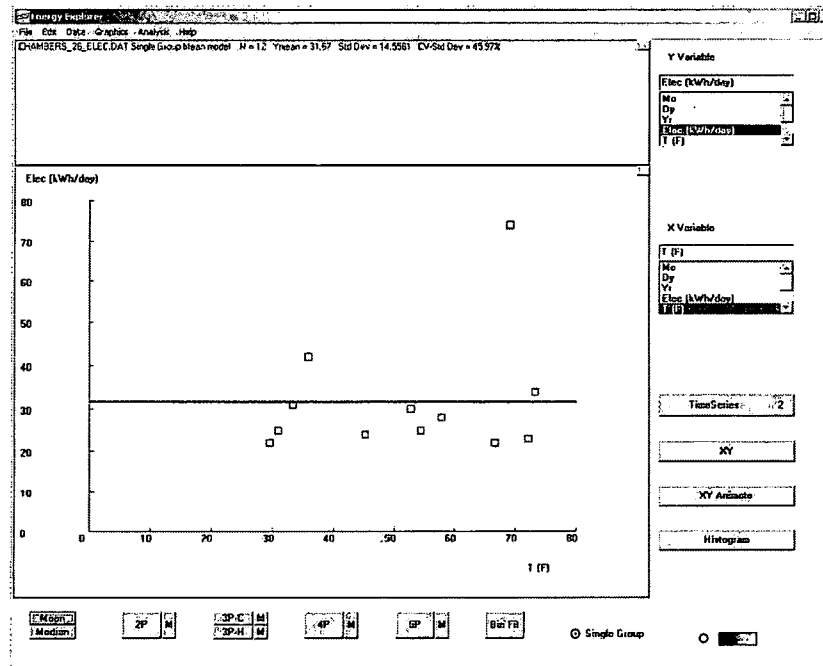
Month	Day	Year	Electricity Usage (kWh/day)	Temperature (F)
6	30	2004	-99	-99
7	31	2004	23	72
8	31	2004	74	69
9	30	2004	22	67
10	31	2004	25	54
11	30	2004	24	45
12	31	2004	25	31
1	31	2005	22	30
2	28	2005	31	33
3	31	2005	42	36
4	30	2005	30	53
5	31	2005	28	58
6	30	2005	34	73

A time series plot of electrical energy consumption and average daily outdoor temperature is shown below.



Time Series of Electrical Energy Use and Outdoor Air Temperature

A mean model shows the relationship between electrical energy use and outdoor air temperature. This model, shown below, indicates that electricity usage does not correlate with temperature. Typically, in residential buildings, electricity use will increase during summer with air conditioning. However, in UD housing, buildings are often unoccupied throughout the summer. Additionally, the building has no central air conditioning.



Electrical Energy Use vs. Outdoor Air Temperature – Mean Model

Electricity use can be predicted using the following equation:

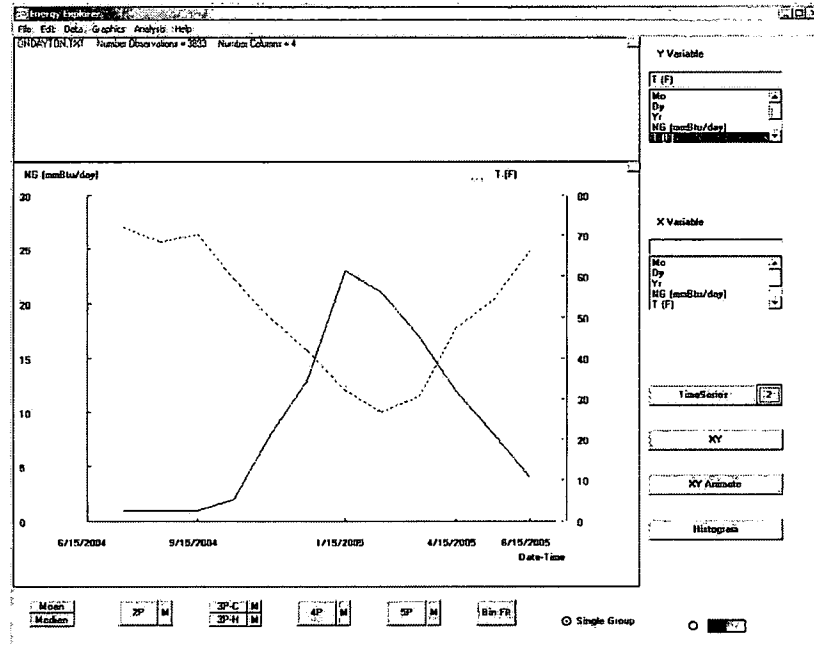
$$\text{Elec (kWh/day)} = 31.67 \text{ kWh/dy}$$

### Statistical Analysis of Natural Gas Use

The data used in this statistical analysis are shown below.

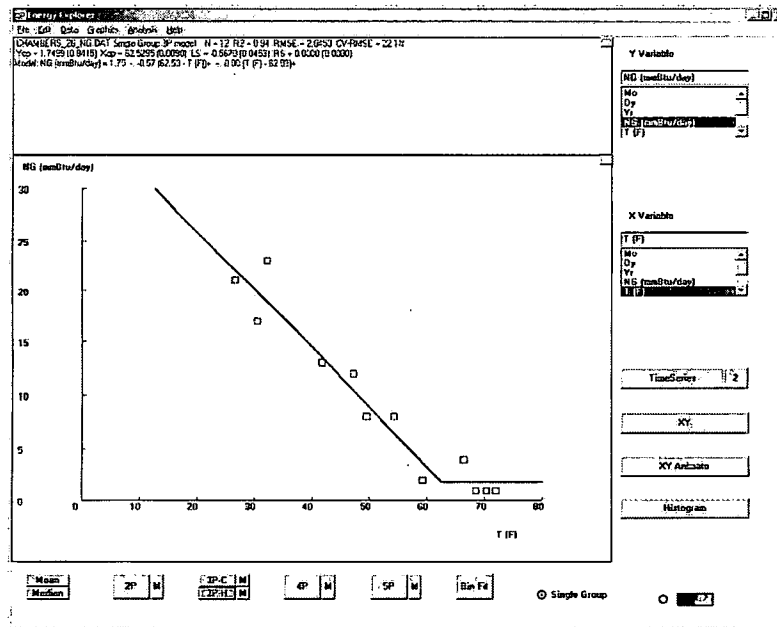
Month	Day	Year	Natural Gas Use (ccf/day)	Temperature (F)
6	15	2004	-99	-99
7	15	2004	1	72
8	15	2004	1	69
9	15	2004	1	67
10	15	2004	2	54
11	15	2004	8	45
12	15	2004	13	31
1	15	2005	23	30
2	15	2005	21	33
3	15	2005	17	36
4	15	2005	12	53
5	15	2005	8	58
6	15	2005	4	73

A time series plot of natural gas energy use and average daily outdoor temperature is shown below. This time series shows that with annual fluctuations in temperature, an inverse trend occurs with natural gas energy use.



Natural Gas Consumption and Outdoor Air Temperature Time Series

A three-parameter heating change-point analysis (3P-H) models the relationship between natural gas use and outdoor air temperature. This model, shown below, has a positive slope as the outdoor air temperature decreases below 64 F.  $R^2$ , 0.81, indicates the fit of data to the model compared to the mean. CV-RMSE is 39.8%, indicating the model represents this data within  $\pm 79.6\%$  error at the 95% confidence interval.



Natural Gas Consumption vs. Outdoor Air Temperature

From Energy Explorer, the slope, x-change point and y-change point are determined. The slope represents the ratio of the UA of the house to the efficiency of the heating plant. The x-change point represents the balance point temperature of the house. The y-change point represents the baseline natural gas use to the water heater.

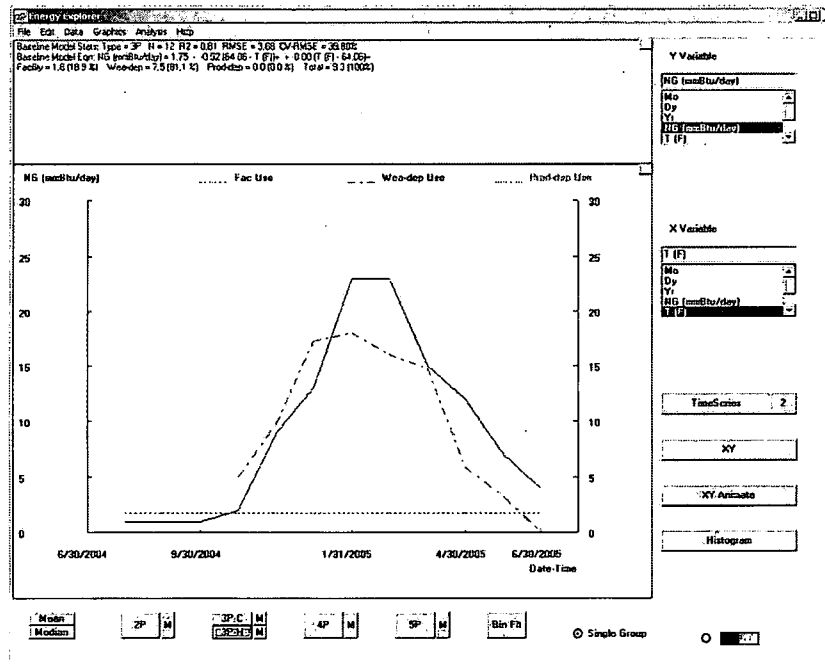
$$\begin{aligned} \text{UA / efficiency} &= 0.57 \text{ mmBtu/day-F} \\ \text{Balance point temperature (Tbal)} &= 62.5 \text{ F} \\ \text{Hot Water Gas Use} &= 1.75 \text{ mmBtu/dy} \end{aligned}$$

