ZERO ENERGY GARAGE APARTMENT

by

HARINI SARANGAPANI

B.Arch., Mumbai University, India, 2004.

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF ARCHITECTURE

Department of Architecture
College of Architecture, Planning and Design

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2008

Approved by:

Major Professor
Gary. J. Coates

Abstract

Buildings account for a large part of total U.S. energy consumption and generate far more greenhouse gas emissions than any other sector of the economy. The purpose of this thesis is to demonstrate how buildings can be designed in a way that helps to mitigate global environmental problems, while resolving local urban design, architecture and social issues.

This purpose was achieved by designing a zero-energy garage apartment for a site located along an alley in Manhattan, Kansas. The methodology for the design was to: identify a client; define project goals and design criteria; determine solar and geothermal renewable energy system requirements; design the garage apartment by employing energy efficient strategies relating to bioregional design and passive solar design; identify eco-friendly materials obtainable within a 500-mile radius of the site; and identify energy-efficient construction methods. The energy performance of the garage apartment was constantly monitored using eQUEST and Energy-10 simulation softwares.

Operational definitions:

Garage apartment- a building behind the main building[1], which is part of the same plot as the main building. It is also called a 'backhouse', 'granny flat' or a 'rear house'.

Zero-energy house- for this thesis, a grid connected self-standing zero-energy house, which results in zero utility bills throughout the year.

---

[1] Garage Apartment. (n.d.). Retrieved April 6, 2006, from Wikipedia: http://en.wikipedia.org/wiki/Garage_apartment

Table of Contents

List of Figures

List of Tables

Acknowledgements

Designing the zero energy garage apartment would have seemed like a Herculean task, if not for all the people who helped me along the way. I express sincere gratitude to Professor Gary Coates for his invaluable guidance, patience and continued support. I would like to express my deep and sincere gratitude to the clients. I am grateful for having experienced and knowledgeable committee members in Professor Todd Gabbard and Professor John Selfridge, who have extended a helping hand whenever needed. Many thanks to Professor Ray Yunk for helping me navigate through the energy simulation softwares and Professor Dragoslav Simic for his assistance in helping me understand the various structural implications of my design ideas.

I am grateful to Professor Stephanie Rolley and Professor Richard Hoag for their initial guidance in refining my thesis ideas. My special thanks to Professor Vladimir Krstic and Professor David Sachs for their inputs during the preliminary stages of the thesis. I would also like to thank Rebecca Stark, Professor Carol Watts and Tracy Ivy for keeping me updated on thesis timelines and other specific requirements. I appreciate the timely help from Ryan Haugaard and all the other contractors, suppliers, dealers and technicians.

I am much obliged to Trishna Pradhan, Avinash Gautam, Subhojit Sinha, Amita Joshi, Neelesh Thakur and Vivek Sai for their continued help. I cannot thank my family enough for always being there. Last but not the least, I am indebted to Kansas State University for giving me an opportunity and identity I will cherish for a lifetime.

Dedication

To my roommates and friends, in alphabetical order:

Amita Joshi

Amit Gud

Harshit Shah

Jaidev Manghat

Neelesh Thakur

Piyush Mandowara

Reshma Sawant

Sarang Mairal

Thank you for being family.

CHAPTER 1 - Introduction

Two great crises are confronting human societies at the beginning of the 21st century, global warming and peak oil and gas production. Global warming is caused when carbon is released into the atmosphere by the burning of fossil fuels. Elevated levels of carbon trap heat in the atmosphere and create a greenhouse effect that heats up the planet and causes climate change.[2]

Peak oil occurs at that moment in time when the maximum global petroleum production rate is reached, after which the rate of production enters its terminal decline. If global consumption is not mitigated before the peak, the availability of conventional oil will drop, prices will rise and the economy will spiral downward.[3] Natural gas has been accepted as an ideal replacement fuel for oil. It burns more cleanly [though it still produces CO_2]; most automobiles can be converted to run on it; it is used in agricultural and industrial purposes, and for household cooking and eating. Natural gas is energy dense and versatile and there is an infrastructure already in place to make use of this fuel. However, increasing shortfalls for natural gas have already resulted in the USA having to import natural gas from Canada. Ultimately, natural gas is also a fuel that, like oil, is doomed to peak.[4]

The United States, along with other advanced technological societies, relies heavily on the concentrated energy sources of oil and natural gas to feed its lavish, high-energy living standards that are largely taken for granted. Oil and natural gas are not only finite energy sources, but they are also compounding environmental problems and are directly responsible for

---

[2] Global Warming. (n.d.). Retrieved November 25, 2007, from Wikipedia: http://en.wikipedia.org/wiki/Global_warming

[3] Peak Oil. (n.d.). Retrieved November 25, 2007, from Wikipedia: http://en.wikipedia.org/wiki/Peak_oil

[4] Heinberg, Richard. (2005). *The Party's Over: Oil, War And The Fate Of Industrial Societies*. (2nd ed.). New Society Publishers.

accelerating global warming and human-related climate change. This thesis addresses both the crises of global warming and peak oil and gas simultaneously by designing an affordable housing unit that:

1) Makes use of renewable energy for all building related energy needs.
2) Uses low energy and renewable building materials produced, as much as possible, within a 500 mile radius.
3) Increases urban density in a socially benign way that enhances walking, biking and the possibilities of using mass transit.

Through architectural design this thesis also addresses a number of regional environmental and socio-economic issues, like those listed in the IPCC [Intergovernmental Panel on Climate Change] report (Parry, M.L., O.F. Canziani, J.P. Palutikof and Co-authors, 2007, TS.2) on future concerns regarding human-related climate change in the USA.[5] The following points cited by the IPCC have been taken into consideration[6] for this thesis:

1) North America has experienced locally severe economic damage, plus substantial ecosystem, social and cultural disruption, from recent weather-related extremes; including hurricanes, other severe storms, floods, droughts, heat waves, and wildfires.
2) Although North America has considerable adaptive capacity, actual practices have not always protected people and property from adverse impacts of climate variability and extreme weather events. Especially vulnerable groups include those who are socially or economically disadvantaged. Traditions and institutions in North America have encouraged a decentralized response framework where adaptation tends to be reactive, unevenly distributed, and focused on coping with rather than preventing problems. 'Mainstreaming' climate change issues into

---

[5] Parry, M.L., O.F. Canziani, J.P. Palutikof and Co-authors. (2007). *Technical Summary. Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 23-78. Retrieved from IPCC: http://www.ipcc-wg2.org/

[6] Ibid.

decision-making is a key prerequisite for sustainability.

3) Rising temperatures will diminish snow pack and increase evaporation, affecting seasonal availability of water. Higher demand from economic development, agriculture and population growth will further limit surface and groundwater availability.
4) Climate change impacts on infrastructure, human health and safety in urban centers will be compounded by failing infrastructure, maladapted urban form and building stock, urban heat islands, air pollution, population growth and an aging population. Increased energy demand and the resultant unreliable energy flow and higher energy costs will further worsen problems.
5) Without increased investments in countermeasures, warmer temperatures and extreme weather are likely to cause increased adverse health impacts from heat-related mortality, pollution, storm-related fatalities and injuries, and infectious diseases. Historically important countermeasures include early warning and surveillance systems, air conditioning, access to health care, public education, vector control, higher infrastructure standards, and air quality management. Cities that currently experience heat waves are expected to experience an increase in intensity and duration of these events by the end of the century, with potential for adverse health effects. The growing number of the elderly is most at risk.
6) Disturbances such as wildfire and insect outbreaks are increasing and are likely to intensify in a warmer future with drier soils and longer growing seasons. Over the 21st century, pressure for species to shift north and to higher elevations will fundamentally rearrange North American ecosystems. Differential capacities for range shifts and constraints from development, habitat fragmentation, invasive species, and broken ecological connections will alter ecosystem structure, function and services.
7) North American city water supply systems often draw water from considerable distances, so climate impacts need not be local to affect cities. However, a region's smaller systems may be vulnerable, leading to a need for enhanced

regional water distribution protocols.[7]

From the above-mentioned IPCC report, it is evident that architecture can allay the effects of climate change while helping people adapt to a changing climate and increasingly erratic weather. Architecture can also help people to move away from patterns of over-consumption toward simpler, smarter and more meaningful lives. Architecture is a major part of the interrelated problems of climate change and fossil fuel depletion [peak oil] and it can be an important part of the solutions to these great challenges confronting humankind.

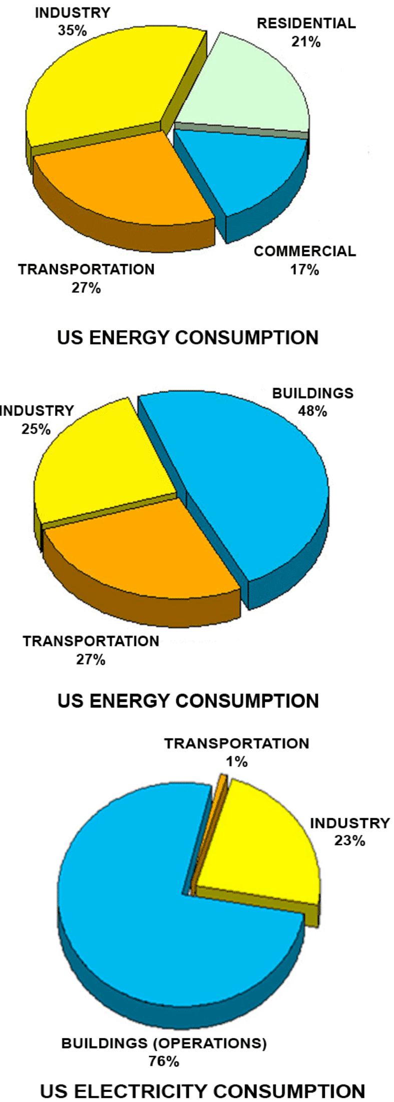
The notion that architecture can allay the effects of climate change is also be validated by data from the U.S. Energy Information Administration, that illustrates that buildings are responsible for almost half (48%) of all greenhouse gas emissions annually[8], as shown in *Figure 1-1*.

---

[7] Ibid.

[8] The Building Sector: A Hidden Culprit. (n.d.). Retrieved April 14, 2007, from Architecture 2030: http://www.architecture2030.org/current_situation/building_sector.html

Figure 1-1: United State energy and electricity consumption in 2000.



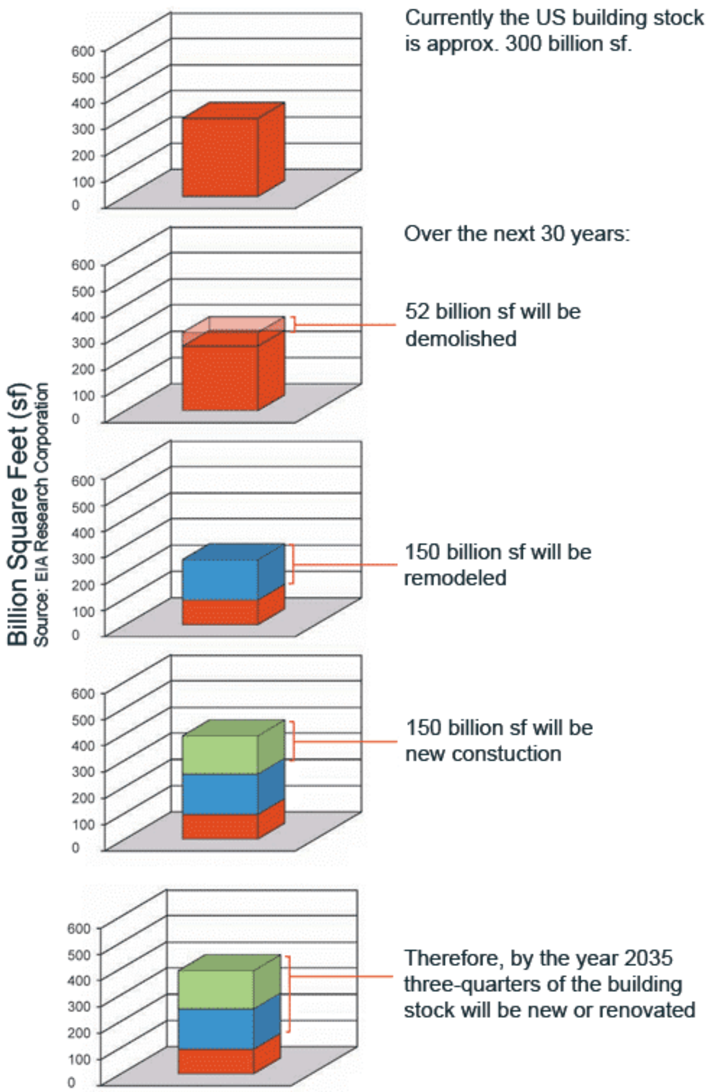
(Source: The Building Sector: A Hidden Culprit. (n.d.). Retrieved April 14, 2007, from Architecture 2030: http://www.architecture2030.org/current_situation/building_sector.html)

Moreover, the greenhouse gases that rapidly accelerate climate change are present in building materials that produce them as a by-product of their manufacture; and 76% of all electricity generated by US power plants goes to supply just the Building Sector.[9] It is now

[9] The Building Sector: A Hidden Culprit. (n.d.). Retrieved April 14, 2007, from Architecture 2030: http://www.architecture2030.org/current_situation/building_sector.html

absolutely necessary to deem architecture as part of the solution to mitigate not just regional, but global climate change and to take immediate action towards that goal. There exists a high potential for such an undertaking, as is illustrated in *Figure 1-2.*

Figure 1-2: Potential for rendering nearly 75% of the built environment [that will be either new or renovated] as eco-friendly.



(Source: The Building Sector: A Historic Opportunity. (n.d.). Retrieved April 14, 2007, from Architecture 2030: http://www.architecture2030.org/current_situation/hist_opportunity.html)

Vision for a sustainable architecture

The 2030 Challenge

The architectural community has devised several ways to achieve the goal of solving global environmental problems through architecture. For example, *The 2030 Challenge*, put forth by architect Ed Mazria and supported by numerous organizations and political establishments, is encouraging people to adopt the challenge, which lays down stage-wise reductions of on-site fossil fuel energy consumption by 90% by year 2030. *The 2030 challenge* is chosen as part of the vision framework for this thesis since it is formulated to make the building sector more responsible towards the environment while radically reducing fossil fuel use. Moreover, *The 2030 Challenge* targets and performance expectations are gaining wide acceptance throughout the nation. The American Institute of Architects [AIA], for example, is a major supporter of *The 2030 Challenge* program. In addition, AIA has created a *Green Building Toolkit* that emphasizes the following points:[10]

1) Reducing human exposure to toxic materials.
2) Conserving non-renewable energy and scarce materials.
3) Minimizing life-cycle ecological impact of energy and materials used.
4) Using renewable energy and materials that are sustainably harvested.
5) Protecting and restoring local air, water, soils, flora, and fauna.
6) Supporting pedestrians and bicyclists, while encouraging mass transit and other alternatives to fossil-fueled vehicles.

The AIA has involved itself in promoting high-quality green buildings that last longer, cost less to operate and maintain, and provide greater occupant satisfaction than standard developments.[11] AIA has also recognized sustainable design rating systems like LEED [Leadership in Energy and Environmental Design]. Inspired and informed by *The 2030 Challenge*, as shown in *Figure 1-3*, the design of the zero energy garage apartment aims at: 1)

---

[10] Toolkit Sustainability 2030. (n.d.). Retrieved November 27, 2007, from AIA: http://www.aia.org/toolkit2030/

[11] Ibid.

reducing human exposure to toxic materials by using materials that produce no off-gassing; 2) conserving non-renewable energy by using renewable energy and by reducing infiltration via its tight shell; 3) conserving scarce materials by utilizing salvaged materials for cabinets and possibly for some fixtures like bathtubs, etc.; 4) minimizing life-cycle ecological impacts of energy and materials by using materials that are highly recyclable and made with post-consumer content; 5) using FSC certified materials that are sustainably harvested; 6) helping to protect and restore local air, water, soils, flora and fauna by not releasing any pollutants into the air; harvesting rainwater, and using xeriscape landscaping; 7) supporting pedestrians and bicyclists by providing bicycle stands and encouraging foot transport due to greater density of the built environment, and finally; 8) supporting urban density to also encourage future mass transit use.

Following the AIA's vision of sustainable architecture , the zero energy garage apartment is also designed: 1) to last for a number of years by providing versatility, adaptability and life-cycle performance; 2) to cost less to operate and maintain, and; 3) to provide greater occupant satisfaction than standard developments.

Figure 1-3: Green Building Toolkit's implementation onto the zero energy garage apartment.