The building natural gas energy use is modeled as:

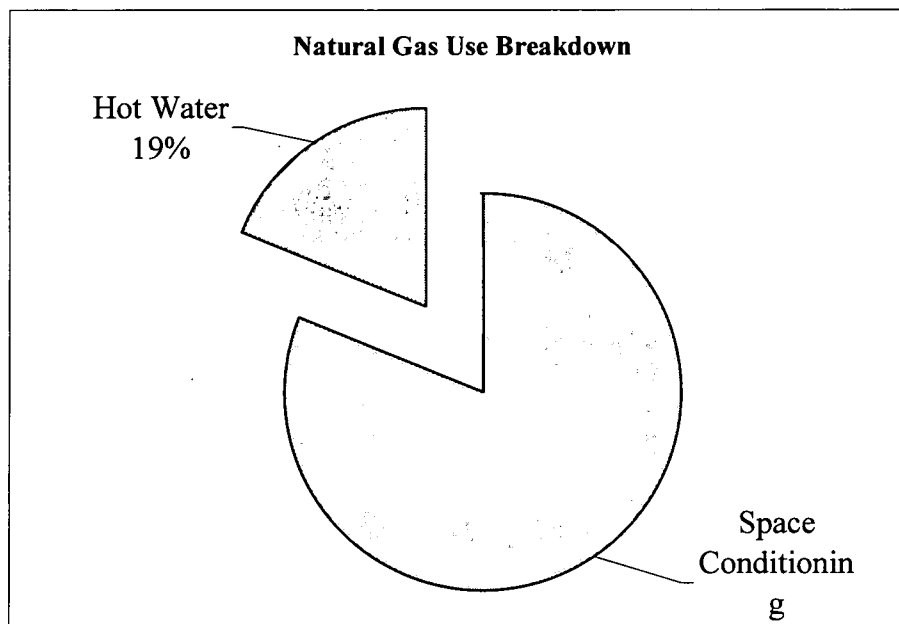
$$\begin{aligned} \text{NG (mmBtu/day)} &= \text{Hot Water Use} + \text{UA / efficiency} \times [\text{Tbal} - \text{T}_{\text{oa}} (\text{F})]^+ \\ \text{NG (mmBtu/day)} &= 1.75 \text{ mmBtu/day} + 0.57 \text{ mmBtu/day-F} \times [62.5 \text{ F} - \text{T}_{\text{oa}} (\text{F})]^+ \end{aligned}$$

where  $T_{\text{oa}}$  is the average outdoor air temperature.

According to the natural gas breakdown, shown below, 19% (628 ccf) of natural gas is for hot water and 81% (2,677 ccf) of natural gas is for space conditioning.



Natural Gas Use Breakdown



## **Assessment Recommendations (ARs)**

The primary goal of our assessment is to help you reduce your energy costs. The Assessment Recommendations (ARs) that follow include descriptions of specific conservation measures and our estimates of the savings and cost of each recommendation. These recommendations do not constitute detailed engineering plans or designs. Additional engineering services may be necessary to implement certain recommendations.

### CO<sub>2</sub> Emission Factors

2.3 lb. CO<sub>2</sub>/kWh is DPL average from "Benchmarking Air Emissions of Electric Utility Generators in the U.S.", National Resources Defense Council, [www.nrdc.org](http://www.nrdc.org), June, 1998.

11.3 lb.CO<sub>2</sub>/ccf natural gas is from combustion equation for stoichiometric combustion of methane

## AR 1: Install Blown Cellulose Insulation in Wood Frame Walls

	Annual Savings			Project Cost			Rate of Return
	Resource	CO <sub>2</sub> (lb)	Dollars	Capital	Other	Total	
Natural Gas	86.5 mmBtu	10,000	\$986	\$508	\$640	\$1,148	86%

### Analysis

The residence at 26 Chambers St. was constructed for NCR factor workers in the early 1900s. During this period, walls were typically constructed without insulation. The walls of the residence at 26 Chambers St. are uninsulated, wood frame, with wood siding on the exterior and plaster finishing on the interior. The residence is shown in the picture below.



Installing blown cellulose insulation in the walls is a cost-effective way to increase the R-value of the walls. In order to install cellulose insulation in existing walls, holes are drilled in the wall from the outside, insulation is blown into the walls, and the



holes are stopped with plastic plugs. Installation of cellulose insulation can be performed by two maintenance personnel in two work days.

### **Recommendation**

We recommend installing blown cellulose insulation in uninsulated wood frame walls.

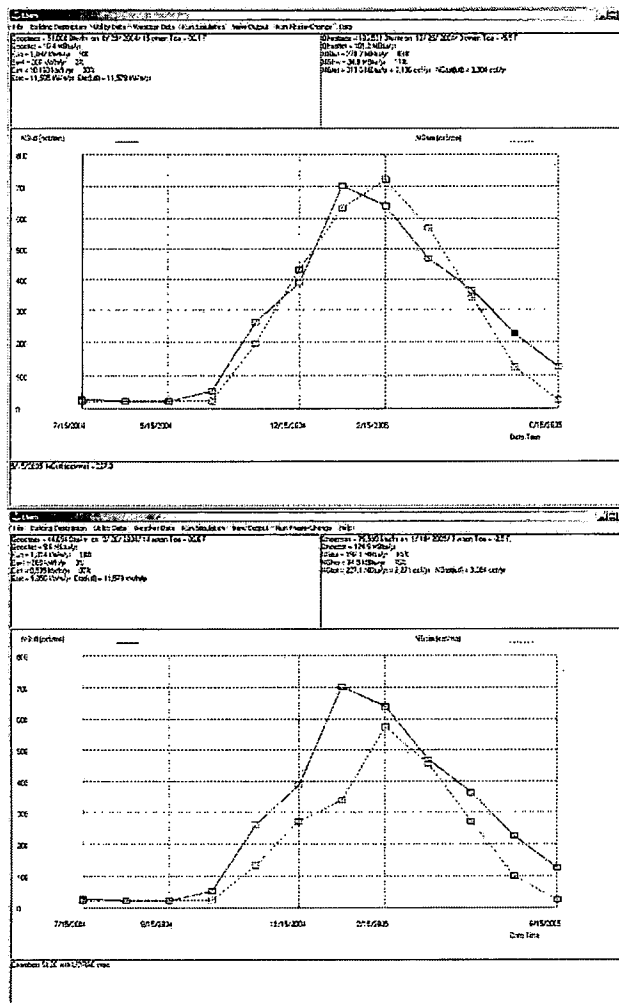
### **Estimated Savings**

The R-value of the house walls is calculated using CalculateRvalue.xls using material properties and wall dimensions. Typical wood frame construction uses 2 x 4 wood studs, 16-inches on center. The material properties, wall dimensions and calculations are shown in the figure below. The calculated wall R-value is about 3.6 hr-ft<sup>2</sup>-F/Btu. We conservatively estimate a wall R-value of 4 hr-ft<sup>2</sup>-F/Btu.

CalculateRvalue.xls was used to estimate the proposed R-value of the wall with blown cellulose insulation installed. The material properties, wall dimensions and calculations are shown in the figure below. The wall R-value with blown insulation would be about 13.5 hr-ft<sup>2</sup>-F/Btu.

CalculateRvalue.xls		CalculateRvalue.xls	
<b>Input Values</b>		<b>Input Values</b>	
Distance Between Stud	16	Distance Between Stud	16
Stud Length (inches)	4	Stud Length (inches)	4
Stud Width (inches)	2	Stud Width (inches)	2
Kstud (hr-ft <sup>2</sup> -F/Btu-in)	0.833	Kstud (hr-ft <sup>2</sup> -F/Btu-in)	0.833
Rsiding (hr-ft <sup>2</sup> -F/Btu)	0.81	Rsiding (hr-ft <sup>2</sup> -F/Btu)	0.81
Rspace (hr-ft <sup>2</sup> -F/Btu)	1.01	Rcellulose (hr-ft <sup>2</sup> -F/Btu)	13.2
Rfinishing (hr-ft <sup>2</sup> -F/Btu)	0.32	Rfinishing (hr-ft <sup>2</sup> -F/Btu)	0.32
ho	5	ho	5
hi	1	hi	1
<b>Calculations</b>		<b>Calculations</b>	
Rstudpath (hr-ft <sup>2</sup> -F/Btu)	7.1	Rstudpath (hr-ft <sup>2</sup> -F/Btu)	7.1
Ropenpath (hr-ft <sup>2</sup> -F/Btu)	3.34	Rinspath (hr-ft <sup>2</sup> -F/Btu)	15.53
Astudpath	0.125	Astudpath	0.125
Aopenpath	0.875	Ainspath	0.875
<b>Total Rvalue</b>	<b>3.6</b>	<b>Total Rvalue</b>	<b>13.5</b>

In the Building Energy Simulation section of the report, we created a model using current building characteristics. The building model is calibrated to actual utility bills. Simulated annual natural gas use is 3,136 ccf and actual annual natural gas use is 3,304 ccf. This gives us confidence in the building model. Assuming the wall R-value would increase from 4 to 13.5 hr-ft<sup>2</sup>-F/Btu natural gas use would be about 2,522 ccf per year. Simulated natural gas use is shown in the figure below.



Predicted natural gas use is compared to current simulated natural gas use.

Natural gas savings from reducing infiltration would be about:

$$3,136 \text{ ccf/yr} - 2,271 \text{ ccf/yr} = 865 \text{ ccf/yr}$$

$$865 \text{ ccf/yr} \times \$1.14 / \text{ccf} = \$986 / \text{yr}$$

The reduction in CO<sub>2</sub> emissions would be about:

$$865 \text{ ccf/year} \times 11.3 \text{ lbs CO}_2/\text{ccf} = 10,000 \text{ lbs CO}_2$$

### Estimated Implementation Cost

According to Lowe's home improvement supply store, the cost of cellulose insulation is \$8.77 per 40 ft<sup>2</sup> bag. The wall area of the residence at 26 Chambers St. is

about 2,300 ft<sup>2</sup>. Thus, the number of bags needed for insulating the house would be about:

$$2,300 \text{ ft}^2 \times 1 \text{ bag} / 40 \text{ ft}^2 = 58 \text{ bags}$$

The total cost of insulation would be about:

$$58 \text{ bags} \times \$8.77 / \text{bag} = \$508$$

We estimate this would take two maintenance personnel about 20 hours. At a labor rate of \$16 per hour, the total labor cost for installing blown cellulose insulation would be about:

$$20 \text{ hrs/person} \times 2 \text{ persons} \times \$16 / \text{hr} = \$640$$

The total cost of implementation would be about:

$$\$508 + \$640 = \$1,148$$

#### **Estimated Rate of Return and Simple Payback**

$$(\$986 / \text{year} / \$1,148) = 86\%$$

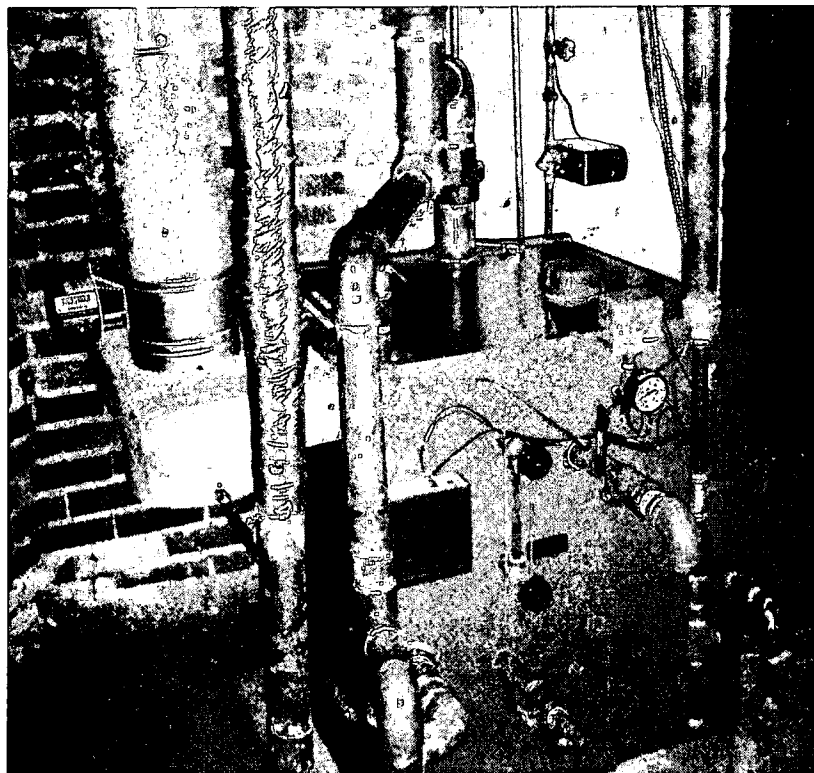
$$(\$1,148 / \$986 / \text{year}) \times 12 \text{ months/year} = 14 \text{ months}$$

## AR 2: Insulate Hot Water Supply and Return Pipes

	Annual Savings			Project Cost			Rate of Return
	Resource	CO <sub>2</sub> (lb)	Dollars	Capital	Other	Total	
Natural Gas	67.5 mmBtu	8,000	\$770	\$540	\$224	\$764	100%

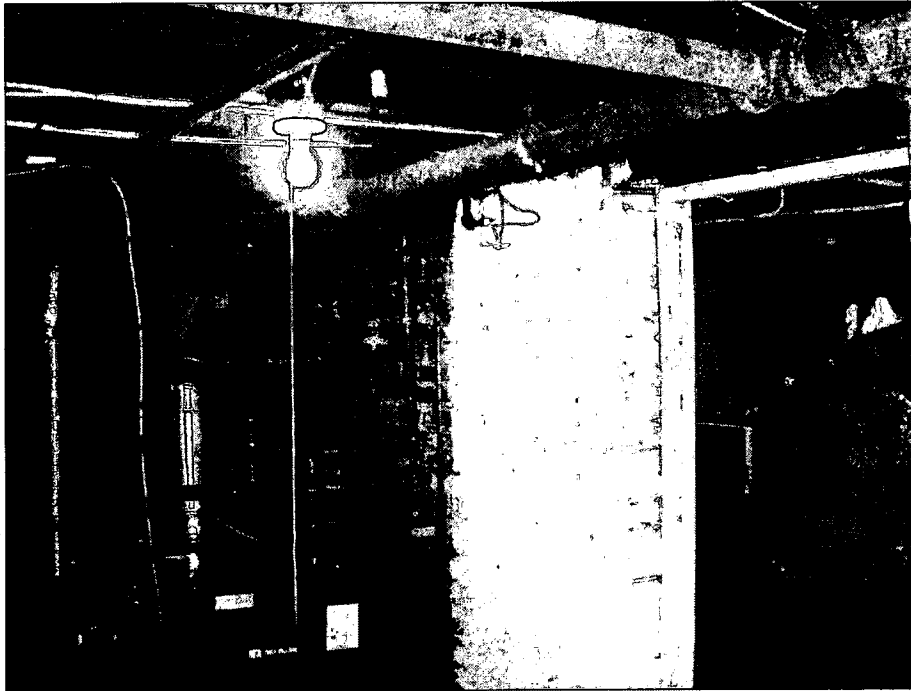
### Analysis

Space heating for 26 Chambers is provided by a hot water boiler, located in the basement. The feed and return pipes for this system are ceiling mounted and currently uninsulated. Uninsulated pipes lose heat through radiation and convection from the pipe surface. This heat loss decreases the amount of available energy that would otherwise be returned to the hot water boiler, increasing the amount of energy the boiler must make up to heat the house. The boiler is shown in the picture below.



Uninsulated pipes, running along the ceiling of the unconditioned basement are shown in the picture below. We measured the surface temperature of the pipes to be

about 200 F and the temperature of the air in the boiler room to be about 80 F. This indicates that much heat is being lost to the surroundings, in an area that does not need to be conditioned.



Uninsulated Pipes in 26 Chambers

### **Recommendation**

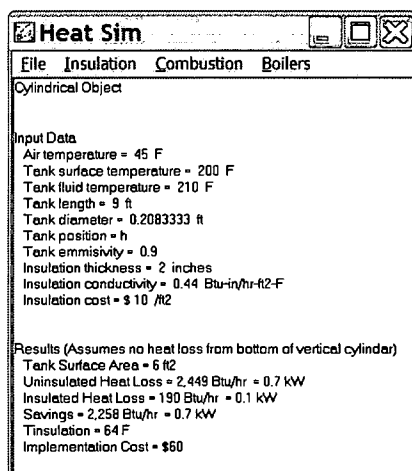
We recommend insulating supply and return pipes for the hot water boiler in the unconditioned basement.

### **Estimated Savings**

To estimate the savings from adding insulation, we use HeatSim software (Carpenter and Kissock, 2005), available free of charge from the University of Dayton Industrial Assessment Center Website. (<http://www.engr.udayton.edu/udiac>)

We measured the basement air temperature to be 45 F and the surface temperature of the hot water pipes to be 200 F. We measured 9 ft of 2.5 inch pipe at 200 F and 61 feet of 3 inch pipe at 200 F. According to the natural gas profile, the house has 6 months

during which the hot water boiler provides heat to the house. Shown below are the results from HeatSim and the tabulated results from these simulations. We estimate the annual fuel utilization efficiency to be 0.65. Natural gas costs \$12.50 per mmBtu.