PRINCIPLES **The Green Building Toolkit**	IMPLEMENTATION **Zero Energy Garage Apartment**
Reduce human exposure to toxic materials.	Used materials that produce no off-gassing.
Conserve non-renewable energy.	Used renewable energy, reduced infiltration.
Conserve scarce materials.	Utilized salvaged materials, fixtures.
Minimize life-cycle ecological impact of energy and materials.	Used recyclable materials, materials made with post-consumer content.
Use renewable energy and materials that are sustainably harvested.	Used FSC certified materials, materials that are sustainably harvested.
Protect and restore local air, water, soils, flora, fauna.	Used materials and systems that do not release any pollutants, harvested rainwater, snowmelt; used xeriscape landscaping.
Support pedestrians and bicyclists, encourage mass transit and other alternatives to fossil-fuelled vehicles.	Provided space for bicycle stands; increased urban density will encourage foot transport, future mass transit use.

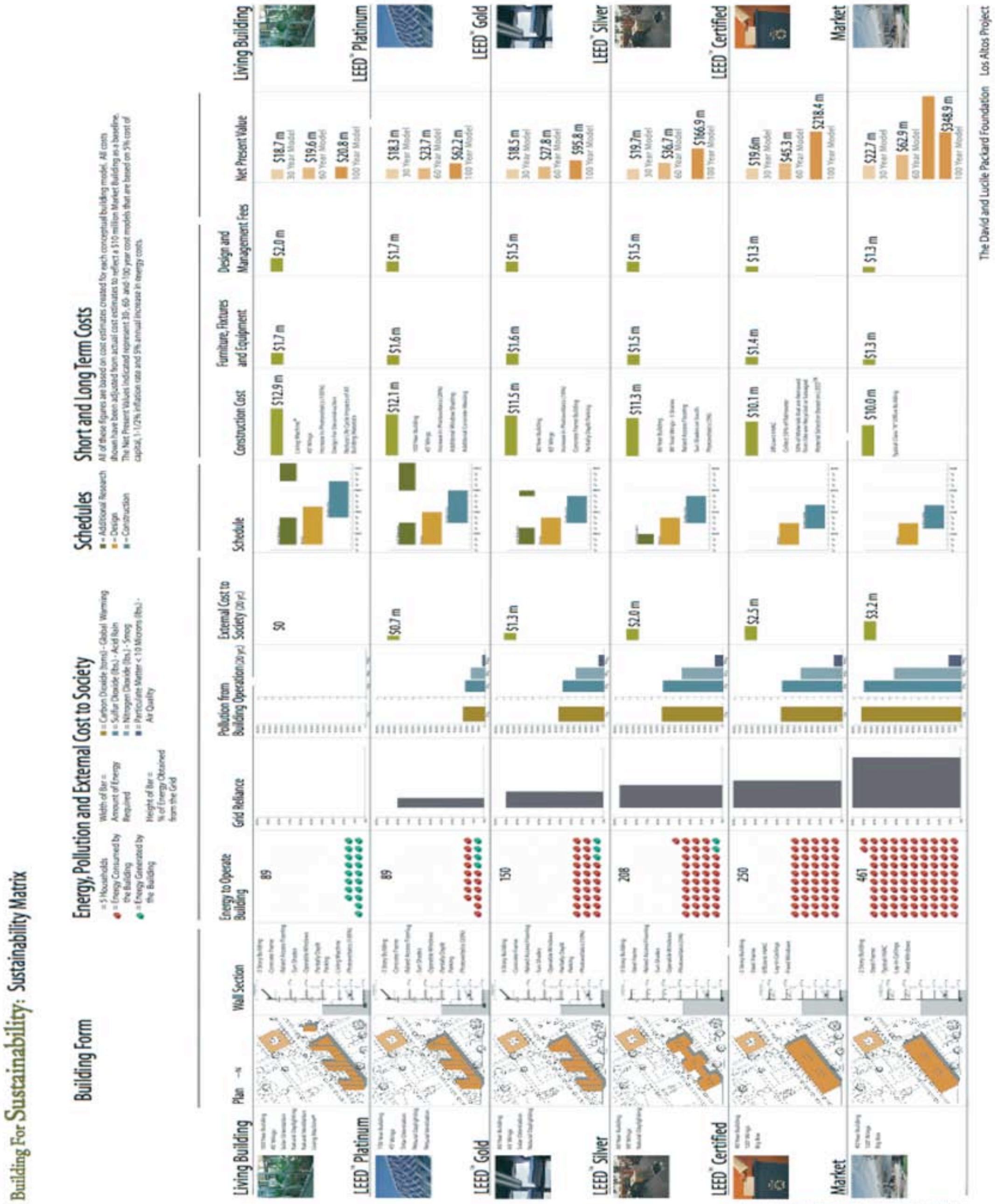
The BNIM Sustainability Matrix

BNIM, an architectural firm in Kansas City, has formed a Sustainability Matrix that compares the building performance of buildings rated by the LEED sustainability rating system to a building classified as a 'Living Building', designed to perform better than LEED's highest rating, LEED Platinum. Refer to *Table 1-1: Sustainability matrix* for the comparison chart. BNIM's Sustainability Matrix is included as part of the vision framework for this thesis since it takes an advanced sustainability rating system, LEED, and shows that high-performance buildings need to encompass social, economic and environmental issues. The BNIM Sustainability Matrix takes into account the health and productivity of the user, the impact of the building on natural resources and the environment, and the distinct and quantifiable fiscal advantages resulting from this balanced approach to building design that are interdependent from the beginning of the design process and continue on throughout the lifetime operation of the building.[12] The BNIM Sustainability Matrix is a compelling vision of the possibilities of architecture and an invaluable decision-making tool.

---

[12] Packard Matrix.(n.d.). Retrieved October 12, 2006, from BNIM: http://www.bnim.com/fmi/xsl/research/packard/index.xsl

Table 1-1: Sustainability Matrix.



(Source: Building for Sustainability: Sustainability Matrix. October 2002. Retrieved October 12, 2006, from BNIM: http://www.bnim.com/newsite/pdfs/2002-Matrix.pdf)

By using BNIM's Sustainability Matrix as a framework, as shown in *Figure 1-4,* the zero energy garage apartment is designed to provide natural ventilation, natural lighting and bioclimatically appropriate solar orientation. In addition, the proposed structure's stand alone solar energy and geothermal energy systems do not rely on the grid for their electrical needs, nor do they pollute the environment as a result of the building operation. The design of the zero energy garage apartment reduces construction waste, fits within the client's budget and does not add to the external cost to society. While this design cannot be yet be described as a "Living Building" it represents a movement in that direction because it considers its larger environmental, social and urban design impacts.

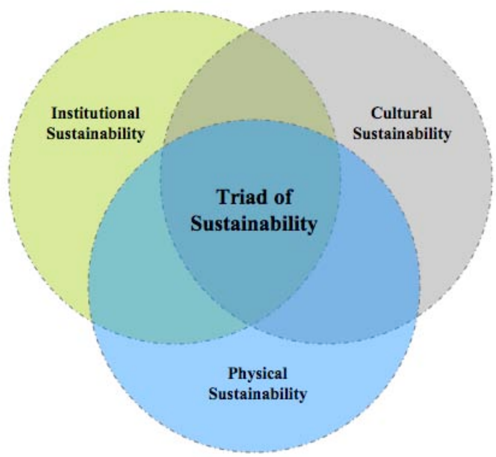
Figure 1-4: Sustainability Matrix's implementation onto the zero energy garage apartment.

PRINCIPLES **The BNIM Sustainability Matrix**	IMPLEMENTATION **Zero Energy Garage Apartment**
100 year building.	Designed versatile plans with life-cycle adaptability; used long-lasting materials.
Solar orientation.	Elongated along E-W axis, maximized Southern exposure for summer solar gain.
Natural daylighting.	Used high-performance windows to maximize natural daylighting, minimize unwanted solar gain.
Natural ventilation, operable windows.	Used high-performance operable windows to maximize natural ventilation, cross ventilation.
Sun shades.	Louvers over South-facing glass to prevent summer solar gain.
Partially daylight parking.	Translucent glass garage doors to aid winter solar gain in un-conditioned garage.
100% photovoltaics.	100% solar energy for electrical needs, geothermal energy for HVAC, hot water needs.
No grid reliance.	Energy used by garage apartment will be produced by it.

Mahesh Senagala: The Triad of Sustainability

Mahesh Senagala, Associate Dean of Academic Affairs and Research at the College of Architecture, University of Texas at San Antonio, has proposed a framework called "The Triad of Sustainability",[13] as shown in *Figure 1-5*. Like BNIM, he believes that sustainable design should be holistic in character. "The Triad of Sustainability" framework divides sustainability into institutional and cultural sustainability [political, economic, sociological, cultural issues], physical sustainability [environmental, technological issues] and existential sustainability [psychological, metaphysical issues]. "The Triad of Sustainability" is included as part of the vision for this thesis because it forms an umbrella framework that further broadens the definition of sustainability beyond just the physical and technical aspects of design.

Figure 1-5: Mahesh Senagala's Triad of Sustainability.



The zero energy garage apartment, within Mahesh Senagala's "Triad of Sustainability" framework, as shown in *Figure 1-6*, will aim to address institutional sustainability via sociological and cultural aspects; physical sustainability through environmental and technological soundness, and economic framework via affordability. Perhaps satisfying the institutional and physical sustainability frameworks laid down by Senagala will lead to a state of

[13] The Triad of Sustainability. (1999). Retrieved April 14, 2006, from Mahesh Senagala's website: http://www.mahesh.org/articles/triad.pdf

existential sustainability, where the psychological and metaphysical needs of the body will be satisfied by the built environment of the zero energy garage apartment.

Figure 1-6: The Triad of Sustainability's implementation onto the zero energy garage apartment.

PRINCIPLES The Triad of Sustainability	IMPLEMENTATION Zero Energy Garage Apartment
Does it link human beings to the local landscape?	Yes. Via porches, windows.
Does the product have a cultural, political, social and ideological agenda? Is the institution founded on a shared ideology other than making profit?	Yes. Respect the prevalent on-site architectural character, encourage the state of Kansas to provide tax credits and other benefits for high performance buildings, use the project as a case-in-point for future such developments in Kansas.
Does the institution promote flexibility, innovation and diversity?	Yes. Via versatile, highly adaptable interior space throughout the projected life-cycle of the building; promote the concept of garage apartments; promote the diverse application possibilities of the project.
Does the product enrich and transform society?	Yes. Encourages more environment friendly, energy secure architectural solutions.
Is it eco-friendly?	Yes. By use of renewable energy systems, reduction in fossil fuel energy dependency, bioregional design strategies, passive solar heating and cooling techniques, and eco-friendly materials.
Does the product espouse low embodied energy, low waste, recycling and re-use ideas?	Yes.
Does it produce enough energy to sustain majority of its needs?	Yes, the resultant being a house that produces all the energy it consumes.
Is it non-toxic?	Yes.

Janine Benyus: Biomimicry

Janine Benyus, the writer of the book *Biomimicry*, believes nature is the ultimate designer and buildings should emulate that performance. According to her, nature runs on sunlight, uses only the energy it needs, fits form to function, recycles everything, rewards cooperation, banks on diversity, demands local expertise, curbs excesses from within and taps the power of limits.[14] Janine Benyus' beliefs were included as part of the vision framework as they provide design direction to explore the possibilities of sustainable design by synthesizing the potential of technology to bring about effective solutions. In relation to Janine Benyus' sustainability framework, as shown in *Figure 1-7*, the zero energy garage apartment will aim to rely on sunlight for its energy needs where a grid connected, stand alone solar energy system will be proposed to be installed. It will also rely on sunlight for its passive solar heating needs. The zero energy garage apartment will use only the energy it needs; fit form into function through its design; recycle grey-water by channeling water from the sinks into the water closet; encourage diversity in society by allowing for various income groups to accumulate within a certain dense area; demand local expertise from local material manufacturers and local builders, and to be designed to curb excesses from within, for example by eliminating the need for a central vacuum by providing floors that can be cleaned easily with a broom. Although the design of the zero energy garage apartment will not absolutely live up to Janine Benyus' portrayal of nature as a designer, it will aim to satisfy most of her criteria in the maximum way possible.

---

[14] Benyus, Janine. (2002). *Biomimicry*. (2nd ed.). HarperCollins Publishers.

Figure 1-7: Biomimicry's implementation onto the zero energy garage apartment.

PRINCIPLES	IMPLEMENTATION
Biomimicry	**Zero Energy Garage Apartment**
Nature runs on sunlight.	Solar energy used for all electrical needs.
Nature uses only the energy it needs.	Garage apartment produces the energy it will use.
Nature fits form into function.	Roof form dominated by photovoltaic area requirements.
Nature re-cycles everything.	Recycled and recyclable materials as maximally possible.
Nature demands local expertise.	Locally available materials within a 500 mile radius used.
Nature curbs excesses from within.	Reduced building footprint, energy conservation Measures.

Janine Benyus' belief, combined with Mahesh Senagala's "The Triad of Sustainability", BNIM's Sustainability Matrix, *The 2030 Challenge* and AIA's Green Building Toolkit form the framework for the vision of sustainability for this thesis, as they in their own ways, recognize the severity of the need for sustainable design solutions and are structured to resolve the problems in the building sector that are currently compounding the crisis of global warming and peak oil.

Project Background

In 2001, Professor Gary Coates and students from his fourth year design studio in Kansas State University's Department of Architecture, worked on an urban infill project addressing Manhattan, Kansas' increasing housing needs (Coates, 2001, p.1). The project was carried out at the request of the Mayor and was conducted within the framework of the city's *Housing Manhattan Plan* (Coates, 2001, p.1), published in July 2000, which identified the magnitude and urgency of a community-wide demand potential for approximately 3000 additional housing units in Manhattan. Out of the total projected demand, it was estimated that 2000 rental units [including 950 units for low-to-moderate income households] and 1000 owner-occupied units [including 215 units for low-to-moderate income households] were needed. As both the *Housing Manhattan Plan* and the April 2000 *Downtown Tomorrow Redevelopment Plan* (Coates, 2001, p.1) identified Manhattan's older traditional neighborhoods as important areas for meeting a significant portion of the community's present and future housing needs, the project undertaken by the design studio aimed to accomplish the goal of establishing long-term housing strategies for traditional neighborhoods, while addressing the challenge of protecting and enhancing the integrity, cultural and architectural character of the concerned areas.[15]

Some of the factors taken into consideration for the project include analyzing the maximum size and density of infill housing that could be absorbed by older neighbourhoods without destroying their sense of human scale and architectural character. Meeting the rental housing needs of students in the older neighborhood area without disrupting existing lifestyles and social patterns were also taken into consideration. The project focused on solutions that would help increase the affordability of owner-occupied housing; and also increase the number and variety of housing options for students and young families. Infill housing in the form of 'granny flats', 'rear cottages' or 'back houses that could be built on existing properties or as part of new infill development were proposed as a solution to address Manhattan's increasing housing needs. Infill housing was also identified as a means towards achieving the following community and housing-related goals:

[15] Coates, Gary. (2001). *Affordable Housing: Reweaving the Fabric of Manhattan's Older Neighborhoods.* (1st ed.).

1) There would be an infusion of investment capital into the older neighborhoods, increasing property values and tax revenues as well as increasing income for existing residents.
2) Families with young children, but limited incomes, would be drawn to live and build in the older neighborhoods, which would help to keep schools open and stabilize areas of the city that are currently at the risk of becoming student ghettoes.
3) It would be possible for low-to-moderate income families, including university staff and faculty, to buy and develop existing houses, or to build new infill houses, that are within walking distance of the campus. Given the low and increasingly uncompetitive salaries offered by Kansas State, such convenient and family-centered housing options could be used as a major recruiting tool.
4) Such an approach would generate a diverse range of new, architecturally distinguished and charming housing options for Manhattan's large and growing rental market. Manhattan might well become known throughout the region and nation as a humanly scaled city of early 20th century bungalows and early 21st century Backhouses and live/ work cottages.[16]

The project was divided into 2 phases: 1) research, and; 2) design. The studio project's research segment involved a detailed visual survey and analysis of the traditional neighborhoods. The design proposals addressed design prototypes for infill housing using the "Front-house-to-own/ Backhouse-to-rent" pattern. An economic assessment of the design proposals was also carried out. The research phase and critical evaluations of the final design proposals led to the establishment of Urban Visual Code and Architectural Guidelines. The Urban Visual Code and Architectural Guidelines was later adopted the city as the basis for the Traditional Neighborhood Ordinance [TNO] and the Multi-Family Residential Ordinance [M-FRO] to guide future in-fill development in the older neighborhoods. However, under the 'Zoning' category, the City did not include the recommended provision for free-standing backhouses.[17] Hence, this thesis also

[16] Coates, Gary. (2001). *Affordable Housing: Reweaving the Fabric of Manhattan's Older Neighborhoods.* (1st ed.).