**Heat Sim**

File Insulation Combustion Boilers

Cylindrical Object

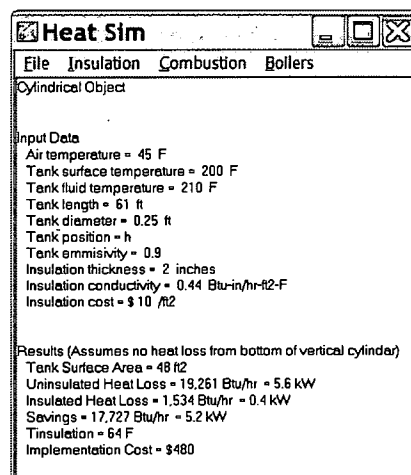
Input Data

Air temperature = 45 F  
 Tank surface temperature = 200 F  
 Tank fluid temperature = 210 F  
 Tank length = 9 ft  
 Tank diameter = 0.208333 ft  
 Tank position = h  
 Tank emissivity = 0.9  
 Insulation thickness = 2 inches  
 Insulation conductivity = 0.44 Btu-in/hr-ft<sup>2</sup>-F  
 Insulation cost = \$ 10 /ft<sup>2</sup>

Results (Assumes no heat loss from bottom of vertical cylinder)

Tank Surface Area = 6 ft<sup>2</sup>  
 Uninsulated Heat Loss = 2,449 Btu/hr = 0.7 kW  
 Insulated Heat Loss = 190 Btu/hr = 0.1 kW  
 Savings = 2,258 Btu/hr = 0.7 kW  
 Tinsulation = 64 F  
 Implementation Cost = \$60

2.5 inch pipe



**Heat Sim**

File Insulation Combustion Boilers

Cylindrical Object

Input Data

Air temperature = 45 F  
 Tank surface temperature = 200 F  
 Tank fluid temperature = 210 F  
 Tank length = 61 ft  
 Tank diameter = 0.25 ft  
 Tank position = h  
 Tank emissivity = 0.9  
 Insulation thickness = 2 inches  
 Insulation conductivity = 0.44 Btu-in/hr-ft<sup>2</sup>-F  
 Insulation cost = \$ 10 /ft<sup>2</sup>

Results (Assumes no heat loss from bottom of vertical cylinder)

Tank Surface Area = 48 ft<sup>2</sup>  
 Uninsulated Heat Loss = 19,261 Btu/hr = 5.6 kW  
 Insulated Heat Loss = 1,534 Btu/hr = 0.4 kW  
 Savings = 17,727 Btu/hr = 5.2 kW  
 Tinsulation = 64 F  
 Implementation Cost = \$480

3 inch pipe

Annual natural gas savings and cost savings from insulating pipes is shown in the table below. According to our calculations, annual natural gas savings would be about 135 mmBtu per year. This is higher than we would expect and about half of the total natural gas used. We conservatively estimate that 50% of the calculated gas use is saved.

Diameter (in)	Length (ft)	Savings (Btu/hr)	Heating Months	Operating Hours	Total Savings (mmBtu/yr)	Unit Cost (\$/mmBtu)	Savings
2.5	9	2,258	6	4,380	15	\$12.50	\$190
3	61	17,727	6	4,380	119	\$12.50	\$1,493
Total	70	19,985			135		\$1,683

Annual savings would be about:

$$135 \text{ mmBtu/yr} \times 50\% = 67.5 \text{ mmBtu/yr}$$

$$67.5 \text{ mmBtu/yr} \times \$11.41 / \text{mmBtu} = \$770 / \text{yr}$$

Annual CO<sub>2</sub> savings would be about:

$$67.5 \text{ mmBtu/yr} \times 113 \text{ lb CO}_2 / \text{mmBtu} = 8,000 \text{ lb CO}_2 / \text{year}$$

### **Estimated Implementation Cost**

According to manufacturer data, the cost of insulation is about \$10 per square foot. According to HeatSim, the cost of insulating hot water pipes is about:

$$\$60 + \$480 = \$540 \text{ for materials}$$

According to the 2002 RSMeans Mechanical Cost Data book, maintenance personnel can install 5 linear feet of 2-inch thick insulation in an hour. Therefore, the total time to install piping insulation would be about:

$$(70) \text{ ft} / 5 \text{ ft/hr} = 14 \text{ hrs}$$

According to management, maintenance labor cost is about \$16 /hour. Thus, the total labor cost to install the insulation would be about:

$$14 \text{ hrs} \times \$16 \text{ /hr} = \$224$$

Therefore, the total implementation cost would be about:

$$\$540 + \$224 = \$764$$

### **Estimated Simple Payback**

$$\$770 \text{ /yr} / \$764 = 100\%$$

$$\$764 / \$770 \text{ /year} \times 12 \text{ months/year} = 12 \text{ months}$$

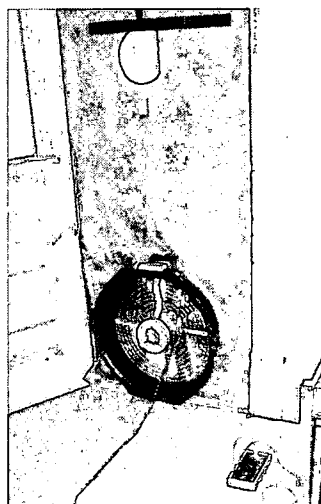


### AR 3: Install Weather Stripping and Caulk to Reduce Infiltration

	Annual Savings			Project Cost			Rate of Return
	Resource	CO <sub>2</sub> (lb)	Dollars	Capital	Other	Total	
Natural Gas	61.4 mmBtu	7,000	\$700	\$200	\$320	\$520	700%

#### Analysis

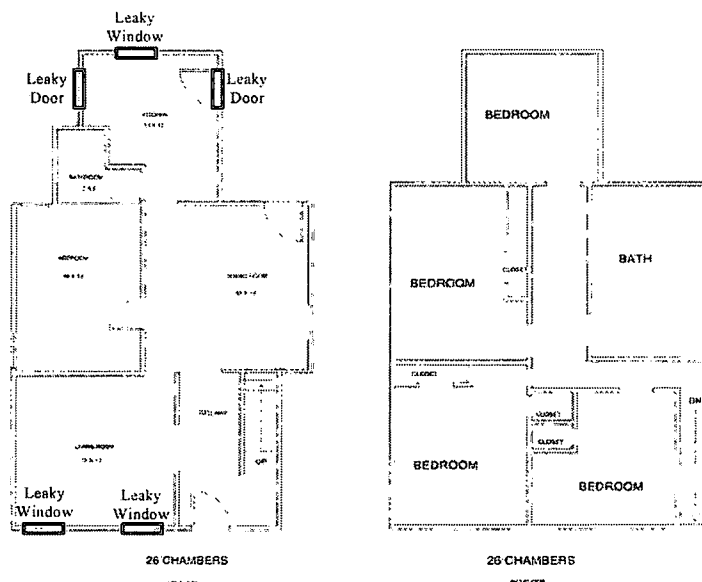
During the assessment, we performed a blower door test on the building. A blower door test consists of pressurizing the house with a variable speed fan. By measuring the pressure that the house can reach and the flow of air into the house, we can estimate the average infiltration of the house on any given day. A picture of the blower door test being performed is shown below. The goal of the test is to pressurize a house to 50 Pa and measure the flow rate of air into or out of the house. However, particularly leaky houses cannot be pressurized to 50 Pa.



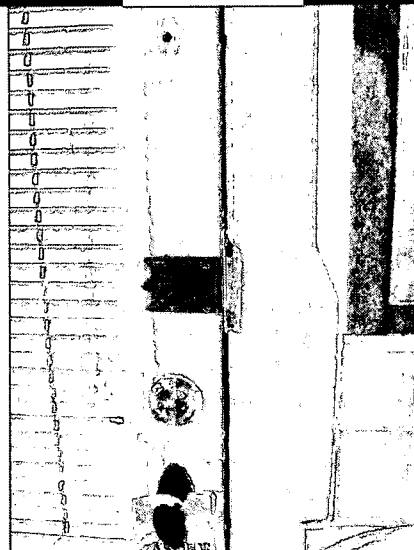
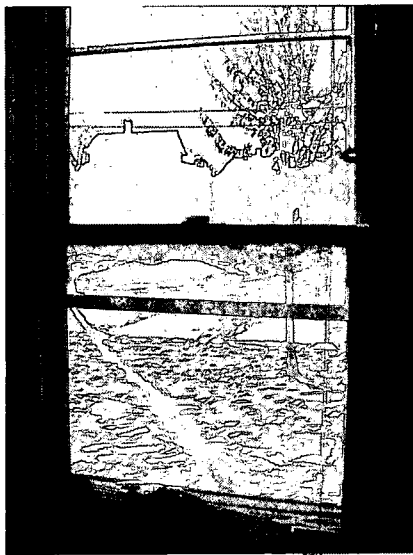
Infiltration typically increases the heating and cooling requirements of the house and should be avoided. According to the American Society of Heating and Air Conditioning Engineers (ASHRAE), the minimum required ventilation is 0.35 air changes per hour (ACH). Only very tight houses fall below this minimum and they require forced ventilation. Newly constructed houses often reach 50 Pa, while old houses

in the student neighborhood almost never reach 50 Pa pressure. No houses in the student neighborhood have less than 0.35 ACH. The house at 26 Chambers reached a final pressure of 6 Pa. This is a very low pressure reading, indicating that 26 Chambers has a very high rate of infiltration.

Since the blower door test fan was blowing air out of the house, and outdoor air was relatively cold, infiltration could be easily spotted. Shown in the figure below are the locations of particularly leaky windows and doors.



We observed three leaky windows and two leaky doors on the ground floor. We expect that upstairs, windows were also very leaky. However, since residents locked the doors, we could not verify this claim. On the ground floor, a window in the kitchen was not even in its track. It is shown in the picture below. Large volumes of outdoor air were flowing through the space. Similarly, two exterior doors had large gaps between them and the frame. They are shown in the pictures below.



Window Out of Track    Leaky Door in Stairwell    Leaky Rear Exterior Door

### **Recommendation**

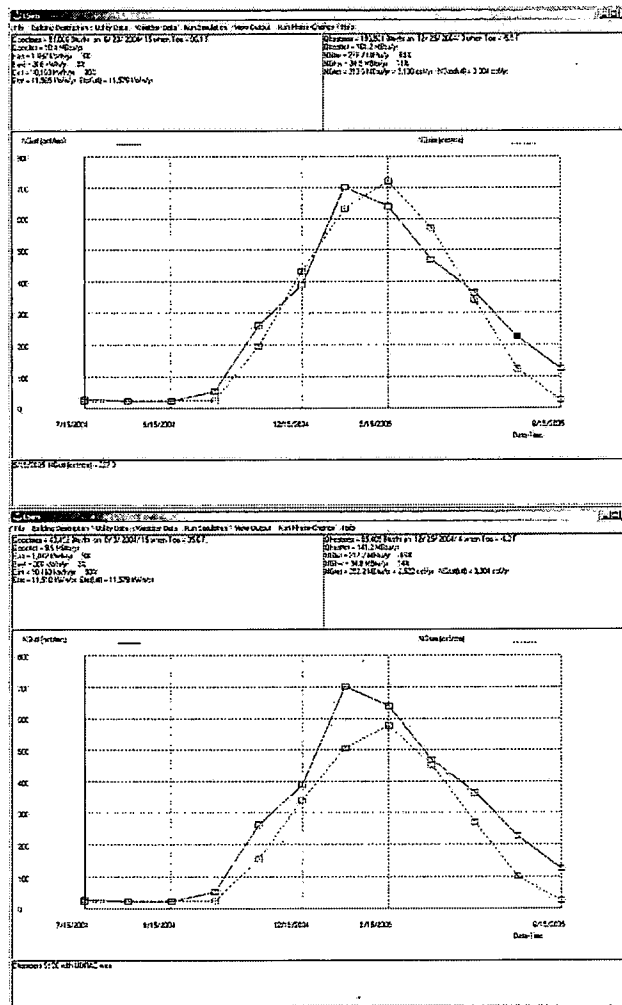
We recommend installing weather stripping and caulking to reduce infiltration.

### **Estimated Savings**

In the Building Energy Simulation section of the report, we created a model using current building characteristics. The building model is calibrated to actual utility bills. Simulated annual natural gas use is 3,136 ccf and actual annual natural gas use is 3,304 ccf. This gives us confidence in the building model. From the blower door test, we calculate the current house infiltration to be 1.7 air changes per hour. We estimate that

infiltration could be reduced by about 50% with weather stripping and caulking.

Assuming the infiltration can be reduced to 0.85 air changes per hour, simulated natural gas use would be about 2,522 ccf per year. Simulated natural gas use is shown in the figure below.



Predicted natural gas use is compared to current simulated natural gas use.

Natural gas savings from reducing infiltration would be about:

$$3,136 \text{ ccf/yr} - 2,522 \text{ ccf/yr} = 614 \text{ ccf/yr}$$

$$614 \text{ ccf/yr} \times \$1.14 / \text{ccf} = \$700 / \text{yr}$$

The reduction in CO<sub>2</sub> emissions would be about:

$$614 \text{ ccf/year} \times 11.3 \text{ lbs CO}_2/\text{ccf} = 7,000 \text{ lbs CO}_2$$

**Estimated Implementation Cost**

Management estimated the cost of materials for installing caulk, weatherstripping and expanding foam to fix a leaky home to be about \$200. We estimate this would take two maintenance personnel about 10 hours. If so, the total labor cost for installing caulk, weatherstripping and expanding foam would be about:

$$10 \text{ hrs/person} \times 2 \text{ persons} \times \$16/\text{hr} = \$320$$

The total cost of implementation would be about:

$$\$200 + \$320 = \$520$$

**Estimated Rate of Return and Simple Payback**

$$\$700/\text{yr} / \$520 = 700\%$$

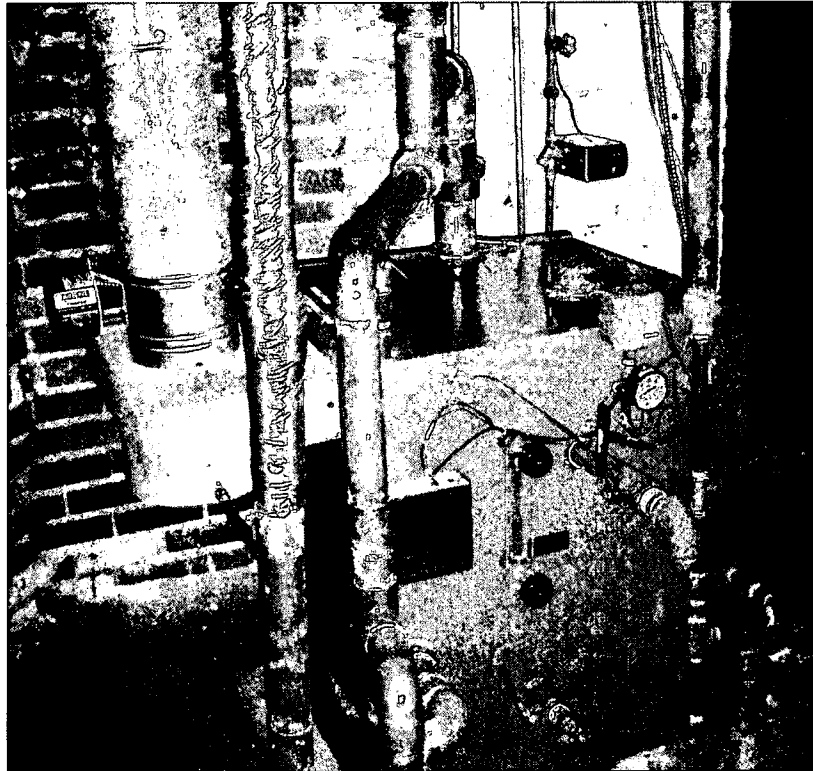
$$(\$520 / \$700/\text{year}) \times 12 \text{ months/year} = 9 \text{ months}$$

#### **AR 4: Decrease Excess Combustion Air to Hot Water Boiler**

	Annual Savings			Project Cost			Rate of Return
	Resource	CO <sub>2</sub> (lb)	Dollars	Capital	Labor	Total	
Natural Gas	548 ccf	6,000	\$685	None	None	None	Infinite

#### **Analysis**

Space heating for 26 Chambers is provided by a hot water boiler, located in the basement. We measured the combustion efficiency of the hot water boiler to be about 66%. The optimal excess air in a gas heating system for energy efficiency and pollution prevention is about 10%. We measured the excess air to the boiler to be about 340%. Higher levels of excess air dilute the combustion stream and decrease the combustion temperature. In addition, higher excess air levels cause the combustion stream to flow at higher velocities, thereby reducing the heat transfer rate within the boiler. If excess air were decreased, the boiler would operate more efficiently and reduce annual natural gas use. The boiler is shown in the picture below.

**Recommendation**

We recommend reducing excess combustion air to about 15% for the hot water boiler in the basement.

**Estimated Savings**

The spreadsheet CombEff.XLS calculates combustion efficiency based on intake air temperature, stack temperature, and excess air. The spreadsheet below calculates the current combustion efficiency of 66%.

CombEff.XLS	
<b>Input Data</b>	
EA = excess air (0=stoch, 0.1 = optimum)	3.4
Tca = temperature combustion air before burner (F)	50
Tex = temperature exhaust gasses (F)	335
<b>Constants for Natural Gas</b>	
LHV = lower heating value (Btu/lb)	21,500
HHV = higher heating value (Btu/lb)	23,900
cpg = specific heat of products of exhaust (Btu/lb-F)	0.26
Tdpg = dew point temp of H2O in exhaust (F)	140
Afs = air/fuel mass ratio at stoichiometric conditions	17.2
<b>Combustion Efficiency Calculations</b>	
hr = heat of reaction = (if Tex<140 then hr=HHV else hr = LHV)	21,500
Tc = temp combustion (F) = Tca+hr/[(1+(1+EA)(Afs))cpg]	1,128
Efficiency = [1 + (1+EA)(Afs)]*cpg*(Tc-TEX)/HHV	66.18%

By reducing the excess air to about 15%, the combustion efficiency would be about 83%.

CombEff.XLS	
<b>Input Data</b>	
EA = excess air (0=stoch, 0.1 = optimum)	0.15
Tca = temperature combustion air before burner (F)	50
Tex = temperature exhaust gasses (F)	335
<b>Constants for Natural Gas</b>	
LHV = lower heating value (Btu/lb)	21,500
HHV = higher heating value (Btu/lb)	23,900
cpg = specific heat of products of exhaust (Btu/lb-F)	0.26
Tdpg = dew point temp of H2O in exhaust (F)	140
Afs = air/fuel mass ratio at stoichiometric conditions	17.2
<b>Combustion Efficiency Calculations</b>	
hr = heat of reaction = (if Tex<140 then hr=HHV else hr = LHV)	21,500
Tc = temp combustion (F) = Tca+hr/[(1+(1+EA)(Afs))cpg]	4,029
Efficiency = [1 + (1+EA)(Afs)]*cpg*(Tc-TEX)/HHV	83.52%

According to these calculations, the boiler's efficiency would increase from 66% to 83%. According to the Utility Analysis section of the report, about 81% of the plant's annual natural gas use or 2,677 ccf is used for space heating. The annual natural gas savings would be about:

$$2,677 \text{ ccf/yr} \times (1 - 66\% / 83\%) = 548 \text{ ccf/year}$$

$$548 \text{ ccf/year} \times \$1.25 / \text{ccf} = \$685 / \text{year}$$

The total reduction in CO<sub>2</sub> emissions would be about:

$$548 \text{ mmBtu/year} \times 11.3 \text{ lb CO}_2 / \text{mmBtu} \approx 6,000 \text{ lb CO}_2 / \text{year}$$



**Estimated Implementation Cost**

We estimate that contacting a boiler maintenance company and adjusting excess combustion air would cost about \$500.