[17] Ibid.

intends to demonstrate the value of amending the City's zoning to make garage apartments and other forms of detached 'backhouses' possible.

Summary: The design studio demonstrated that it is indeed possible to increase the density and diversity of affordable home-ownership and rental housing options in the older Manhattan neighborhoods without negatively impacting either their quality of life or architectural character. As judged by most observers, the infill housing proposed by the students was seen as a way to enhance the character of many areas of the city. The economic analyses documented in the project report showed that the proposed infill designs would put homeownership within reach of households earning as little of $25,000 per year. It was concluded that infill housing was the best and perhaps the only strategy for enhancing and preserving the character of existing older neighborhoods while simultaneously meeting the housing needs of low-to-moderate homeowners and renters.[18]

This conclusion formed the foundation for this thesis, where an infill house in the form of a zero energy garage apartment is proposed to meet the housing needs of a "real" client while also serving the needs of the larger community. This thesis takes into account the life-cycle flexibility of the garage apartment and the versatility it accordingly demands to function most effectively through the years.

Thesis structure

This thesis is structured with respect to how the design of the garage apartment evolved. Chapter 1 'Phase 1: Project Goals and Design Criteria' section: introduces the client; describes existing property details, in the backyard of which the alley garage apartment is designed to be built; gives the client brief [value matrix programming document] and the designer's value matrix. This context formed the basic parameters for the design.

Chapter 2 'Phase 2: Design' focuses largely on the analysis of the garage apartment's design. This segment documents the methodology and process of carrying out the design of the zero energy garage apartment. It documents related research and the techniques that have been implemented in the design of the zero energy garage apartment. Chapter 2 also provides details

---

[18] Coates, Gary. (2001). *Affordable Housing: Reweaving the Fabric of Manhattan's Older Neighborhoods.* (1st ed.).

of the renewable energy systems applied to the design and summarizes the results of the energy performance simulations that were carried out using eQUEST and Energy10 softwares. Phase 2 includes chapters on the materials proposed as well as the cost evaluation chart for the entire project.

Chapter 3 ‘Conclusion’ is the final chapter of the thesis. This segment summarizes the entire project and considers its limitations and shortcomings as well as giving directions for further design and research. The ‘Appendix’ section documents additional information related to the design of the garage apartment and outlines the current status of the project. It also carries a section on relevant city requirements and codes.

CHAPTER 2 - Phase 1: Project Goals and Design Parameters

This chapter begins by summarizing the intent of this thesis under the ‘Introduction’ section. It then proceeds to address the goals of the project, while citing the methodology for achieving the same under the section titled ‘Project Goals’. The zero energy garage apartment was designed around certain parameters that were established after careful analysis of Manhattan’s climatic and geographical conditions, demographic and socio-economic conditions, as well as the client’s desired outcome from the project and a study of the property in which the structure is proposed to be built. The design framework is elaborated under the section titled ‘Design Parameters’. A sub-section following the description of Manhattan’s climatic and geographical conditions and demographic and socio-economic conditions, titled ‘The Zero Energy Garage Apartment as a Solution to the Need for Affordable Housing’, elaborates on how the zero energy garage apartment provides effective solutions for Manhattan’s regional housing demand and affordability problems while also responding to prevailing global energy and environmental issues.

Keywords: goals; client; property; weather, climate, geography; demography; socio-economics; garage apartment; zero energy garage apartment; LEED, LEED checklist.

Introduction

Today, in a time of global instability with a looming environmental crisis, energy security is essential. In light of the fact that the building sector in the U.S. consumes the largest amount of energy and is one of the biggest contributors to global warming, securing buildings from fluctuating energy prices while designing them within a sustainable and affordable framework becomes critical. This thesis addresses the issues of global warming, energy security, sustainability and affordability through the design of a zero energy garage apartment along an alley in the older neighborhood area of Manhattan, Kansas. A garage apartment is a building behind the main building,[19] within the confines of the same plot. It can also be called a 'backhouse', 'granny flat' or an 'accessory apartment'. A zero energy garage apartment, with respect to this thesis, is a grid connected, sustainable and affordably designed structure that aims to produce zero utility bills throughout the year.

This aim is achieved by reducing energy needs through efficiency gains, with the balance of the apartment's energy needs supplied by renewable technologies.[20] Energy needs are radically reduced by means of: 1) a the high performance building envelope; 2) bioregional design strategies including the extensive use of daylighting; 3) passive solar heating and cooling strategies, and; 4) EnergyStar rated high efficiency appliances and energy efficient and waste reducing construction methods. The design of the zero energy garage is discussed in further detail under a sub-section in this chapter titled 'The Design of the Zero Energy Garage Apartment'.

---

[19] Garage Apartment. (n.d.). Retrieved April 6, 2006, from Wikipedia: http://en.wikipedia.org/wiki/Garage_apartment

[20] Building Technologies Program- About the Program. (n.d.). Retrieved March 2, 2007, from U. S. Department of Energy: http://www.eere.energy.gov/buildings/about/

Project Goals

The methodology for setting the goals for this thesis project is based on the main objective of designing a sustainable, affordable zero energy garage apartment for a specific client and site. With the aim of designing the zero energy garage apartment, eight project goals were established as shown in *Figure 2-1: Project goals diagrammatic representation*.

The first task in designing the zero energy garage apartment was to identify a client. To select a client it was necessary to find someone who: 1) wanted to have a garage apartment built on their property; 2) shared similar views on the importance of a sustainable design that nurtures not just the environment, but is also sensitive to the region's architectural and socio-economic conditions, and; 3) was willing to spend the time necessary to work with the author in developing the design.

Once the client was chosen it became possible to proceed with the research and analysis necessary to identify the renewable energy systems that are most suitable for the region and fit within the budget allocated by the client. In order to design a zero energy garage apartment that produces the amount of energy it uses, identifying the appropriate renewable energy system/ systems became critical and, hence, became the second project goal.

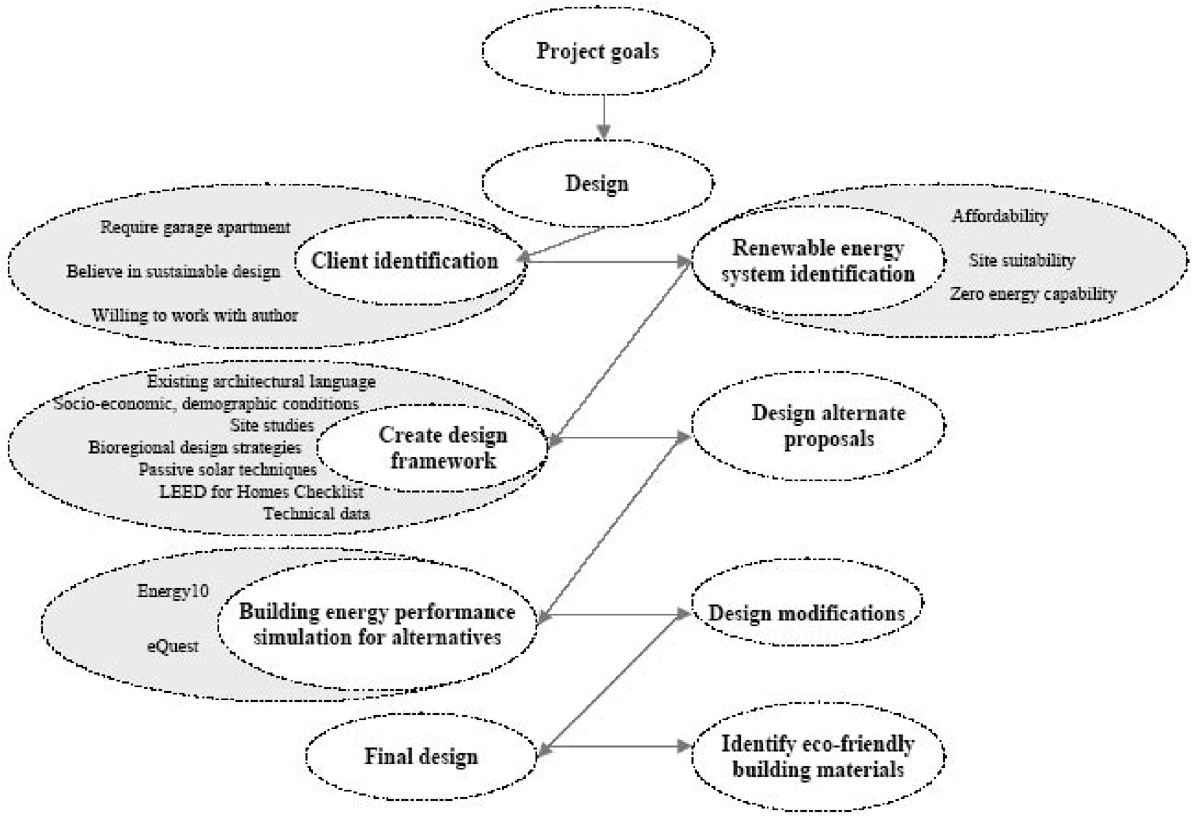
The third goal in designing the zero energy garage apartment involved creating a framework that would establish the design parameters within which the zero energy garage apartment had to be structured. Since the intent of this thesis is to not only that the design the zero energy garage apartment to be technically sound, but also holistic in character, research and analysis were carried out on the following topics: 1) Manhattan's socio-economic and demographic conditions, which help in understanding the need and potential of Manhattan's housing market; 2) the architectural language of the front house already existing on the site in order to design a garage apartment that would be compatible with it; 3) the existing site in terms of site measurements, the location of utility lines, existing on-site features such as outdoor rooms, gardens and paths; 4) bioregional design strategies and passive solar design strategies appropriate for Manhattan's temperate continental climate; 5) the stringent conditions laid down by the LEED for Homes Project Checklist, which when adhered to helped reinforce the sustainability of the zero energy garage apartment, and; 6) technical data required to be considered while designing the exterior and space planning the garage apartment, for example, location and specifications for the building integrated photovoltaic system and its related requirements for solar power battery storage.

The fourth, fifth and sixth goals are those of producing design alternatives for the zero energy garage apartment. For each alternative, energy performance was simulated using Energy10 and eQuest softwares and the final design grew out of this iterative process of design and modification based on the simulated building energy performance .

The seventh goal of this thesis was identifying affordable healthy and renewable building materials and interior finishes based on the criteria derived from the LEED Green Building Rating System. LEED is a Green Building Rating System, which is a nationally accepted benchmark for the design, construction, and operation of high performance green buildings. The LEED for Homes Project Checklist Version 1.72 was used as a measuring device to keep track of the sustainability of the design of the zero energy garage apartment. LEED is further discussed towards the end of this chapter. Part of the objective of identifying eco-friendly building materials is to simultaneously identify building materials that offer energy-efficiency during the construction phase.

In conclusion, to verify if the intent of this thesis in designing a zero energy garage apartment was met, inferences derived from the simulation software outputs and the capacity of the renewable energy systems to generate adequate power throughout the year were periodically monitored.

Figure 2-1: Project goals diagrammatic representation.



Design Parameters

Preliminary design exercises require strong foundational knowledge about the client, the client's expectations from the project, details of the property in which the zero energy garage apartment is scheduled to be built and regional climatic, geographical, demographic and socio-economic factors.

The Clients, Client Brief

As listed under the 'Project Goals' section of this chapter, the first goal was to identify a client living in Manhattan, Kansas. This was preferred due to the designer's familiarity with the local climate and proximity to the location that would permit adequate site visits and client meetings. The clients identified for this thesis project are acquaintances of Professor Gary Coates, who had previously expressed a desire to build an environment friendly garage apartment on their property to help satisfy their immediate and future needs. Being politically influential, the clients also wanted to display living proof of the personal and social benefits of a garage apartment and the importance of environment friendly design.

The clients: The clients identified for this thesis project are a husband and wife in the age group of 55-64, who are Professors at Kansas State University and residents of the older neighborhood area of Manhattan, Kansas. Passionate about historic preservation, they currently live in one of the oldest houses in Manhattan, where they run a Bed and Breakfast [B&B].

The clients were approached when they expressed an interest in building an eco-friendly garage apartment on their property to facilitate their immediate and future needs. Their present residence was built in 1871 and is comprised of a front yard, main house (front house) and a backyard, which is bounded by a back alley. The front house was purchased by them and painstakingly restored to its original state, revealing the building's excellent craftsmanship and fine detailing. The interiors of the front house are quaint and decorated in period furniture with flowing draperies. These finishes give the house a calm, homey feeling and hint at the temperament of the clients. Some of the rooms, like the upstairs bedrooms, have been decorated to match their original use.[21] The clients said that their passion for restoration includes a desire to educate and inspire the public about the significance of historic preservation of houses. They believe that houses, being landmarks on their own, remind the community of its heritage and their beauty is a positive addition to the visual environment. They also believe that houses belong more to the community than to the owner and in this way, they enrich the community with the value of long-lasting timeless architecture.

The clients are ardent nature lovers and relish adventure sports. They enjoy walking and have a deep appreciation for the proximity of their home to shops, schools, churches, etc. They also love their various outdoor rooms, in part because they permit them to enjoy their gardens and the surrounding residences. The clients keep themselves well informed about the latest developments in environmental issues.

The clients' perseverance in following their passion for restoration, their understanding of architecture's contribution to the community, their appreciation of nature and their belief in the importance of a sustainable built environment and way of living made them the perfect candidates for this thesis project.

Client Brief: Initially, the clients expressed a desire to build an eco-friendly garage apartment in their backyard that would be sympathetic to the architectural character of the front house and employ some kind of a renewable energy systems to lessen the apartment's reliance on fossil fuel energy. When told about the possibility of designing a garage apartment that would produce zero utility bills throughout the year, the clients voiced their strong interest towards pursuing this goal. They put forth a budget of $80,000. Their main purpose in building a garage apartment was to possibly use it in the future as a home either for themselves, if their children chose to move into the front house, or for their children to use if they themselves chose to move into the garage apartment. The clients have children with separate families who visit them occasionally.

Presently, they envision using the garage apartment as a detached honeymoon suite or a B&B for families with children since the B&B service in the front house does not permit guests who are accompanied with their children. The garage apartment could also be given out to rent

---

[21] Shortridge House- History. (n.d.). Retrieved November 30, 2007, from Shortridge House: http://www.shortridgehouse.com/history.html

for visiting scholars/ students. The clients said that sometime in the future, the B&B service would be completely shut down. Another possibility discussed was that if the property was to be sold, the zero energy garage apartment would increase the property value of their home.

Thus, it became evident that, besides being sympathetic to the existing architectural character of the front house, the zero energy garage apartment would have to be designed to offer maximum versatility and easy adaptability to future uses, including the possibility of converting the garage in the ground floor into an apartment for the clients to live in while they rent out the apartment on the second floor. In addition to meeting these requirements for architectural compatibility with the existing house and for a high level of energy efficiency, it was established that the structure should be designed using healthy and environment-friendly building materials.

<u>Client's Value Matrix Programming Document:</u> In order for the clients to identify and communicate their requirements for the design of the zero energy garage apartment systematically, a Value Matrix Programming Document [22] [obtained from Alchemy Design + Architecture, a firm based in Long Beach, California] was discussed with them. This document describes the expected building performance from the clients' perspective and is one way of methodically identifying the needs of the client. It is categorized into certain values that are integral to designing a zero energy garage apartment. These values are grouped under the categories of human, environmental, cultural, technological, progressional, economics, aesthetics and safety. Each of these categories is further divided into sub-categories that are relevant to the main ones, as seen in an example of the Value Matrix Programming Document in *Table 2-1: Example of Value Matrix Programming Document*. The 'human' value is sub-divided into functional, social, physical and psychological criteria within which are listed the corresponding goals, needs and ideas. Similarly, the 'environmental' value is sub-divided into the values of climate, resources and waste; the 'cultural' value is sub-divided into legal; the 'technological' value into materials and systems; the 'progressional' one into growth, change and permanence; 'economic' into construction, operations, energy and maintenance; 'aesthetics' into form, space, color and meaning; and the 'safety' value category is sub-divided into the values of structural, fire, chemical, personal and criminal. The objectives of these values/ principles are listed under

---

[22] Loring, Laura, & Holmes, Michael. (1998). *Value Matrix Programming Document: Alchemy Design+ Architecture.*

the ‘Goals’ section in the Value Matrix Programming Document and the client needs pertaining to those goals and values/ principles are listed under the ‘Needs’ section. The ‘Ideas’ section lists possible ways of satisfying the respective client needs through design. All of these above-mentioned details are significant aspects of the design of the zero energy garage apartment and the Value Matrix Programming Document helped classify information provided by the clients in a tabular format that allowed easy referencing during the design process.