**Estimated Rate of Return and Simple Payback**

$$\$685 \text{ /yr} / \$500 = 137\%$$

$$\$500 / (\$685 \text{ /yr}) \times 12 \text{ months/yr} = 9 \text{ months}$$

## **AR 5: Install Digital Thermostats and Implement Night Setbacks**

	Annual Savings			Project Cost			Rate of Return
	Resource	CO <sub>2</sub> (lb)	Dollars	Capital	Other	Total	
Natural Gas	51.3 mmBtu	6,000	\$585	\$80	\$16	\$96	609%

### **Analysis**

The residence at 26 Chambers St. was constructed for NCR factor workers in the early 1900s. During this period, walls were typically constructed without insulation. The residence currently has an analog thermostat which does not have the capability of night temperature setbacks. Thus, the house is heated to the same temperature throughout the day and night.

When occupants are awake and using the space, it is necessary to heat the residence to a comfortable level. However, at night, when residents are asleep, under covers, temperatures can be reduced to save energy. Digital thermostats frequently have night setback capabilities and can be installed for a low cost.

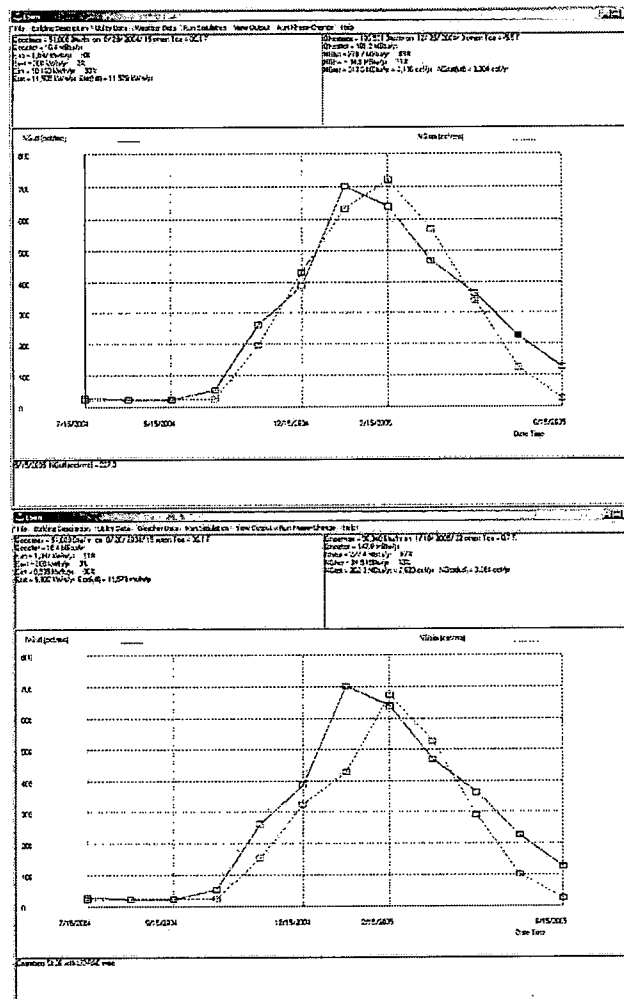
### **Recommendation**

We recommend installing digital thermostats and reducing night time temperatures from 72 F to 60 F from 10 pm to 8 am.

### **Estimated Savings**

In the Building Energy Simulation section of the report, we created a model using current building characteristics. The building model is calibrated to actual utility bills. Simulated annual natural gas use is 3,136 ccf and actual annual natural gas use is 3,304 ccf. This gives us confidence in the building model. The house is currently set at about 72 F during the entire winter heating season. A digital thermostat, positioned in the living room would enable night temperature setbacks to be implemented from 12 am to 8

am. Reducing the house temperature from 72 F to 60 F would result in natural gas use of about 2,623 ccf per year.



Predicted natural gas use is compared to current simulated natural gas use.

Natural gas savings from implementing night temperature setbacks would be about:

$$3,136 \text{ ccf/yr} - 2,623 \text{ ccf/yr} = 513 \text{ ccf/yr}$$

$$513 \text{ ccf/yr} \times \$1.14 / \text{ccf} = \$585 / \text{yr}$$

The reduction in CO<sub>2</sub> emissions would be about:

$$513 \text{ ccf/year} \times 11.3 \text{ lbs CO}_2 / \text{ccf} = 6,000 \text{ lbs CO}_2$$

**Estimated Implementation Cost**

Programmable night set-back thermostats cost about \$80 each. We estimate that the time to install each thermostat would be about one hour. At a labor rate of \$16 per hour, the labor cost would be about:

$$1 \text{ thermostats} \times 1 \text{ hour/thermostat} \times \$16 / \text{hour} = \$16$$

The total implementation cost would be about:

$$\$80 + \$16 = \$96$$

**Estimated Rate of Return and Simple Payback**

$$(\$585 / \text{year} / \$96) = 609\%$$

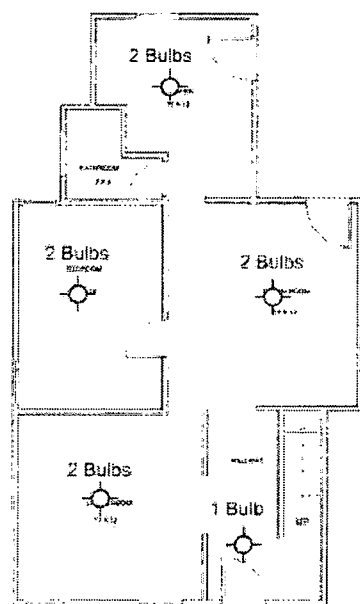
$$(\$96 / \$585 / \text{year}) \times 12 \text{ months/year} = 1 \text{ months}$$

## AR 6: Install Compact Fluorescent Lights

	Annual Savings			Project Cost			Simple Payback
	Resource	CO <sub>2</sub> (lb)	Dollars	Capital	Labor	Total	
Electrical Energy	3,761 kWh	8,650	\$314	None	None	None	Immediate

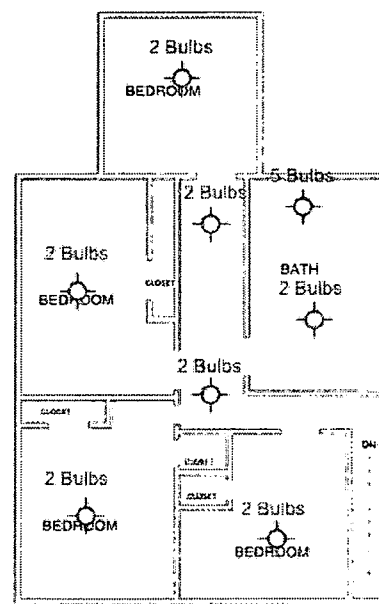
### Analysis

Lighting for 26 Chambers is provided by 28 incandescent 60-W bulbs. Electrical energy use can be reduced by installing compact fluorescent bulbs. For example, a 14-W compact fluorescent bulb produces the same amount of light output as a 60-W incandescent bulb. Additionally, compact fluorescent bulbs have a lifetime of about 10,000 hours compared to 1,000 hours for an incandescent bulb. Compact fluorescent bulbs can be installed in existing fixtures which are currently occupied by incandescent bulbs. A layout of 26 Chambers is shown in the figure below with the locations and numbers of fixtures and bulbs.



26 CHAMBERS

13/1/2000



26 CHAMBERS

2/10/2000

**Recommendation**

We recommend replacing 60-W incandescent bulbs with 14-W compact fluorescent bulbs.

**Estimated Savings**

According to prior work by mechanical engineering students calibrating appliance and lighting energy use for UD housing, lights in houses are on for an average of 8 hours per day. Compact fluorescents save on electrical energy costs and replacement costs. According to management, UD purchases incandescent bulbs at about \$0.29 per bulb and 14-W compact fluorescent bulbs at about \$5 per bulb. Annually, each bulb operates for about:

$$8 \text{ hrs/dy-bulb} \times 365 \text{ dys/yr} = 2,920 \text{ hrs/yr-bulb}$$

Since the university currently purchases incandescent bulbs in 1,000-bulb packages, incandescent bulbs are comparatively cheap for the university to purchase. At current rates, the incandescent bulbs are less expensive to install than compact fluorescent bulbs. However, if the university were to purchase compact fluorescent bulbs in bulk, their unit cost would be reduced. Additional costs for installing compact fluorescent bulbs would be about:

$$(\$5 / \text{replacement} \times 1 \text{ replacement} / 10,000 \text{ hrs} - \$0.29 / \text{replacement} \times 1 \text{ replacement} / 1,000 \text{ hrs}) \times 2,920 \text{ hrs/yr-bulb} \times 28 \text{ bulbs} = \$17 / \text{yr}$$

Annual electrical energy savings from replacing incandescent bulbs with compact fluorescent bulbs would be about:

$$(60 \text{ W} - 14 \text{ W}) \times 28 \text{ bulbs} \times 2,920 \text{ hrs/yr-bulb} = 3,761 \text{ kWh/yr}$$

$$3,761 \text{ kWh/yr} \times \$0.088 / \text{kWh} = \$331$$

Annual cost savings would be about:

$$\$331 / \text{yr} - \$17 / \text{yr} = \$314 / \text{yr}$$

The reduction in CO<sub>2</sub> emissions would be about:

$$3,761 \text{ kWh/year} \times 2.3 \text{ lbs CO}_2/\text{kWh} = 8,650 \text{ lbs CO}_2$$

**Estimated Implementation Cost**

There would be no net additional implementation cost since fluorescent bulbs last longer and save energy over incandescent bulbs.