The clients rated their preferences on the Value Matrix Programming Document on a scale of 1 to 4 [1- most important, 4- least important/ not important], as shown in *Table C-1: Value Matrix Programming Document* listed in Appendix C. The numbers thus assigned to the goals are placed under the ‘value assignment of goal’ category. The Value Matrix Programming Document is formatted to be read along the X-axis. As rated highest [number 1] by the clients, the most important goals were those of providing: adequate built-in storage; privacy for the guests; good daylighting; a connection to nature; a climatically efficient design; a reduction in the amount of construction material being sent into the landfill; a facility that meets all current building codes; a structure that uses eco-friendly, cost effective materials and a design that offers life-cycle adaptability and employs energy saving and producing systems.

Besides rating the values on the Value Matrix Programming Document, the clients requested that the following services be accommodated in the garage/ first floor: laundry room, wash station, utility sink with cabinetry, potting table set, aerated closet large enough to hang Kayaking gear [one 14’ long canoe, long ropes, etc.], tool space and a space for hanging bicycles. On the second floor, the clients requested for a minimal-use kitchen counter facility; space allocation in the kitchen for a refrigerator; a solid surface kitchen counter-top and tiles in the bathroom.

In essence, the Value Matrix Programming Document was formulated to ensure a more effective and efficient design brief documentation, which is easier to understand and interpret. The document also helped encourage a detailed discussion with the clients and a better comprehension of their project requirements. Therefore, the Value Matrix Programming Document formed the most important part of the client brief.

Table 2-1: Example of Value Matrix Programming Document.

VALUES	GOALS	NEEDS	IDEAS	VALUE ASSIGNMENT OF GOAL
HUMAN				
FUNCTIONAL				
General				
	o Please confirm the number of apartments needed and number of people allowed to occupy each one.			**1 apartment, 2 people**
	o Provide an exercise room or space for exercise equipment.		o Provide for an easily accessible mini-exercise room.	4
	o Provide sound proofing between studios.		o Use sound-proofing materials and strategically locate storage spaces between rooms to avoid sound transmission across rooms.	4
	o Provide adequate amount of built-in storage - located where it is most needed.	o Storage for clothes, shoes, coats and other necessities.	o Locate built-in storage cabinets in such a way as to allow easy access.	1
	o Provide a space which has proper provision for technological equipment to enable guests to stay connected to the world.		o Use electronic communication methods and systems, such as internet and telephones.	1
	o Provide a facility that incorporates the proper adjacencies to enable efficiency.		o Design wet areas so that they can share plumbing, etc.	1
	o Provide for privacy requirements of the guests.		o Provide blinds/curtains over windows, provide facilty for do-not-disturb signs, etc.	1
	o Provide even and adequate artificial lighting and daylighting.			1
	o Provide a vending machine.		o Provide the machine at the lobby/gathering space.	4
	o Provide an adequate number of electrical outlets to support laptops, charging cell phones, etc.			1
	o Provide a laundary room.			1
Kitchen				
	o Provide a large counter space.			**No.** kitchen counter is for minimal use.
	o Provide a separate dining area.			**4.** Maybe a little island or counter if space permits.
	o Provide a refridgerator.			1
	o Provide cabinets for storage.			1
Living Room Area				
	o Provide a physical seperation between living area and kitchen.		o Provide an opaque/ transparent seperation-wall between kitchen and living areas.	4
	o Provide living room furniture like sofas, coffee table, etc.			3

The Property

The front house on the property was built in 1871 in a Greek Revival style with Italianate features and is of architecturally historical importance. South of the front- house is a backyard where the zero energy garage apartment is to be built.

The plot measures 80’ x 181’ 7”. At present, there are no parking spaces on the property. The clients and their guests park along the road. The gas, electrical and water lines run along the north-south direction under the backyard, feeding off the alley which runs in an east-west direction along the back of the house. The property adjoining this plot on the East also belongs to the clients. There is an expanse of green space next to the property on the West as shown on *Figure 2-8: Satellite view of property*. Residential properties are located on the North and South.

Figure 2-2: Existing site plan [↑N]

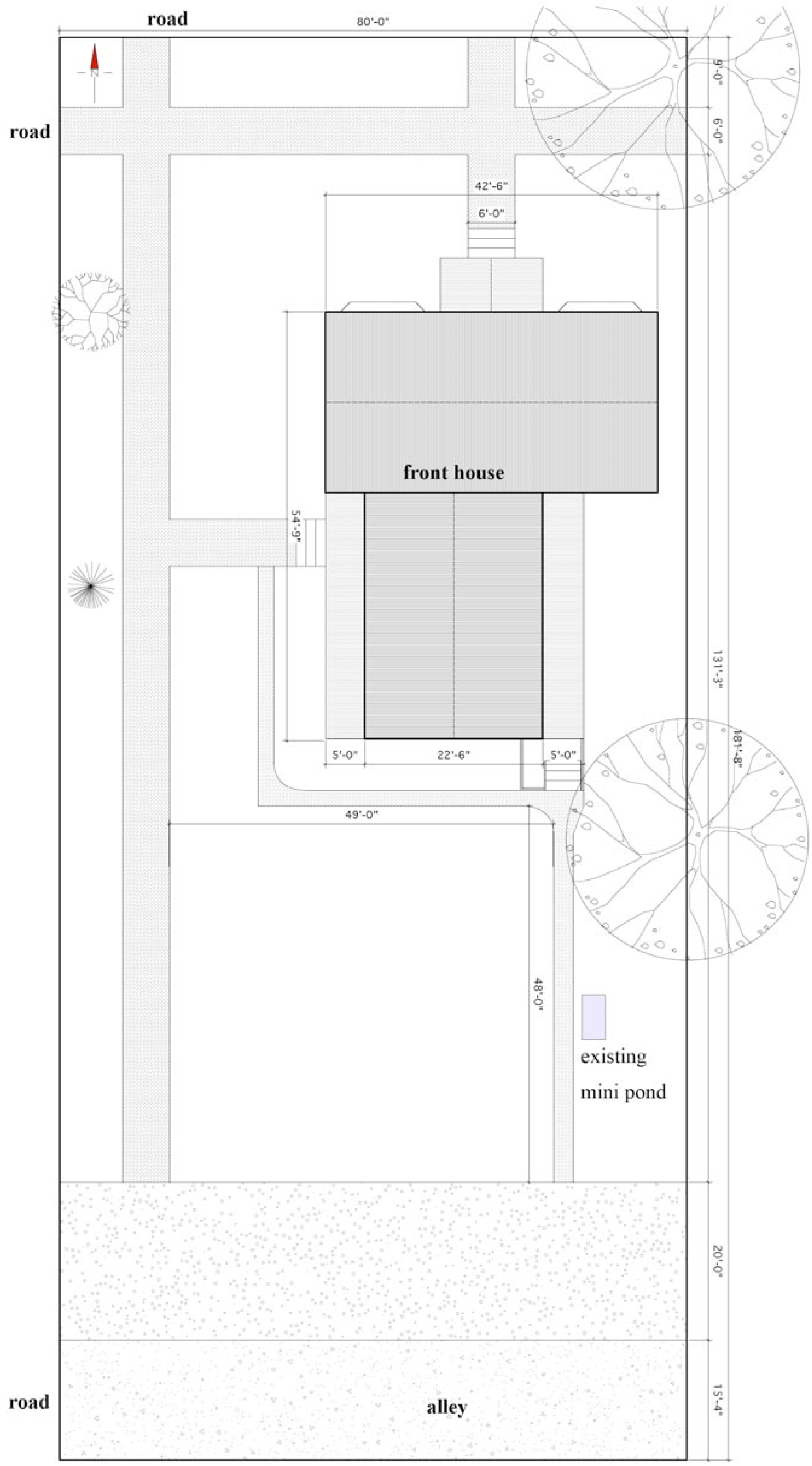


Figure 2-3: Front house West facade

Figure 2-4: Front house North facade

Figure 2-5: Front house East facade.

Figure 2-6: Front house South facade.

Figure 2-7: Front house West facade with green area on West.

Figure 2-8: Satellite view of property.

Manhattan's Weather, Climate and Geographic Conditions

Manhattan is located in the central portion of U.S.A., at the heart of northeast Kansas' Flint Hills region, as can be seen in *Figure C-1: Location map, Manhattan, Kansas* in Appendix C. The combination of ample sunshine, summer rains and availability of flat, arable lands accounts for the high rank of the state of Kansas in crop production, finished livestock, and dairy products. Manhattan is globally positioned at 39°11.5′N longitude and 96°35.5′W latitude. This University town has an area of 18 square miles and is populated with approximately 50,000 people as of 2006.[23]

Manhattan lies across the path of alternate masses of warm moist air moving north from the Gulf of Mexico and currents of cold, dry air moving from the polar regions. This causes the build-up of tornadoes. The high Rocky Mountains in Colorado block almost all moisture that might come to Manhattan from the Pacific Ocean. Manhattan's weather is subject to frequent and sharp changes. Summers are hot with low relative humidity and good wind movement. Winters are partly sunny and dry with sparse snowfall and strong winds.

As seen in *Table 2-2: Manhattan, Kansas weather data*, over the course of a year, temperatures range from an average low of almost 15°F in January to an average high of nearly 93°F in July. The maximum temperature reaches 90°F an average of 56 days per year and reaches 100°F an average of 9 days per year. The minimum temperature falls below the freezing point (32°F) an average of 118 days per year. Typically the first fall freeze occurs between the last week of September and the end of October, and the last spring freeze occurs between the first week of April and early May. The area receives nearly 35 inches of precipitation during an average year with the largest share being received in May and June—the April–June period averages 33 days of measurable precipitation. During a typical year the total amount of precipitation may be anywhere from 24 to 46 inches. There are on average 97 days of measurable precipitation per year. Winter snowfall averages almost 16 inches, but the median is less than 10 inches. Measurable snowfall occurs an average of 10 days per year with at least an

---

[23] Manhattan, Kansas- Welcome to Manhattan. (n.d.). Retrieved December 25, 2006, from the City of Manhattan: http://www.ci.manhattan.ks.us/index.asp?NID=127

inch of snow being received on six of those days. Snow depth of at least an inch occurs an average of 20 days per year. The average annual number of clear days in Manhattan is 145.[24]

Table 2-2: Manhattan, Kansas weather data.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year
Temp [°F]													
Mean high	39.5	46.8	57.5	67.9	77.5	87.1	92.5	90.8	82.1	70.7	54.5	42.9	67.5
Mean low	16.1	21.5	31.4	42.2	52.5	62.3	67.3	65.1	55.5	43.2	30.2	19.9	42.3
Highest	74	84	95	99	103	112	115	116	112	98	87	77	116
Lowest	131	-26	-12	5	23	39	38	40	26	13	-9	-22	-31
Precipitation [inches]													
Median	0.79	0.92	2.11	2.22	4.53	4.62	3.2	2.93	3.28	2.38	1.51	0.85	34.34
Mean no. of days	5.4	5.2	7.9	10	12	12.9	8.6	9.2	8.1	7.7	7	5.2	97.2
Highest monthly	3.16	2.48	7.4	9.52	14.7	11.5	17.5	7.25	9.89	6.49	5.79	3.4	
Snowfall [inches]													
Median	3.7	3.2	0.8	0	0	0	0	0	0	0	0.1	1.7	9.5
Mean no. of days	4.5	3.2	1.7	0.6	0	0	0	0	0	0	1.5	3.5	15
Highest monthly	16.2	18.5	9	4.8	0	0	0	0	0	1.1	8.8	14.6	

(Source: Manhattan, Kansas. (n.d.) Retrieved January 15, 2007, from Wikipedia: http://en.wikipedia.org/wiki/Manhattan,_Kansas)

Manhattan's Demographic, Socio-economic Conditions

Demographic conditions: As per the United States Census Bureau's 2000 Census data, there were 44,831 people, 16,949 households, and 8,254 families residing in Manhattan. The population density was 2,983.9 people per square mile. There were 17,690 housing units at an average density of 1,177.4/sq mi. The racial makeup of the city was 87.28% White, 4.86% African American, 0.48% Native American, 3.93% Asian, 0.07% Pacific Islander, 1.30% from other races, and 2.07% from two or more races. Hispanic or Latino of any race was 3.49% of the population. The projected rise in population can be seen in *Table 2-3: Population Trends and Projections: Planning Area*.[25]

---

[24] Manhattan, Kansas. (n.d.) Retrieved December 25, 2007, from Wikipedia: http://en.wikipedia.org/wiki/Manhattan,_Kansas

[25] Ibid.

Table 2-3: Population Trends and Projections: Planning Area.

	Housing Element 0.72% annually		Kansas Water Office 1.31% annually		Historic [1950-90] 1.73% annually	
Year	**Population**	**Change**	**Population**	**Change**	**Population**	**Change**
2000	50,144		50,144		50,144	
2005	51,975	1,831	53,503	3,359	54,634	4,490
2010	53,873	1,898	57,086	3,583	59,526	4,892
2020	57,879	4,006	64,990	7,904	70,664	11,138
2000-2020		7,735		14,846		20,520

(Source: Manhattan, Kansas. (n.d.) Retrieved January 15, 2007, from Wikipedia: http://en.wikipedia.org/wiki/Manhattan,_Kansas)

Socio-economic conditions: As per the *United States Census Bureau*'s 2000 Census data, there were 16,949 households out of which 22.7% had children under the age of 18 living with them, 39.6% were married couples living together, 6.6% had a female householder with no husband present, and 51.3% were non-families. 30.5% of all households were made up of individuals and 6.3% had someone living alone who was 65 years of age or older. The average household size was 2.30 and the average family size was 2.89.

The age distribution is 15.8% under the age of 18, 39.2% from 18 to 24, 24.0% from 25 to 44, 13.2% from 45 to 64, and 7.8% who were 65 years of age or older, as shown in *Table 1-4: Population Age Distribution, Manhattan: 1980-2000*[1]. The median age was 24 years. For every 100 females there were 106.4 males. For every 100 females age 18 and over, there were 105.4 males. The general age distribution is typical of a university town; the sex distribution is not uncommon in areas dominated by major land-grant universities.[26]

---

[26] Manhattan, Kansas. (n.d.) Retrieved December 25, 2007, from Wikipedia: http://en.wikipedia.org/wiki/Manhattan,_Kansas

Table 2-4: Population Age Distribution, Manhattan: 1980-2000.

Age Group	1980		1990		2000	
	Number	%	Number	%	Number	%
Under 5	2,195	6.7	2,355	6.2	2,083	4.6
5-17	4,526	13.9	5,195	13.8	5,016	11.2
18-24	10,532	32.3	11,681	31	17,562	39.2
25-34	6,252	19.2	6,670	17.7	6,293	14
35-54	4,679	14.4	6,953	18.4	8,313	18.5
55-64	1,971	6.2	1,804	4.8	2,072	4.6
65+	2,478	7.6	3,054	8.1	3,492	7.8
Total	32,506	100	37,712	100	44,831	100
Median Age	**24.4**		**24.8**		**23.5**	

(Source: Manhattan, Kansas. (n.d.) Retrieved January 15, 2007, from Wikipedia: http://en.wikipedia.org/wiki/Manhattan,_Kansas)

The median income for a household in the city was $30,463, and the median income for a family was $48,289. Males had a median income of $31,396 versus $24,611 for females. The per capita income for the city was $16,566. About 8.7% of families and 24.2% of the population were below the poverty line, including 10.1% of those under age 18 and 7.8% of those age 65 or over, as shown in *Table 1-5: Household Income, Manhattan: 1990-2005*[1]. However, traditional poverty statistics can be misleading when applied to communities with large student populations, such as Manhattan.[27]

[27] Manhattan, Kansas. (n.d.) Retrieved December 25, 2007, from Wikipedia: http://en.wikipedia.org/wiki/Manhattan,_Kansas

Table 2-5: Household Income, Manhattan: 1990-2005.

Income Group	1990		2000		2005	
	Number	%	Number	%	Number	%
<10,000	3,599	24.5	3,311	19.3	2,913	15.5
10,000-24,999	3,297	22.4	3,132	18.3	2,693	14.3
25,000-34,999	3,426	23.3	4,847	28.4	5,937	31.5
35,000-49,000	2,046	13.9	2,895	16.9	3,547	18.8
>50,000	2,351	15.9	2,915	17	3,760	19.9
Total	14,719	100	17,100	100	18,850	100
Median Income	$25,531		$42,800		$61,520	

(Source: Manhattan, Kansas. (n.d.) Retrieved January 15, 2007, from Wikipedia: http://en.wikipedia.org/wiki/Manhattan,_Kansas)

According to the *Housing Manhattan Plan* that was published in July 2000, housing demand in Manhattan is expected to be particularly strong for households in the 19-34 year old age group and for households made up of persons 65 years or older.[28] *Housing Manhattan Plan* is an official publication that documents Manhattan's housing demands. Manhattan was recently featured in *Money Magazine*'s top 10 Places to Retire [due to a thriving economy and access to recreational activities][29] and an increasing influx of military personnel and their families into Fort Riley has also further strained housing demand in Manhattan.