**Estimated Rate of Return and Simple Payback**

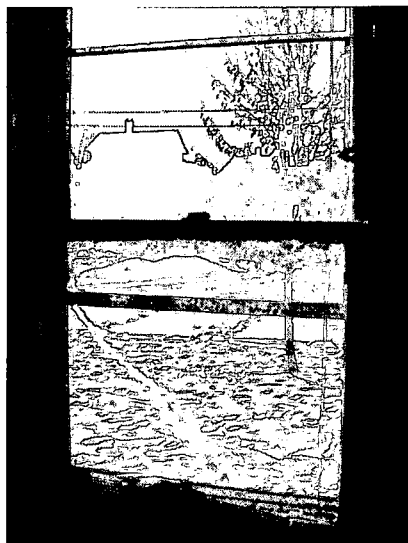
This project would immediately pay for itself and has an infinite rate of return.

## AR 7: Install Replacement, Double-Pane, Low-e Windows

	Annual Savings			Project Cost			Rate of Return
	Resource	CO <sub>2</sub> (lb)	Dollars	Capital	Labor	Total	
Natural Gas	249 ccf	7,000	\$284	None	None	\$5,250	5%

### Analysis

Along with having leaky windows, 26 Chambers has 1/8-inch single glaze, wood framed, windows with an R-value of 0.9 hr-ft<sup>2</sup>-F/Btu. These windows have very low resistance to heat transfer and allow much heat to escape from the house during winter. A window from 26 Chambers is shown in the picture below.



### Recommendation

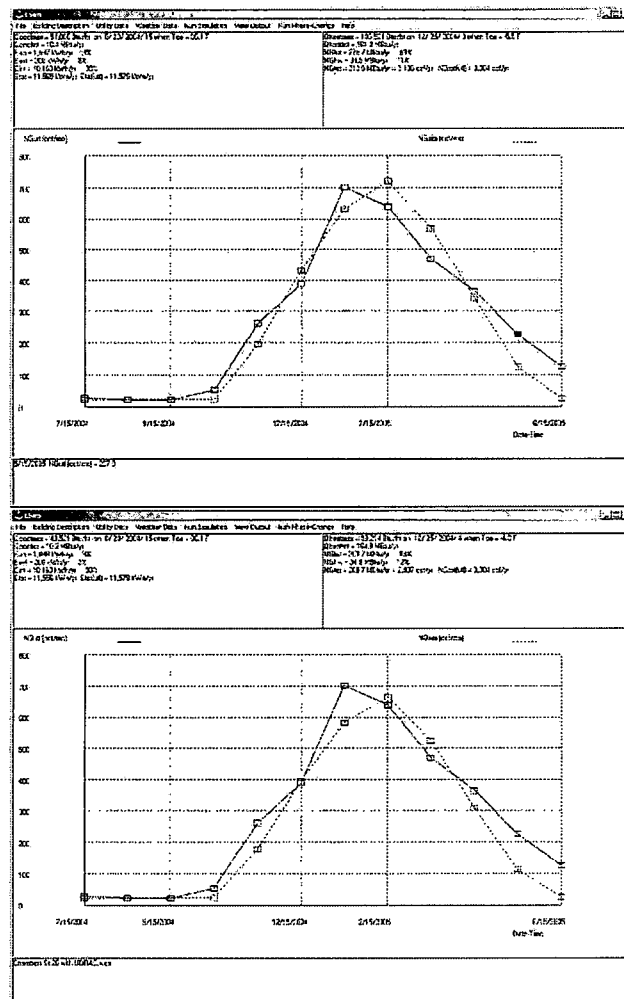
We recommend replacing the 15 single pane windows with double pane, low e, argon or krypton-filled vinyl replacement windows.

### Estimated Savings

In the Building Energy Simulation section of the report, we created a model using current building characteristics. The building model is calibrated to actual utility bills. Simulated annual natural gas use is 3,136 ccf and actual annual natural gas use is 3,304 ccf. This gives us confidence in the building model. From manufacturer's data, we



estimate the R-value of the current windows is 0.9 hr-ft<sup>2</sup>-F/Btu. New double pane, wood windows from Pella have an R-value of 2 hr-ft<sup>2</sup>-F/Btu. Simulated natural gas use is shown in the figure below.



Predicted natural gas use is compared to current simulated natural gas use.

Natural gas savings from installing new windows would be about:

$$3,136 \text{ ccf/yr} - 2,887 \text{ ccf/yr} = 249 \text{ ccf/yr}$$

The reduction in CO<sub>2</sub> emissions would be about:

$$249 \text{ ccf/year} \times 11.3 \text{ lbs CO}_2/\text{ccf} = 3,000 \text{ lbs CO}_2$$

**Estimated Implementation Cost**

According to management, the installed cost of replacement vinyl windows is about \$350 per window. The cost of replacing 15 windows would be about:

$$15 \text{ windows} \times \$350 / \text{window} = \$5,250$$

**Estimated Rate of Return and Simple Payback**

$$(\$284 / \text{yr} / \$5,250) = 5\% \text{ per year}$$

$$(\$5,250 / \$284 / \text{yr}) = 222 \text{ months}$$

### **AR 8: Replace Existing Water Heater with Tankless Water Heater**

	Annual Savings			Project Cost			Rate of Return
	Resource	CO <sub>2</sub> (lb)	Dollars	Capital	Other	Total	
Natural Gas	9.3 mmBtu	1,050	\$116	\$500	\$0	\$1,200	10%

#### **Analysis**

Domestic hot water for 26 Chambers is provided by a traditional 80-gallon domestic hot water heater which is located in the basement. These types of hot water heaters have high (80-85%) listed efficiencies, but they lose efficiency when not firing due to heat loss through the tank surface area.

#### **Recommendation**

We recommend replacing the traditional tank hot water heater with a tankless "on demand" hot water heater.

#### **Estimated Savings**

We measured the air temperature of the basement to be 41 F. We also measured the properties of the exhaust stack and calculated the combustion efficiency to be about 74% to be in CombEff.xls below. The second table accounts for heat loss through the hot water tank walls. Accounting for heat loss, the efficiency of the current hot water heater is about 63% as shown in the second table below.

<b>CombEff.XLS</b>	
<b>Input Data</b>	
EA = excess air (0=stoch, 0.1 = optimum)	0.855
Tca = temperature combustion air before burner (F)	45
Tex = temperature exhaust gasses (F)	485
<b>Constants for Natural Gas</b>	
LHV = lower heating value (Btu/lb)	21,500
HHV = higher heating value (Btu/lb)	23,900
c <sub>pp</sub> = specific heat of products of exhaust (Btu/lb-F)	0.26
T <sub>dpp</sub> = dew point temp of H <sub>2</sub> O in exhaust (F)	140
A <sub>fs</sub> = air/fuel mass ratio at stoichiometric conditions	17.2
<b>Combustion Efficiency Calculations</b>	
hr = heat of reaction = (if Tex<140 then hr=HHV else hr = LHV)	21,500
T <sub>c</sub> = temp combustion (F) = Tca+hr/[(1+(1+EA)(A <sub>fs</sub> ))c <sub>pp</sub> ]	2,558
Efficiency = [1 + (1+EA)(A <sub>fs</sub> )]*c <sub>pp</sub> *(T <sub>c</sub> -Tex)/HHV	74.21%
<b>Hot Water Heater</b>	
h <sub>i</sub> (Btu/hr-ft <sup>2</sup> -F)	1.5
n <sub>comb</sub>	74.21%
T <sub>s</sub> (F)	65
T <sub>a</sub> (F)	50
Height (in)	62
Diameter (in)	26
A (ft <sup>2</sup> )	35
Daily Gas Use (mmBtu/dy)	0.175
Q <sub>conv</sub> (mmBtu/dy)	0.018991
AFUE	63.36%

Replacing the current hot water heater with a tankless hot water heater would at least bring the efficiency up to 74% because there would be no shell losses.

Annual natural gas savings would be about:

$$628 \text{ ccf/year} \times (1 \text{ mmBtu} / 10 \text{ ccf}) = 62.8 \text{ mmBtu}$$

$$62.8 \text{ mmBtu} \times 0.63/0.74 = 53.5 \text{ mmBtu/year}$$

$$62.8 \text{ mmBtu} - 53.5 \text{ mmBtu} = 9.3 \text{ mmBtu/year}$$

$$9.3 \text{ mmBtu/yr} \times \$12.50 / \text{mmBtu} = \$116 / \text{yr}$$

Annual CO<sub>2</sub> savings would be about:

$$9.3 \text{ mmBtu/yr} \times 113 \text{ lb CO}_2 / \text{mmBtu} = 1,050 \text{ lb CO}_2 / \text{year}$$

**Estimated Implementation Cost**

According to a representative at home depot, the cost of a tankless, natural gas hot water heater is about \$800 including a venting kit. We believe that if UD were to buy these from a supplier, that they would be able to receive approximately a 40% discount like on most of their appliances. This would mean that the replacement heater would cost just about \$500.

According to Residential Properties, the cost of installing a tankless natural gas hot water heater would be about \$1,200.