The majority of all households in Manhattan were projected by the *Housing Manhattan Plan* to remain in the low- to- moderate-income range in 2005. "60% of all these households were expected to be composed of students and the rest, of single parent families and households

---

[28] Coates, Gary. (2001). *Affordable Housing: Reweaving the Fabric of Manhattan's Older Neighborhoods.* (1st ed.).

[29] Best Places to Retire Young. (2007). Retrieved April 6, 2007, from CNN Money: http://money.cnn.com/galleries/2007/moneymag/0703/gallery.bp_retireyoung_new.moneymag/9.html

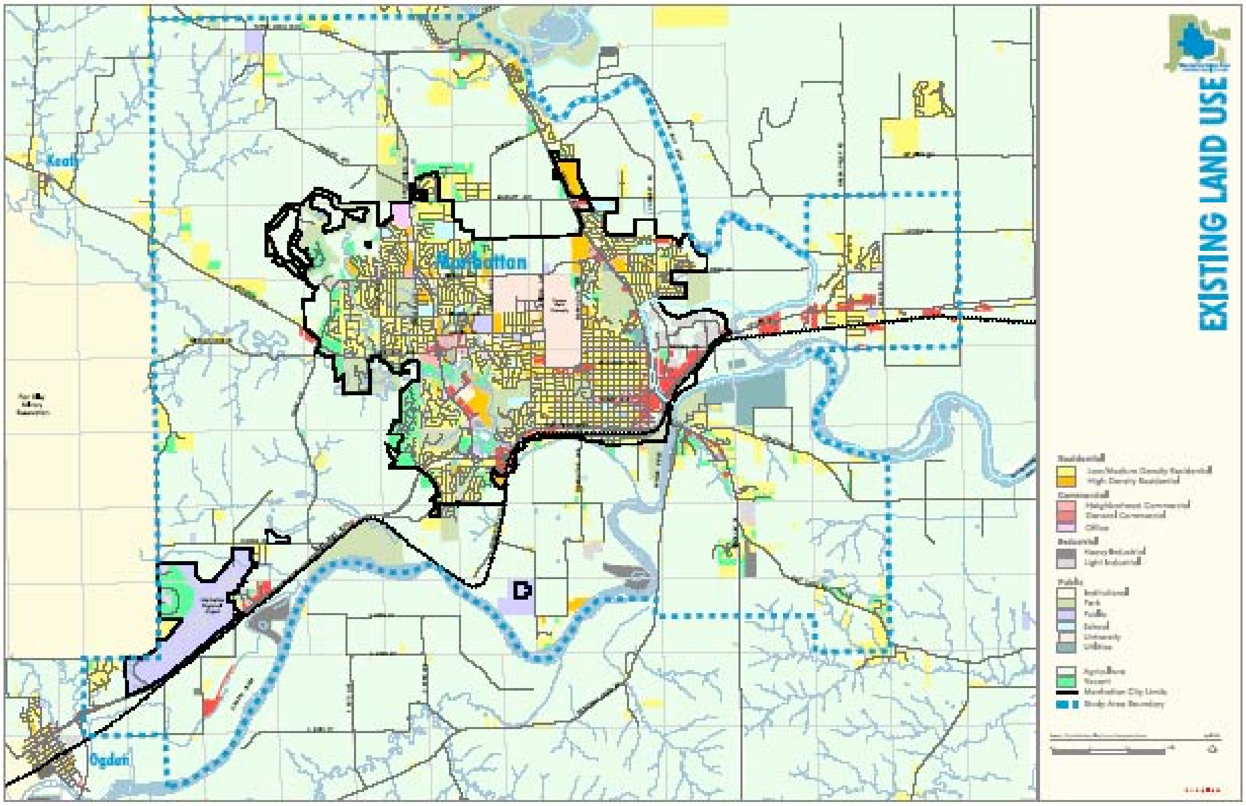
made up of older adults" (Coates, 2001, p.1). In Manhattan, transportation is automobile-centric. There exists no internal mass transit system.

In response to Manhattan's increasing housing needs, the City of Manhattan formulated a *Manhattan Urban Comprehensive Plan*[30] in 1999 with a growth vision that intends to provide a broad understanding of the community's vision for future growth and development within the Manhattan Urban Area. The objective of the *Manhattan Urban Comprehensive Plan* is to achieve an economically vital community, which provides employment and income opportunities to its residents. Some of the important goals of the Plan were to provide stable, cohesive neighborhoods offering a variety of housing types; co-ordinated and efficient patterns of growth; and an attractive functional development that promotes a strong community identity and preserves and enhances the natural environment. The *Manhattan Urban Comprehensive Plan* illustration can be seen in *Figure 2-10: Proposed land use map, Manhattan, Kansas*. *Figure 2-9* is the existing land use map of Manhattan, Kansas.

---

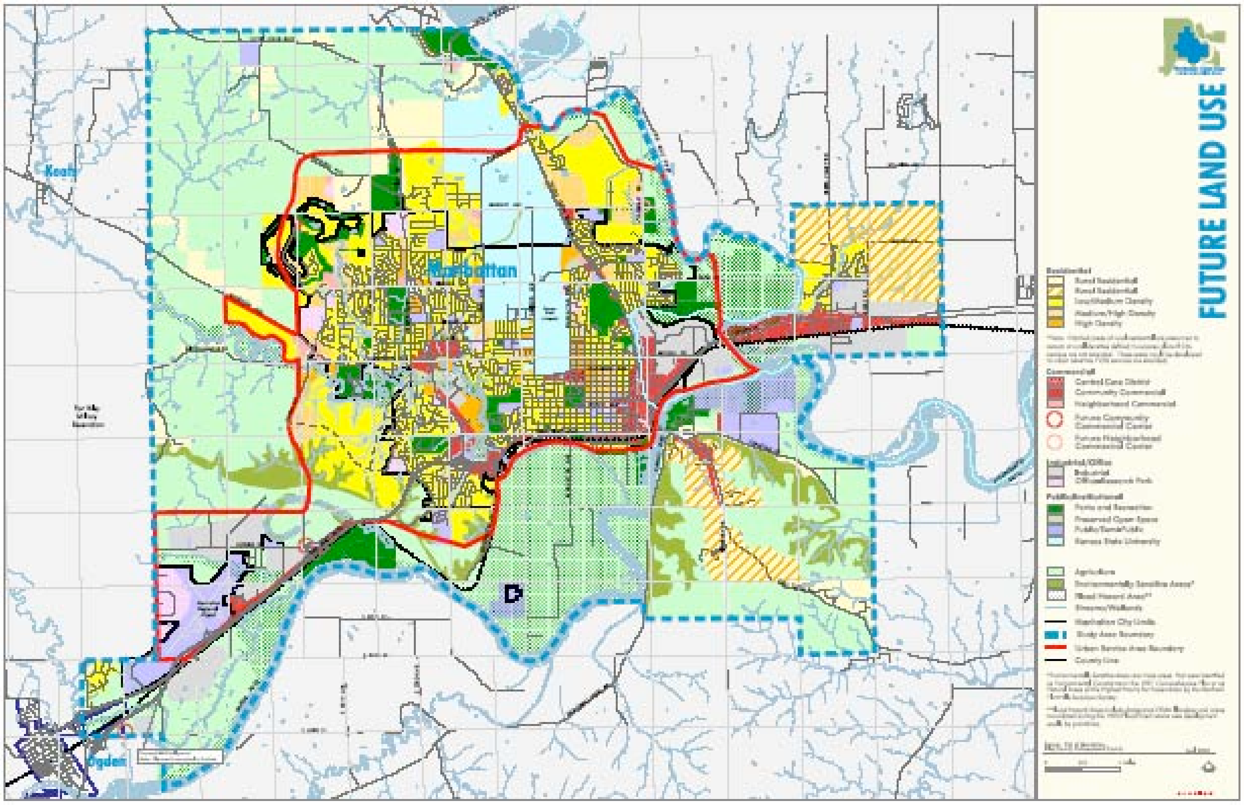
[30] Manhattan Area Urban Comprehensive Plan. April 2003. Retrieved April 6, 2007, from City of Manhattan: http://www.ci.manhattan.ks.us/index.asp?NID=493

Figure 2-9: Existing land use map, Manhattan, Kansas.



(Source: Manhattan Area Urban Comprehensive Plan. April 2003. Retrieved April 6, 2007, from City of Manhattan:
http://www.ci.manhattan.ks.us/DocumentCenterii.asp?Folder=Community%20Development%5CLong-Range%20Planning%5CManhattan%20Urban%20Area%20Comprehensive%20Plan)

Figure 2-10: Proposed land use map, Manhattan, Kansas.



(Source: Manhattan Area Urban Comprehensive Plan. April 2003. Retrieved April 6, 2007, from City of Manhattan: http://www.ci.manhattan.ks.us/DocumentCenterii.asp?Folder=Community%20Development%5CLong-Range%20Planning%5CManhattan%20Urban%20Area%20Comprehensive%20Plan)

The City's *Manhattan Area Urban Comprehensive Plan* has identified the following areas of concern in the Manhattan housing sector:

1) Lack of affordable housing.
2) Neighborhood/ student conflicts.
3) Preservation of older and student neighbourhoods.[31]

The City has targeted some goals to facilitate better quality of life and living conditions for people in Manhattan, in response to which the zero energy garage apartment has been designed. Under the 'Housing and Neighborhoods' and 'Mobility and Transportation Options' segments, their policies focus on:[32]

1) Fostering the stabilization of Manhattan's established and older core neighborhoods.
2) Ensuring that new housing represents a variety of housing types [with varied densities] and costs appropriate to the neighborhood. This is intended to be realized by providing opportunities for a greater mix of housing types, which are appropriately located, scaled and designed, in relation to surrounding neighborhoods; and by providing housing opportunities for all income levels.
3) Guiding the development of new housing and neighborhoods to ensure sustainability by promoting energy efficiency in building construction and site design.
4) Encouraging construction of affordable housing by including sites at a variety of scales to also accommodate small infill projects. Infill development is mandated to be compatible with the surrounding neighborhood character and is expected to enhance the same.

---

[31] Manhattan, Kansas. (n.d.) Retrieved December 25, 2007, from Wikipedia: http://en.wikipedia.org/wiki/Manhattan,_Kansas

[32] Manhattan Area Urban Comprehensive Plan. April 2003. Retrieved April 6, 2007, from City of Manhattan: http://www.ci.manhattan.ks.us/DocumentCenterii.asp?Folder=Community%20Development%5CLong-Range%20Planning%5CManhattan%20Urban%20Area%20Comprehensive%20Plan

5) Promoting urban patterns and densities that will also support future bus public transit.

Zero Energy Garage Apartment: One Solution to Manhattan's Housing Needs

From the City's *Manhattan Area Urban Comprehensive Plan* discussed above, it is apparent that there is an urgent need to increase the density levels in Manhattan's older neighborhoods. Urban sprawl generally tends to be a financial burden since maintaining a vast area and facilitating development with additional infrastructure hampers the city's economic viability. Over time, some infrastructure lies underused/ underutilized, which adds to the economic cost of sprawl. Since the United States economy fails to assign costs to intangible losses such as air pollution, when the costs of a clean environment are added to the direct and indirect economic costs of low-density development, sprawl becomes even less tenable.[33]

Urban sprawl does not have only economic costs, but also social and health-related costs. Denser settlements help foster a close-knit community, create a better sense of place and are less environmentally demanding. Density helps reduce automobile dependency and renders ordaining future mass transit systems and renewable energy integrated societies economically feasible.

Mixing populations of different income groups is another factor that will nurture coherence and cultivate tolerance in the Manhattan neighborhoods. Such development will distinguish Manhattan as a close-knit community, whose differences and distinguishing identities can be celebrated.

A practical solution to address Manhattan's increasing housing needs is to revitalize the older residential neighborhoods. This is because of the area already being well established with respect to social, physical and institutional infrastructure. *The Housing Manhattan Plan, Downtown Tomorrow Redevelopment Plan* (Coates, 2001, p.1) and the City of Manhattan have identified Manhattan's older neighborhood area for meeting a significant portion of the community's present and future housing needs. "For individuals and households in the 19-34 year old age group, homes in older Manhattan are walking distance or a short drive of the

---

[33] Kelbaugh, Douglas. (2002). *Repairing The American Metropolis.* University of Washington Press. Seattle and London.

University, K-12 schools and the downtown area, which is not only a major shopping destination but also a source of significant employment opportunities. For the over-65 population, which is expected to increase, housing located in the older neighbourhoods also offers similar benefits of pedestrian access to shopping, recreation, parks, churches and special services like Riley County Seniors Service Center" (Coates, 2001, p.4).

Garage apartments: From the above-mentioned factors, it can be established that infill development in the form of a garage apartments is possibly the best solution to Manhattan's increasing housing needs, as it leads to a reduction in sprawl and an increase in density, offers the possibility of mixing populations of different income groups and will help revitalize the older neighborhood area.

"A diverse range of housing options for both owners and renters is required in the low to moderate- income range" (Coates, 2001, p.1) in Manhattan. "A solution to this lies in the alleys of the older neighbourhoods. A small apartment built above the garage or adjacent to a carport or garage located on an alley can be used as a rental unit, home office, studio, workshop" (Kelbaug, 2002, p. 148), teenage cottage, or, as in the case of this project, a detached bed and breakfast facility that can be designed in a versatile manner so that the owners can utilize it as the future demands. Such infill housing can be built to lessen the strain on rental housing needs in Manhattan "without disrupting existing lifestyles and social patterns" (Kelbaug, 2002, p. 151).

Garage apartments located along older Manhattan's existing alleys provide a more permanent supply of affordable housing units, because they are not traded up in price like many types of subsidized housing. They make housing more affordable for singles and young families by providing starter units, and for large extended families by providing extra space or extra income as a rental dwelling unit or office. Rental units with resident landlords are usually better maintained with more responsible tenant selection than apartment houses (Kelbaug, 2002, p. 145). Increased alley surveillance by the police department will help reduce crime, as was observed when alley garage apartments were proposed at Laguna West, Sacramento's first Transit Oriented development. Such smaller sized residential developments will also provide more jobs to local builders.

An alley is a traditional urban component that was created as a means of handling garbage, utilities, parking, car washing, children's play, etc. With regards to parking, since alleys allow vehicles to access the interior of the block, they enhance the street front by allowing for cars to be parked away from pedestrian view. “Alleys also provide opportunities to mediate between different scales of building and to increase residential densities unobtrusively” (Kelbaug, 2001, p. 148).

One of the most important functions of the garage apartment as a building type, though, is its potential to address sustainability in both the urban and the block scale. Financial sustainability can be attained by owners of the front house by renting out the garage apartment and repaying a portion of the mortgage for the front house. Thus, the garage apartment can function as an incentive for more medium income families to buy houses and as an opportunity for low-income families to rent affordable houses.

Zero energy garage apartment: The zero energy garage apartment designed in this thesis intends to isolate the clients from energy price fluctuations by producing as much energy as it needs from the renewable energy systems incorporated into its structure. In order to provide the owners with energy security by providing zero utility bills throughout the year, the zero energy garage apartment is designed using energy efficient principles of bioregional design, passive solar design, building integrated photovoltaics, eco-friendly materials and energy-efficient construction methods. In many cities, surplus energy produced by renewable energy systems employed by a building can be sold back to the grid at the same cost that the building owner pays the utility for the energy that the building imports from the grid, but this is not yet permitted in the state of Kansas. Surplus energy produced by the zero energy garage apartment’s building-integrated photovoltaic energy system will, however, be used to power a portion of the adjoining front-house belonging to the same client. The solar energy system in the zero energy garage apartment has also been designed with 1 battery with the capacity to store excess energy generated and allow for stand alone functioning.

Although all zero-energy high performance buildings require a higher upfront cost compared to regular, energy intensive buildings, attempts have been made to restrict the budget of the zero energy garage apartment to increase its affordability for the clients. Some costs of the zero energy garage apartment will be eased due to federal incentives and the option of installing the solar renewable energy system in phases.

The zero-energy garage apartment is designed to look and feel like a regular house without compromising the ready availability of energy services. For example, the proposed structure can still offer the luxuries of heating and cooling the interiors to current American residential standard for this region, but it has been done in a way that is much safer for the environment and easier on the monthly budget. Thus, the zero-energy garage apartment, by isolating the clients from energy price fluctuations, will offer a higher resale value for their property.

LEED for Homes Project Checklist: Testing the zero energy quality of the garage apartment involved the study of the output results of the Energy10 and eQuest simulation softwares and regular interaction with geothermal energy and solar energy experts to ensure that the garage apartment will produce as much energy as it needs to use. To keep a check on and maximize the eco-friendliness of the design of the zero-energy garage apartment, a LEED checklist was used as a guide. LEED [Leadership in Energy and Environmental Design] Green Building Rating System is the nationally accepted benchmark for the design, construction, and operation of high performance green buildings. It gives building owners and operators the tools they need to have an immediate and measurable impact on their building's performance. LEED promotes a whole-building approach to sustainability by recognizing performance in five key areas of human and environmental health: sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality.[34] The LEED for Homes Project Checklist Version 1.72, as seen in *Table 2-6: LEED checklist*, helped to serve as a reference to categorically supervise the environmental performance of the zero energy garage apartment.

The LEED checklist describes the possible ways in which a building can be designed in an eco-friendly manner. Corresponding to that, columns to the left of the list have been manually filled in affirmative [yes], negative [no] or [don't know] depending on whether or not the zero energy garage apartment satisfies the condition put forth by LEED. For every affirmative, points are assigned. Some conditions are mandatory to be met. Out of the total possible points of 108, the LEED Certified rating can be achieved with scores between 30-49 points. The LEED Silver rating can be achieved with scores between 50-69 points, the LEED Gold rating with 70-89 points and the LEED Platinum rating is given for scores between 90-108 points. An official LEED certification can be achieved only after a formal application is filed, but that is not included in the scope of this project.

---

[34] LEED Rating Systems. January 2008, from USGBC: http://www.usgbc.org/DisplayPage.aspx?CMSPageID=222

The total number of points achieved for the zero energy garage apartment designed for this project is 80/108, a LEED Gold. Although a project of such potential should have achieved the LEED Platinum rating, the highest rating, drawbacks in the LEED checklist act as a limitation. For example, owing to the smaller scale of the project, certain points are difficult to be claimed. Here is a list of them:

1) Sustainable Sites [SS]: Surface Water Management: 4.3 Design and install permanent erosion controls. Total points assigned: 2.
2) Water Efficiency [WE]: Irrigation System: 2.3 Rain sensing controls. Total points assigned: 1
3) Third party testing for a project of this scale and type is difficult to be carried out because of how much such a procedure will increase the already strained budget. Besides, this may also be the reason why it could be challenging to encourage more projects like the alley garage apartment to get LEED Certified.

Figure 2-11: LEED checklist.

LEED FOR HOMES				Project Checklist			
Yes	**?**	**No**		**Location and Linkages [LL]**			**10**
HOLD				**LEED-ND neighbourhood.**			10
Y			2	**Site Selection**		Avoid Environmentally Sensitive Sites and Farmland	2
Y			3.1	**Infrastructure**		Site Within 1/2 Mile of Existing Sewer and Roads	1
Y			3.2			Select an Infill Site	1
Y			4.1	**Community Resources**		Within 1/4 Mile of Basic Community Resources/ Public Transportation	1
		N	4.2		***OR***	Within 1/4 Mile of Extensive Community Resources/ Public Transportation	2
Y			4.3		***AND/OR***	Within 1/2 Mile of Green Spaces	1
		N	5.1	**Compact Development**		Average Housing Density >/= 7 units/acre	1
Y			5.2		***OR***	Average Housing Density >/= 10 units/acre	2
		N	5.3		***OR***	Average Housing Density >/= 20 units/acre	3
			Subtotal				**8**
Yes	**?**	**No**		**Sustainable Sites [SS]**			**14**
Y			1.1	**Site Stewardship**		Minimize Disturbed Area of Site [If Site > 1/3 acres]	Mandatory
Y			1.2			Erosion Controls [During Construction]	Mandatory
Y			2.1	**Landscaping**		Basic Landscaping Design	Mandatory
Y			2.2			Apply 3/4 inches of Mulch Around Plants	1
Y			2.3			Limit Turf	3
Y			2.4			Minimize Landscape Water Demand	2
	Y		3	**Shading of Hardscapes**		Locate and Plant Trees to Shade Hardscapes	1
Y			4.1	**Surface Water Management**		Install Permeable Material for Atleast 65% of the Lot [If Lot >= 1/4 acre]	Mandatory
Y			4.2			Use Permeable Paving Materials	3
	Y		4.3			Design and Install Permanent Erosion Controls	2
Y			5	**Non-toxic Pest Control**		Select Insect and Pest Control Alternatives from List	2
			Subtotal				**11**
Yes	**?**	**No**		**Water Efficiency [WE]**			**12**
Y			1.1	**Water Re-use**		Rainwater Harvesting System	1
Y			1.2			Greywater Re-use System	1
		N	2.1	**Irrigation System**		Main Shut-off Valve, Sub-meter and Third-party Inspection	Mandatory

	Y		2.2		Select High-efficiency Measures from List	3
		N	2.3		Rain Sensing Controls	1
		N	3.1	**Indoor Water Use**	High Efficency Fixtures [Toilets, Showers and Faucets]	3
Y			3.2		***OR*** Very High Efficiency Fixtures [Toilets, Showers and Faucets]	6
			Subtotal			**8**
Yes	**?**	**No**	**Indoor Environment Quality [IEQ]**			**14**
Y			1	**ENERGY STAR with IAP**	Meets ENERGY STAR w/ Indoor Air Package [IAP]	10
Y			2.1	**Combustion Venting**	Space Heating With DHW Equip w/power-exhaust; & CO monitor	Mandatory
		N	2.2		Fireplaces w/outside Air Supply and Closed Combustion	Mandatory
Y			3	**Humidity Control**	Analyze Moisture Loads & Install Central System [When Needed]	1
Y			4.1	**Outdoor Air Ventilation**	Meets ASHRAE std 62.2	Mandatory
		N	4.2		Dedicated Outdoor Air System [w/Heat Recovery]	2
		N	4.3		Third-party Testing of Outdoor Air Flow Rate Into Home	1
Y			5.1	**Local Exhaust**	Meets ASHRAE std 62.2	Mandatory
		N	5.2		Timer/ Automatic Controls for Bathroom Exhaust Fans	1
		N	5.3		Third-party Testing of Exhaust Air Flow Rate Into Home	1
Y			6.1	**Supply Air Distribution**	Meets ACCA Manual D	Mandatory
		N	6.2		Third-party testing of supply air flow rate into each room in home	2
Y			7.1	**Supply Air Filtering**	>/= 8 MERV Filters, w/Adequate System Air Flow	Mandatory
		N	7.2		>/= 10 MERV Filters, w/Adequate System Air Flow	1
		N	7.3		***OR*** >/= 12 MERV Filters, w/Adequate System Air Flow	2
Y			8.1	**Contaminant Control**	Seal-Off Ducts During Construction	Mandatory
Y			8.2		Permanent Walk-Off Mats OR Central Vacuum	1
		N	8.3		Third-Party Testing of Particulates and VOCs before Occupancy	1
Y			9.1	**Radon Protection**	Install Radon Mitigation System if Home is Located in EPA Region 1	Mandatory
		N	9.2		Install Ground Contaminant Mitigation System (Outside of EPA Region 1)	1
Y			10.1	**Vehicle Emissions Protection**	No Air Handling Equipment OR Return Ducts in Garage	Mandatory
Y			10.2		Tightly Seal Shared Surfaces between Garage and Home	Mandatory
Y			10.3		Exhaust Fan in Garage OR No Garage in Contact with Home	1
			Subtotal			**13**

Yes	?	No	Materials and Resources [MR]			24
Y			1	**Home Size**	Home that is Smaller than National Average	2/10
Y			2.1	**Material Efficient Framing**	No Extra Uses of Lumber for Aesthetic Purposes	Mandatory
Y			2.2		Advanced Framing Techniques	2
Y			3	**Local Sources**	Materials Extracted / Manufactured / Produced within 500 Miles	3
Y			4.1	**Durability Plan**	Detailed Durability Plan; (Pre-Construction)	Mandatory
		N	4.2		Third-Party Verification of Implementation of Durability Plan	3
Y			5.1	**Environmentally Preferable**	Tropical Hardwoods, if used, must be FSC	Mandatory
Y			5.2	**Products**	Select Environmentally Preferable Products from List	4
Y			6.1	**Waste Management**	Max of 2.5 Lbs Per Square Foot of Construction Waste Sent to Landfill	Mandatory
Y			6.2		0.5 Pts for Each Additional 0.5 Lbs Per Square Foot Reduction	2
			Subtotal			13

Yes	?	No	Energy and Atmosphere (EA)			29
Y			1.1	**ENERGY STAR Home**	Meets ENERGY STAR for Homes with Third-Party Testing	Mandatory
	Y		1.2		Exceeds ENERGY STAR for Homes, 2 Pts Per HERS Point > HERS 86	16
		N	2.1	**Insulation**	Third-Party Inspection of Insulation Installation, At Least HERS Grade II	Mandatory
		N	2.1		Third-Party Inspection of Insulation Installation, At Least HERS Grade I	1
		N	2.3		***OR*** Above Code Insulation; At Least 5% > Local Code Per REScheck	1
Y			3.1	**Air Infiltration**	Third-Party Envelope Air Leakage Tested </= 0.35 ACH	Mandatory
		N	3.2		Third-Party Envelope Air Leakage Tested </= 0.25 ACH	1
		N	3.3		***OR*** Third-Party Envelope Air Leakage Tested </= 0.15 ACH	2
Y			4.1	**Windows**	Windows Meet ENERGY STAR for Windows (See Table)	Mandatory
		N	4.2		Windows Exceed ENERGY STAR for Windows by >/= 10%	1
Y			4.3		***OR*** Windows Exceed ENERGY STAR for Windows by >/= 20%	2
Y			5.1	**Duct Tightness**	Third-Party Duct Leakage Tested </= 5.0 CFM25 / 100 SF to Outside	Mandatory
	Y		5.2		Third-Party Duct Leakage Tested </= 3.0 CFM25 / 100 SF to Outside	1
	Y		5.3		***OR*** Third-Party Duct Leakage Tested </= 1.0 CFM25 / 100 SF to Outside	2
Y			6.1	**Space Heating and Cooling**	Meets ENERGY STAR for HVAC w/ Manual J & refrigerant charge test	Mandatory
		N	6.2		Exceeds ENERGY STAR for HVAC by >/= 10%, w/ Manual J	1
Y			6.3		***OR*** Exceeds ENERGY STAR for HVAC by >/= 20%, w/ Manual J	3
Y			7.1	**Water Heating**	Improved Hot Water Distribution System	3

Yes	?	No	Credit	Requirement	Points
Y			7.2	Improved Water Heating Equipment	3
		N	8.1 **Lighting**	Energy Efficient Fixtures and Controls	1
Y			8.2	***OR*** ENERGY STAR Advanced Lighting Package	3
Y			9.1 **Appliances**	Select Appliances from List	2
Y			9.2	Very Efficient Clothes Washer (MEF > 1.8, AND WF< 5.5)	1
Y			10 **Renewable Energy**	Renewable Electric Generation System (1 Point / 10% Annual Load Reduction)	6
Y			11 **Refrigerant Management**	Minimize Ozone Depletion and Global Warming Contribution	1
			Subtotal		**24**
Yes	**?**	**No**	**Materials and Resources [MR]**		**1**
Y			1.1 **Homeowner Awareness (HA)**	Basic Owner's Manual and Walkthrough of LEED Home	Mandatory
Y			1.2	Comprehensive Owner's Manual and Multiple Walkthroughs / Trainings	1
			Subtotal		**1**
Yes	**?**	**No**	**Innovation and Design Process (ID)**		**4**
	Y		1.1 **Innovative Design**	Provide Description and Justification for Specific Measure	1
Y			1.2	Provide Description and Justification for Specific Measure	1
Y			1.3	Provide Description and Justification for Specific Measure	1
		N	1.4	Provide Description and Justification for Specific Measure	1
			Subtotal		**2**
			Project Totals 1 (pre-certification estimates)		**80/ 108**

(Source: LEED for Homes Rating System. February 10, 2006 from USGBC: http://www.usgbc.org/ShowFile.aspx?DocumentID=3638)

CHAPTER 3 - Phase 2: Design

The following chapter documents the design of the zero energy garage apartment after the client brief was set. It begins with summarizing some of the most important aspects of the building energy systems and building construction in the form of text and illustrations, and is then divided into various sections. ‘Section 1: Design Documentation’ addresses the ways in which the zero energy garage apartment incorporates some of the architectural features of the front house and lists the energy-saving bioregional design strategies used in the design of the zero energy garage apartment. This section includes the architectural drawings of the zero energy garage apartment and a mathematical analysis of the zero energy garage apartment’s bioclimatic performance referencing Mark DeKay’s *Sun, Wind and Light*.

‘Section 2: Energy Modeling’ summarizes the results obtained from Energy10 and eQuest energy performance simulations of the zero energy garage apartment. The results listed in this section are principle to determining if the zero energy garage apartment has the ability to reach the goal of producing zero utility bills throughout the year/ producing enough energy to run the apartment.

‘Section 3: Renewable Energy Systems’ is a detailed documentation of the working, component details, advantages, disadvantages and the cost of the geothermal energy system. It includes information on the solar energy system’s working, sizing calculations, advantages, disadvantages and cost.

‘Section 4: Materials’ comprises of a material choice framework that was used as a guide to select appropriate materials for the zero energy garage apartment. Materials thus chosen are listed in a tabular format and each material is assigned a reference number, which can be used to navigate through product details outlined in the remaining part of Section 4.

‘Section 5: Cost Estimation’ deals with cost calculation for the entire project in a tabular format.

Introduction

Once the location of the project was determined and the client brief set, as discussed in Chapter 2- Phase 1: Project Goals and Design Parameters, renewable energy systems were chosen based on the criteria of affordability, efficiency, site suitability and maintainability, thus achieving the second goal of this project. Local companies were consulted on its feasibility in the older neighborhood area of Manhattan, Kansas. A ground source (or geothermal) heat pump was chosen to heat the zero energy garage apartment in winter and cool it in summer due to its several benefits, some of which include a 400% efficiency rating compared to only a 94% efficiency rating of fossil fuel based HVAC systems,[35] zero utility bills throughout the year and environment safety. The greatest benefit of using an electricity powered ground source heat pump for the zero energy garage apartment's HVAC requirements, is that such a system is able to provide hot water throughout the year as a byproduct of the operation of the system. Out of 1 unit of electricity fed in, the geothermal system produces 4 units of energy to heat and cool the garage apartment.[36] To provide for this 1 unit of electricity required for the geothermal system and for the various appliances that would be used in the apartment, amorphous silicon roof integrated standing seam photovoltaic panels manufactured by Unisolar were chosen. [See *Figure 3-1: Project Summary*]. Finally, both the adequately sized solar energy and geothermal energy systems would produce enough energy to operate the zero energy garage apartment, provide energy independence from the grid and thus produce zero utility bills throughout the year. The ground source heat pump and solar electric energy system used in this thesis project are outlined in detail under 'Section 3: Renewable Energy Systems' of this chapter.