**Estimated Rate of Return and Simple Payback**

$$\$116 / \text{yr} / \$1,200 = 10\%$$

$$\$1,200 / \$116 / \text{year} \times 12 \text{ months/year} = 124 \text{ months}$$

## Synergistic Summary of Savings

	Annual Savings			Project Cost			Rate of Return
	Resource	CO <sub>2</sub> (lb)	Dollars	Capital	Other	Total	
Natural Gas	229 mmBtu	26,000	\$2,613	-	-	-	-
Electricity	5,519 kWh	13,000	\$538	-	-	-	-
Total Savings		39,000	\$3,151	-	-	\$9,058	35%

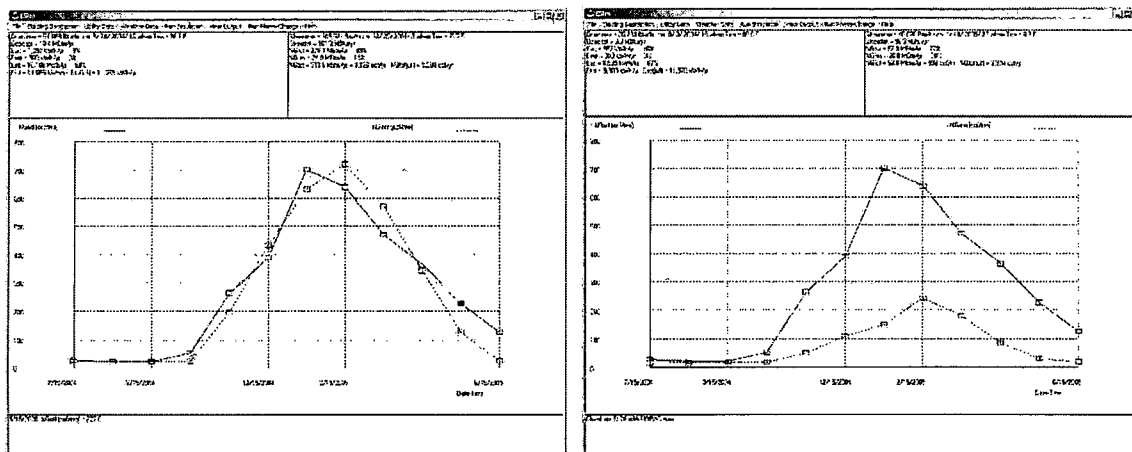
## Analysis

In the utility summary section of the report, annual electricity and natural gas costs were \$1,067 and \$3,377, respectively. The annual utility cost for 26 Chambers St. is about \$4,444. In the Summary of Assessment Recommendations section of the report, annual savings from all of the recommendations totals \$4,664. This is higher than the current annual utility costs and is a result of the fact that we have, until now, considered each recommendation individually. Synergistic affects arise when multiple building components are changed at once. While installing blown cellulose insulation by itself might save \$986 per year and installing weather stripping and caulk would save \$700 per year, together they will not save \$1,686. Together they will save less than the total of their individual savings. In order to account for the synergistic effects of modifying building characteristics, analysis will be performed incorporating all of the proposed building modifications.

## Estimated Savings

In the Building Energy Simulation section of the report, we created a model using current building characteristics. The building model is calibrated to actual utility bills. Simulated annual natural gas use is 3,136 ccf and actual annual natural gas use is 3,304 ccf. This gives us confidence in the building model. Building energy is simulated again with the following modifications to the building characteristic file:

- Install Blown Cellulose Insulation in Wood Frame Walls
- Install Weather Stripping and Caulk to Reduce Infiltration
- Install Digital Thermostats and Implement Night Setbacks
- Install New Windows
- Decrease Excess Combustion Air to Hot Water Boiler
- Replace Existing Water Heater with Tankless Water Heater



ESim predicts the annual natural gas use after these four retrofits to be about 938 ccf per year. Natural gas savings would be about:

$$3,136 \text{ ccf/yr} - 938 \text{ ccf/yr} = 2,198 \text{ ccf/yr}$$

Energy savings are estimated from the following building changes:

- Insulate Hot Water Supply and Return Pipes
- Replace Incandescent Bulbs with Compact Fluorescent Bulbs

Of the remaining 938 ccf per year of natural gas use, we estimate about 10% could be saved by insulating the hot water supply and return pipes and decreasing excess combustion air to the hot water boiler. Additional savings would be about:

$$938 \text{ ccf/yr} \times 10\% = 94 \text{ ccf}$$

Electrical energy savings from installing compact fluorescent bulbs would be about 5,519 kWh per year.

#### Natural Gas Savings

Annual natural gas savings would be about:

$$2,198 \text{ ccf/yr} + 94 \text{ ccf/yr} = 2,292 \text{ ccf/yr}$$

$$2,292 \text{ ccf/yr} \times \$1.14 / \text{ccf} = \$2,613 / \text{yr}$$

$$229 \text{ mmBtu/yr} \times 113 \text{ lb CO}_2 / \text{mmBtu} = 26,000 \text{ lb CO}_2 / \text{year}$$

#### Electricity Savings

Annual electricity savings would be about:

$$5,519 \text{ kWh/yr} \times \$0.088 / \text{kWh} = \$538 / \text{yr}$$

$$5,519 \text{ kWh/year} \times 2.3 \text{ lbs CO}_2 / \text{kWh} = 13,000 \text{ lbs CO}_2$$

#### Total Annual Savings

Annual cost savings would be about:

$$\$2,613 / \text{yr} + \$538 / \text{yr} = \$3,151 / \text{yr}$$

### **Estimated Implementation Cost**

From the Summary of Assessment Recommendations section of the report, the cost of implementation for all of the recommendations is about \$9,058.

### **Estimated Rate of Return and Simple Payback**

$$(\$3,151 / \text{year} / \$9,058) = 35\%$$

$$(\$9,058 / \$3,151 / \text{year}) \times 12 \text{ months/year} = 34 \text{ months}$$



## **Chapter 7**

### **Summary and Conclusions**

Chapters 1 and 2 discussed the need for society to value sustainability as a categorical duty through the application of Kantian ethics and common sense. There are many ways for people to strive towards sustainability, and energy efficiency was discussed as a first and important step. It was argued that a focus on decreasing energy used in residences is both a simple and cost-effective way to reduce worldwide energy use.

Chapter 3 discussed the initial conceptual design of the net-zero energy University of Dayton Eco-house, and the associated analysis. Energy use of current student houses was analyzed to provide a baseline and to identify energy saving opportunities. The use of the whole-system inside-out approach to guide the overall design was described. Using the inside-out method as a guide, the energy impacts of occupant behavior, appliances and lights, building envelope, energy distribution systems and primary energy conversion equipment were discussed. The design of solar thermal and solar photovoltaic systems to meet the hot water and electricity requirements of the house were described. Eco-house energy use was simulated and compared to the energy use of the existing houses. The analysis showed the total source energy requirements of the Eco-house could be reduced by about 340 mmBtu per year over older baseline

houses, resulting in CO<sub>2</sub> emission reductions of about 54,000 lb per year and utility cost savings of about \$3,000 per year.

Chapter 4 discussed both the design and cost-benefit analysis of a net-zero energy campus residence. This paper improved upon the initial conceptual design and provided the associated cost-benefit analysis. This paper began by presenting the energy use of current student houses to provide a baseline for determining energy savings. Using the inside-out method, the energy impacts of occupant behavior, appliances and lights, building envelope, energy distribution systems and primary energy conversion equipment were discussed. The designs of solar thermal and solar photovoltaic systems to meet the hot water and electricity requirements of the house were described. Cost-benefit analysis was first performed on house components and then on the whole house. At a 5% discount rate, 5% borrowing rate for a 20 year mortgage, a 35 year lifetime, and an annual fuel escalation rate of 4%, the Eco-house can be constructed for no additional lifetime cost.

Chapter 5 described a four-step method to analyze monthly utility billing and weather data to target residential buildings for energy assistance programs and assessments. After applying the four step method, targeted buildings were visited to determine the accuracy of the method. Of the houses visited, 89% of the high independent gas use houses, 100% of the high balance temperature houses, and 80% of the high heating slope houses had at least one significant issue as previously identified in the method. Of the high independent gas use houses, the most significant and frequent issues found were high hot water temperature setpoints (66%) and low efficiency hot water heaters (66%). Of the high balance temperature houses, the main issues found

were no nighttime set-backs (100%) and high rate of infiltration (drafty houses) (70%). Finally, of the high heating slope houses, the issues were low furnace efficiency (70%) and high UA value (80%). The method is also helpful in identifying billing and transcription errors, which are significant problems for managers of multiple sites.

Chapter 6 showed the process of an energy assessment for a single residence. This chapter contains more detailed descriptions of how energy is used, current practices that are already energy efficient, and the energy conservation opportunities identified. Considering synergistic effects, natural gas savings would be about 2,290 ccf per year. Electricity savings would be about 5,519 kWh per year. Cost savings would be about \$3,151 per year. The rate of return on the investment is 35% annually. The simple payback on the investments is 34 months.

Each chapter of this thesis discusses residential energy in a different manner. After understanding each chapter separately, we can draw a major overall conclusion. Energy-efficiency measures, reductions in energy use, and the minimalization of energy from fossil fuels are important, intelligent, and necessary steps if humanity wishes to survive, flourish, and positively effect the environment. With this understanding, sustainability is no longer a far off dream, but an attainable reality. Energy-efficiency is not the only solution, but it is a good place to start. As with any great puzzle, no progress may be made without putting the first few, simple pieces together to help you realize that the big picture is truly within your reach.

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