Once the renewable energy systems were identified, the zero energy garage apartment was designed with reference to the technical requirements that the respective systems demand. For example, the roof area of the apartment had to be maximized to help the standing seam

---

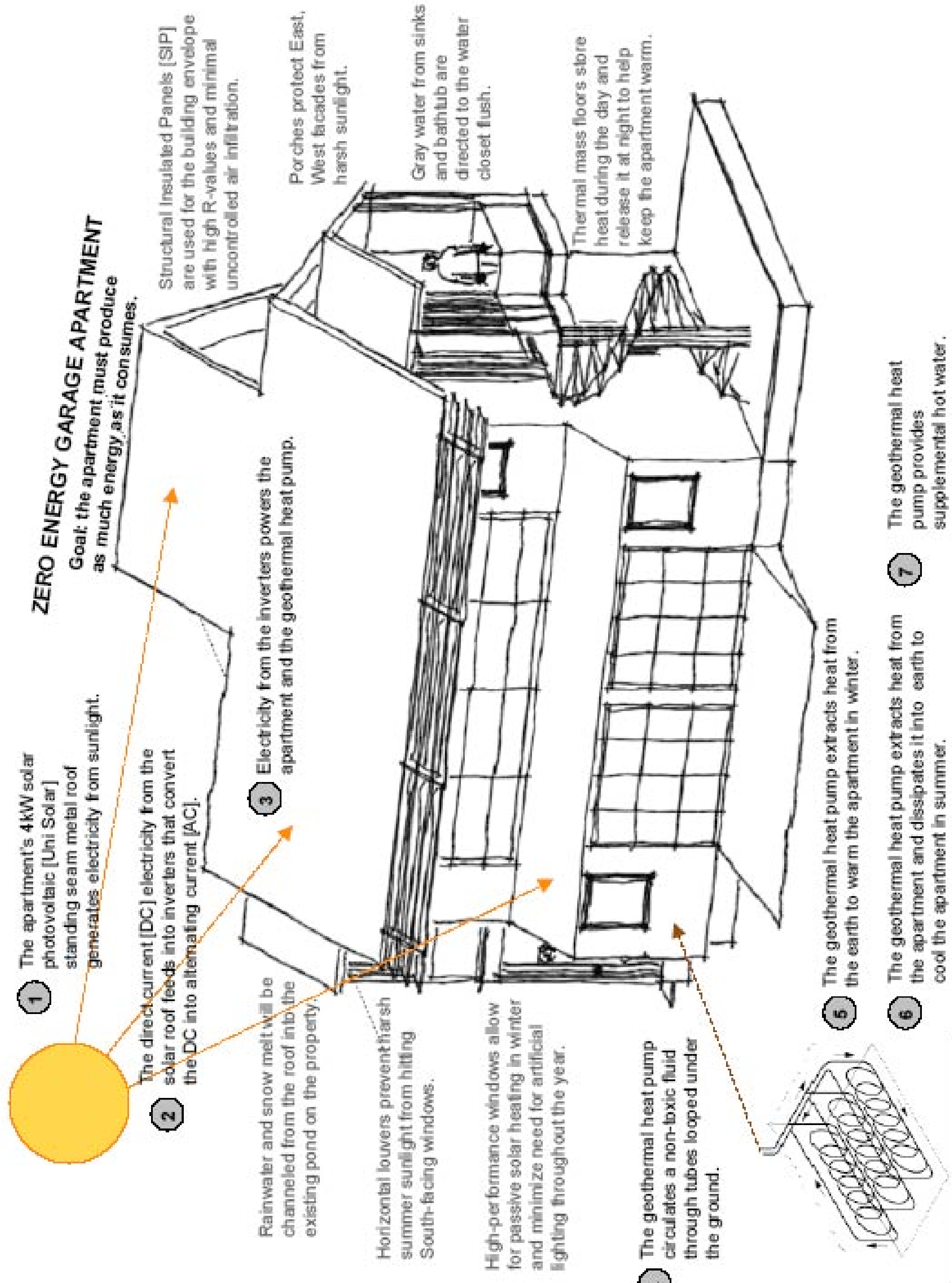
[35] Envision- Geothermal Comfort Systems- Envision Series Indoor Split Units. April 2007. Retrieved April 21, 2007, from Envision: http://www.waterfurnace.com/marketing/brochures/pdf/WF1592.pdf

[36] Ibid.

photovoltaic panels generate 4 kW of solar energy. Decisions on some of the building materials and interior finishes were taken before finalizing the design of the zero energy garage apartment. Doing so helped comprehend the structural system and basic building construction of the zero energy garage apartment and helped make critical design decisions at an early stage. For example, while it was decided that Structural Insulated Panels [SIPs] be used to construct the building envelope, a thermal mass concrete floor was slated to be used as part of the passive solar design strategy. SIPs are engineered sandwich panels with OSB boards and foam core insulation and do not have an inherent capacity to carry the weight of a 4” thick thermal mass concrete floor, unless supported by steel columns, the use of which would escalate the cost of the project. To avoid cost overruns, Extreme Panel Technologies [SIP company] (personal phone conversation, August 2007) and contractors were consulted and a decision was made to pour a 3” thick thermal mass concrete floor, which could be supported by the SIP floor bolstered by wooden trusses: analysis showed that this 1” reduction in the thickness of the concrete floor would not greatly affect the thermal mass storage capacity of the floor and that the trusses would not escalate the cost of the project . Identifying building materials and interior finishes before finalizing the design of the zero energy garage apartment also helped feed appropriate and adequate data required to simulate the building energy performance using Energy10 and eQuest softwares.

Figure 3-1 summarizes basic details about the zero energy garage apartment’s building systems and building construction.

Figure 3-1: Project summary.



Section 1: Design Documentation

This section elaborates on the project goal of establishing a design framework. The objectives of this goal involving the analysis of Manhattan's socio-economic and demographic conditions, and the LEED for Homes checklist have been addressed in Chapter 2. Other objectives of the goal that involve studying the existing architectural character on the site and bioregional and passive design strategies are documented in this section.

Maintaining architectural character

The clients' front house, being one of Manhattan's oldest houses, has a strong architectural character as can been seen in pictures of the property in Chapter 2. True to Greek Revival style, the house is characterized by grand porches with columns and pilasters that emphasize straight line and symmetry. In the entry porch, the columns extend on to the second floor to form a verandah with a pedimented gable. The main door is accentuated by sidelights and the front house embodies tall interior spaces. An elongated porch on the West and a smaller one on the South also serve as seasonal outdoor spaces.

In order for the zero energy garage apartment to be integrated into the neighborhood without it being a negative visual influence, its design had to embrace some part of the architectural history. It was determined that some of the predominant design attributes of the front house would be incorporated into the zero energy garage apartment in a way that would be reminiscent of historical character and yet be representative of it's own time. The inviting entry porch, its columns, verandah, pedimented gable and sidelights from the front house were decided to be incorporated into the design of the zero energy garage apartment. Besides adapting porches on to the design of the zero energy garage apartment, it was decided that the front house's 30^0 roof angles, vertically proportioned 3.5'x6' windows and tall interior spaces would also be incorporated to achieve harmony between the two structures on the property. Siding colors were decided to be matched and the zero energy garage apartment would be positioned on the property with respect to that of the front house, as discussed in the following section. *Figures 3-2, 3-3, 3-4* and *3-5* are illustrations of the front house.

Figure 3-2: Front house elevation- West.

Figure 3-3: Front house elevation- North.

Figure 3-4: Front house elevation- East.

Figure 3-5: Front house elevation- South.

Bioregional Design Strategies

Manhattan, Kansas has its own distinct climate and ecological characteristics. By designing the zero energy garage apartment in conjunction with those characteristics and using nature to the best advantage, an increase in occupant comfort and reduction in the energy required to operate the apartment can be achieved. Bioregional design strategies help in energy cost savings, provide long-term financial benefits and hence increase the affordability of the building. Since buildings designed using bioregional strategies consume less energy, such strategies also provide environmental benefits by reducing air pollution and improving the surrounding air quality. The bioregional strategies used to design the zero energy garage apartment focus on passive solar design techniques that help keep the garage apartment warm in winter and cool in summer, which will in turn help decrease the heating and cooling loads on the geothermal energy system respectively. The design objectives for the bioregional strategies are:

1) Keeping the heat in and cold out in winter:[37] In order to retain heat in winter, two main techniques are used in the zero energy garage apartment. South facing glazing is appropriately sized to maximize winter solar gain, and thermal mass concrete floor is used to store heat from the sun during the day and release it in the night. In order to keep the cold out, windows on the winter windward side are minimized. Also, Structural Insulated Panels [SIPs] with high R-values and minimal air infiltration are proposed to construct the envelope of the zero energy garage apartment to protect from cold winds. High-performance glazing that offers insulative as well as solar gain properties are designed specific to the façade where they are used.
2) Keeping the heat out, offering shade from the sun and opening the building to cool breezes in summer:[38] In order to keep the heat out in summer, precautions are taken to prevent solar gain by providing adequate overhangs and tinting

---

[37] Coates, Gary. (n.d.). *Bioclimatic Dwelling Design. A Workbook Compilation to Sun, Wind and Light.*

[38] Ibid.

windows. Porches are designed and trees strategically placed to provide shade on the structure and cool the breezes. Operable windows are provided to allow user controlled cross-ventilation.

Site: Site studies of the property were conducted after finalizing the client. As part of documenting the existing site conditions to create a site plan drawing, plot boundaries were measured and the property photographed for reference. Site features, like the front house, an existing pond and surrounding trees, are documented on the site plan, as seen in *Figure 2-2: Existing site plan*. The front house was intricately measured to produce elevation drawings illustrated in *Figures 3-2, 3-3, 3-4* and *3-5*. Proposed additions in the form of the zero energy garage apartment and alterations in the landscape design were resolved on the site plan.

The plan of the zero energy garage apartment is elongated along the East-West axis to maximize winter solar gain into both the 1st floor/ garage and the 2nd floor apartment. It can be noted that once the zero energy garage apartment will be built, solar access to the front house's already narrow South façade [adjacent to the zero energy garage apartment] will be diminished. In order for this to have been avoided, the distance between the front house and the zero energy garage apartment for solar access during the month of December would have to be 52',[39] as illustrated in *Figure 3-7: Solar access*. This cannot be achieved due to plot boundary restrictions. Since the rooms facing the South in the front house are a kitchen and corridor space on the lower floor, which are spaces that, on the one hand require minimal use and on the other, generate heat, it was decided that restricted solar access into those spaces would not greatly affect the thermal balance of the existing house. The advantage of such an arrangement for the zero energy garage apartment is that the front house will act as a windbreak from cold Northern winds.

---

[39] Brown, G. Z., DeKay, Mark. (2000). *Sun, Wind and Light.* (2nd ed.). Wiley Publications.

Figure 3-6: Site plan.

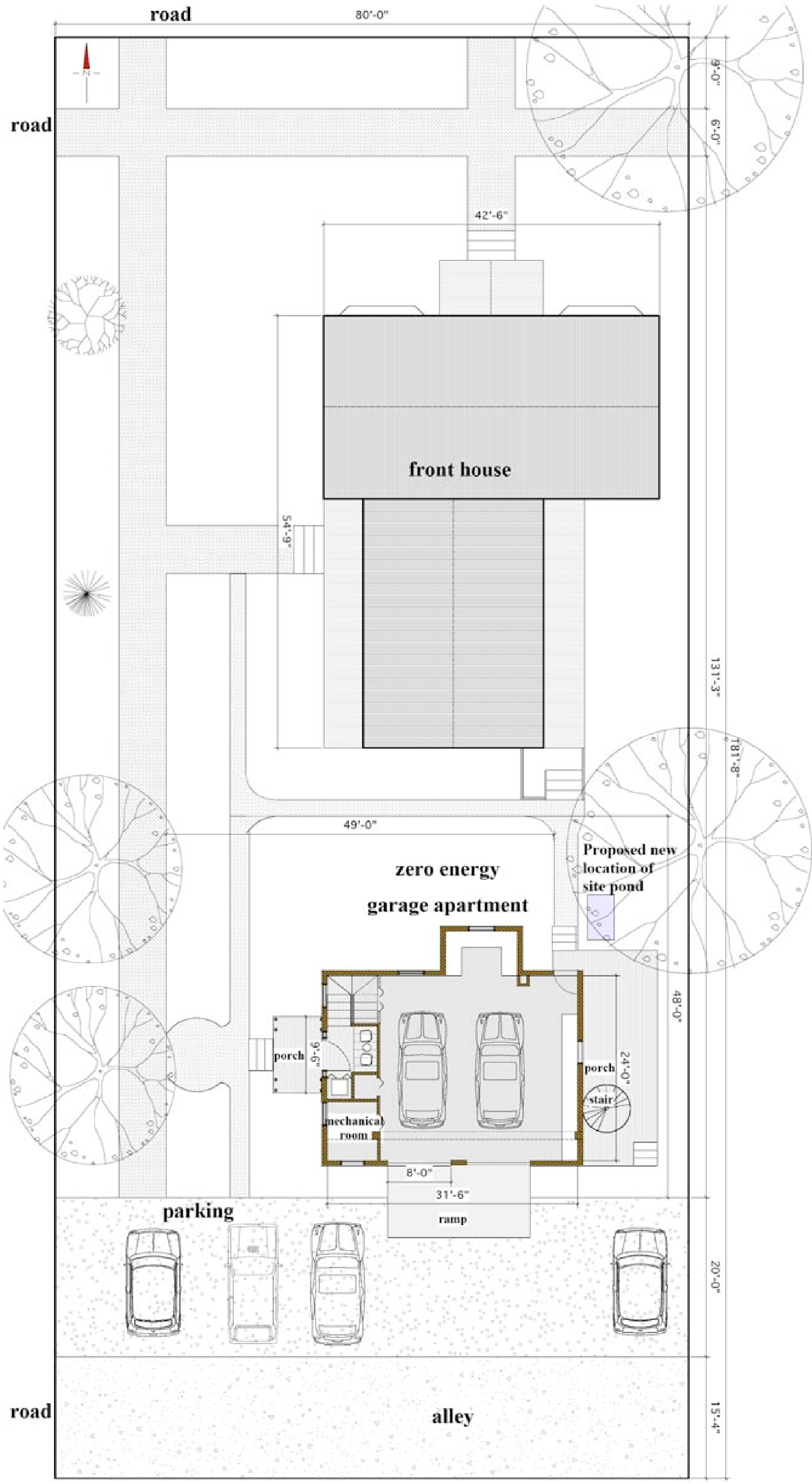
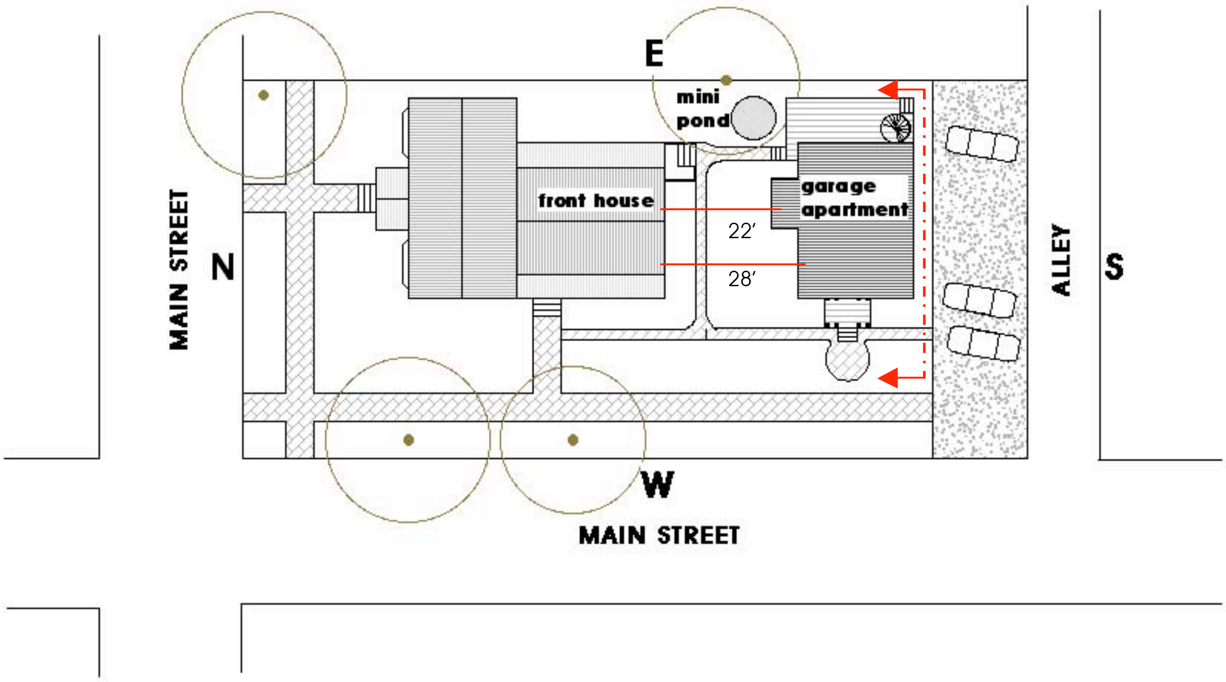


Figure 3-7: Solar access.



West: Since this is the main street-facing side of the zero energy garage apartment, the West façade is designed to accommodate the main entrance and is highlighted by a vertical porch similar to that of the front house, as illustrated in *Figures 3-8, 3-9 and 3-10*. The physical boundary of the zero energy garage apartment on the West was designed to coincide with that of the front house on the West, to give an appearance of uniformity from the street. The zero energy garage apartment is designed to conform to the historical character of the front house, and is characterized by windows symmetrically placed on either side of the entry porch. The columns extending from the porch form a verandah on the 2nd floor apartment that could be used as a seasonal outdoor space. The clients expressed an affinity towards verandah spaces adjacent to the street, as they, or their guests, could use it to relax in the evenings while engaging in conversations with their friends walking along. The porch extends out and gives an impression of verticality by visually breaking the masses of the envelope and the roof of the zero energy garage apartment. By doing so, it protects the building envelope from being subject to direct unwanted solar radiation gains in summer. Summer winds blowing from the West will also be cooled by the shade from the porches before entering the interior of the zero energy garage apartment. As seen in *Figure 3-12: Floor plan- 1st floor/ garage level*, service rooms on the first floor/ garage floor are located toward the West to cocoon the unconditioned garage space from the heat and cold. Living spaces on the second floor are also located away from the West for similar reasons, as shown in *Figure 3-13: Floor plan- 2nd floor/ apartment level*.

During winter some cold winds blow from the West[40] because of which typically, openings on the structure are avoided to help reduce winter heating loads on the geothermal system. Openings on the West façade also fare poorly in summer as they permit undesired solar gain and increase summer cooling loads on the geothermal system. Since windows and doors on the West side of the zero energy garage apartment were unavoidable, they were tinted to mitigate the amount of incident solar radiation. With the aim of reducing heating loads in winter and cooling loads in summer, double paned high-performance windows and doors filled with Argon gas and sheathed with a low-e [low solar gain] coating were decided to be used in the zero energy garage apartment. Double-glazing was used since it displays better insulating properties than single glazing and the Argon gas fill helps reduce heat loss from the windows and doors significantly in winter. The low solar gain, low-e coating not only reduces heat loss in winter but also reduces heat gain from the glazing in summer. Although windows in the front house are double-hung, casement windows are used in the zero energy garage apartment as they offer better air-tightness. All the windows on the West façade are operable to provide for user-controlled ventilation needs.

Figures 3-8 and *3-9* diagrammatically represent the West façade elevations of the zero energy garage apartment and highlight the bioregional strategies described above.

---

[40] Brown, G. Z., DeKay, Mark. (2000). *Sun, Wind and Light.* (2nd ed.). Wiley Publications.

Figure 3-8: Zero energy garage apartment elevation- West.

Figure 3-9: West site elevation.

Figure 3-10: Isometric view showing West and North facades.

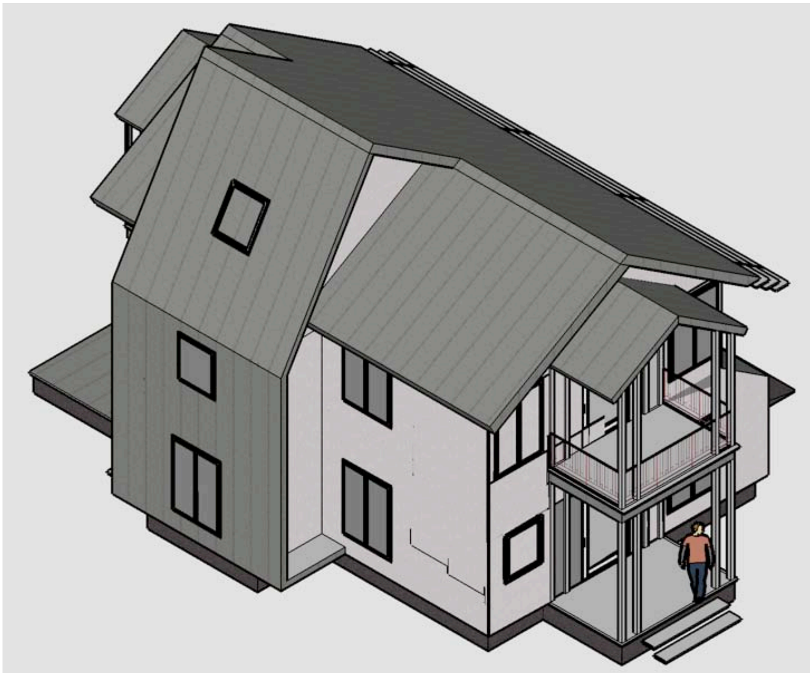


Figure 3-11: Section towards West.

Figure 3-12: Floor plan- 1st floor/ garage level.

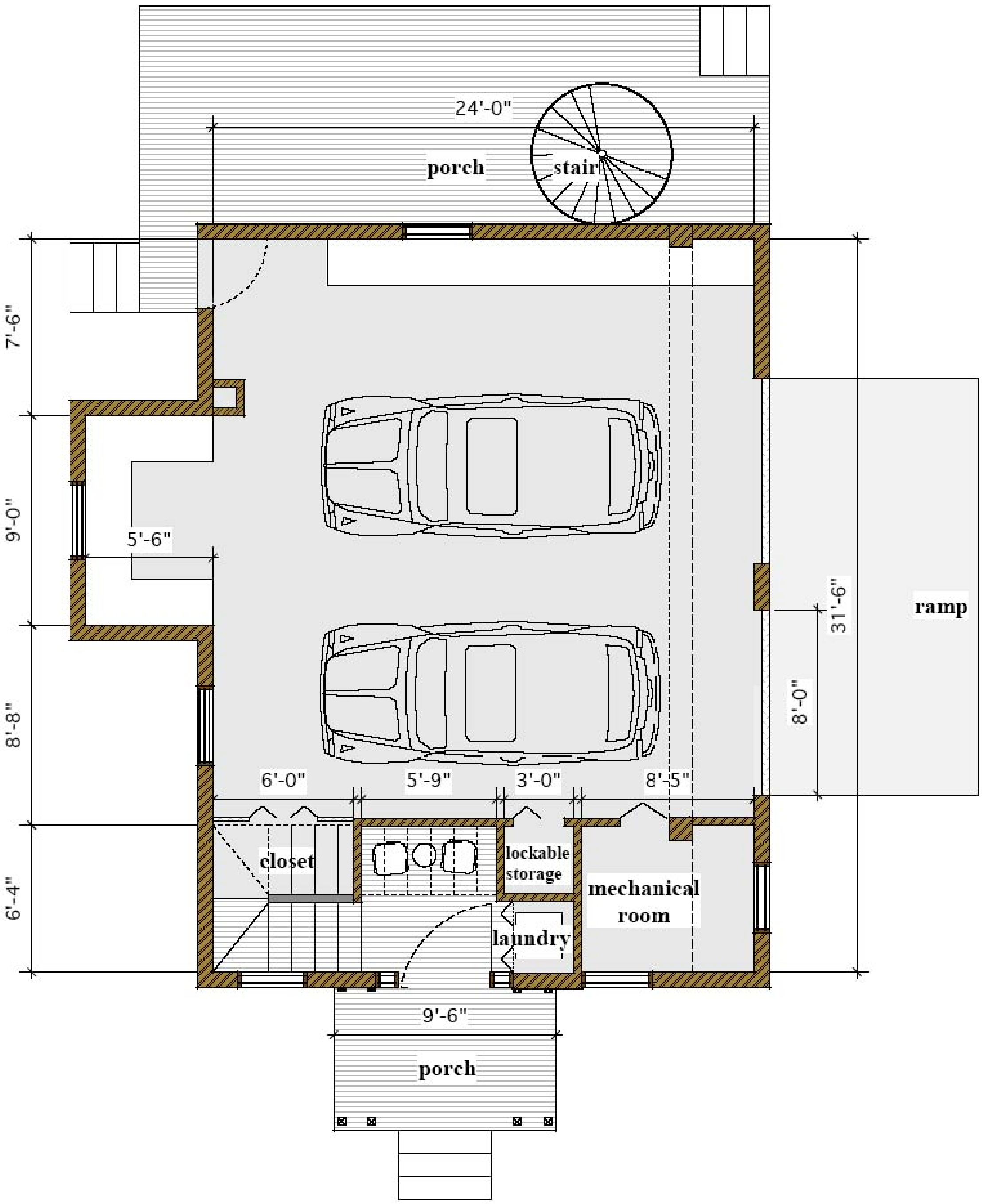
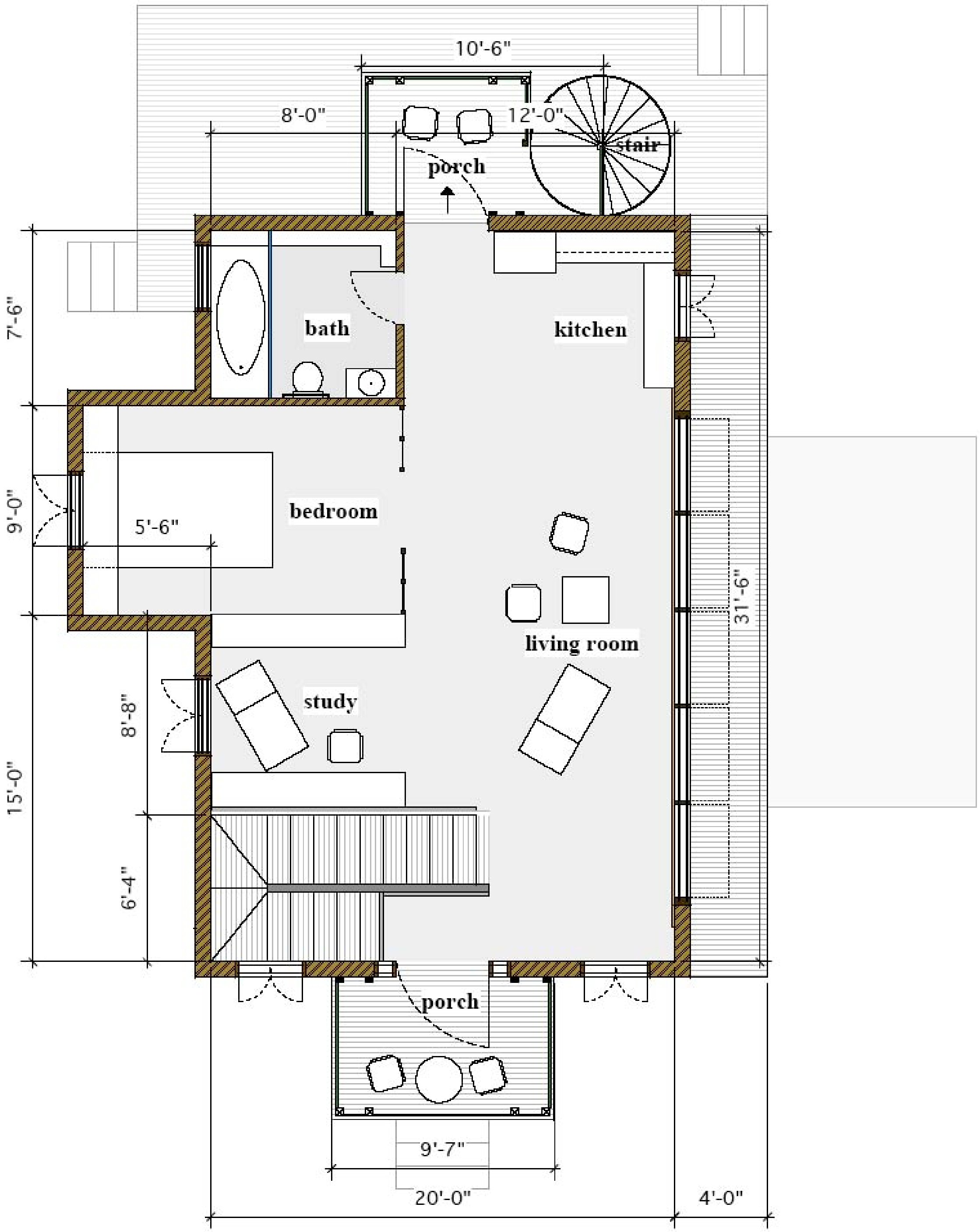


Figure 3-13: Floor plan- 2nd floor/ apartment level.



North: The North side of the zero energy garage apartment faces the South side of the front house. *Figure 3-14: Zero energy garage apartment elevation- North* illustrates the North façade of the zero energy garage apartment. The width of the North façade of the garage apartment is designed to coincide with that of the front house. The entry to the garage in the zero energy garage apartment coincides with the backdoor entry to the front house on its South.

The form of the zero energy garage apartment on the North is entirely governed by the interior layout of the 2nd floor/ apartment level, as seen in *Figures 3-12* and *3-13*. Since the clients requested a bedroom that could be optionally closed off for privacy, it was designed as an alcove. By extending the bedroom beyond the rectangular layout of the zero energy garage apartment, a cleaner living room space could be achieved in the interior. Since the bedroom is a smaller space with walls on 3 sides, the roof over it has been designed to increase the interior volume and thus make the space seem larger. This alcove on the floor plan of the 2nd floor/ apartment level was mirrored onto the floor plan of the 1st floor/ garage level to facilitate the future possibility of converting the garage into an apartment for the clients. Presently, the alcove in the garage level is designed to be used as an area where the clients could carry out activities related to gardening. On the 2nd floor/ apartment level, the study area is located in such a way as to benefit from the indirect sunlight streaming in from the North, which is excellent for reading.

Although glazing on the North façade does not increase heat gain in summer, cold winds blow directly from the North in winter[41]. Since the North side of the structure does not receive any direct sunlight, no heat gain can be obtained in winter either. Openings increase air infiltration and hence it is best to reduce the number of North-facing windows and doors to lessen winter heating loads. In the zero energy garage apartment, windows are minimized on the North façade, but are not completely avoided to facilitate cross ventilation. Due to the incident strong cold winds in winter, windows require better insulation on this side compared to those on the other façade. Hence, triple glazing is used in the windows facing North as they offer higher insulation than double glazing. Like the West, the casement windows are argon gas filled and

---

[41] Brown, G. Z., DeKay, Mark. (2000). *Sun, Wind and Light.* (2nd ed.). Wiley Publications.

low-e low solar gain coated. Low solar gain coating is used since solar gain is anyways not available from the North. The windows are operable to allow for cross-ventilation.

Figure 3-14: Zero energy garage apartment elevation- North.

Figure 3-15: Section towards North.

East: The East façade is designed like that of the West, where a less elaborate porch frames the door on the 2nd floor/ garage level to achieve structural symmetry. A similarly smaller porch exists on the South side of the front house that frames the lower level. The physical boundary of the East side of the zero energy garage apartment is designed to coincide with that of the front house. *Figure 3-16: Zero energy garage apartment elevation- East* illustrates the East façade of the zero energy garage apartment. A spiral staircase leads out to the proposed outdoor seating area, as can be seen in *Figures 3-12, 3-13.* The front house casts a shadow on part of the East side of the property where a strip of land adjoining the house is presently used by the clients as an outdoor seating area in the evenings. A similar area was assigned to the side of the property adjoining the East of the zero energy garage apartment. As can be seen in *Figure 3-6: Site Plan*, the existing mini-pond on the property had to be moved slightly North of the site to accommodate for the new garage apartment. Rainwater and snowmelt are designed to be channeled from the roof of the apartment into the mini-pond. Landscaping on the East of the apartment can be designed in the future with the mini pond as a focal element.

Like the West, unwanted summer sun strikes the East façade.[42] Windows on the East and West sides tend to lose more heat than they gain in winter. As a result, to reduce undesired solar gain and decrease summer cooling load on the geothermal energy system in summer, openings on the East façade of the zero energy garage apartment are minimized. To aid cross-ventilation in summer, the door on the 2nd floor can be left open. Winds entering in through this door in summer will be cooled by the shade of the external porch before they enter the zero energy garage apartment. A small window facing East is provided on the garage level for daylighting purposes. Like the West façade, the porch on the East could perform as a seasonal outdoor space and help block unwanted summer sun from directly hitting the main structure. Functionally, the East porch can also serve as a fire escape route. Window specifications for the East façade are similar to those of the West.

---

[42] Brown, G. Z., DeKay, Mark. (2000). *Sun, Wind and Light.* (2nd ed.). Wiley Publications.

Figure 3-16: Zero energy garage apartment elevation- East.

Figure 3-17: Section towards East.

South: This façade faces the alley, which facilitates vehicular entrance into the garage as well as parking at the rear of the site, as seen in *Figure 3-19: Zero energy garage apartment elevation- South*. Currently, the clients and their B&B clients park along the roads on the North and West of the property. The zero energy garage apartment, once built, will facilitate a 2 car garage and 3 car parking spaces along the alley.

The design of the South façade is the result of using passive and active solar strategies for space heating and electricity production. The roof area over the main structure was maximized to accommodate the 20 solar photovoltaic panels required to face South in order to generate 4 kW of electricity per day. To increase roof area exposure towards the South, the 1^{st} floor/ garage level was extended 4' beyond that of the 2^{nd} floor/ apartment level, and the roof over this 4' extension is scheduled to be used for installing photovoltaic panels, as can be seen in *Figure 3-1*: *Project Summary*. Although roof angles for achieving maximum efficiency from the photovoltaic panels are +/- 15^0 of the latitude of the location,[43] i.e +/- 15^0 of Manhattan's 39^0 latitude, the front house's characteristic 30^0 roof angle was maintained in the design of the zero energy garage apartment for aesthetic reasons. According to Bob Dolan from BMK Plumbing company [local solar energy system installers from Salina, Kansas] the 30^0 roof angle would still ensure high performance efficiency from the photovoltaic panels (personal phone conversation, October 3, 2007). Photovoltaic panels tend to impart a modern, industrial look to buildings. Since the zero energy garage apartment had to be designed in a visually non-intrusive manner, Unisolar photovoltaic panels of the amorphous silicon building integrated standing seam laminate type were chosen. These photovoltaic panels appear to visually blend into the structure and have proven to generate more efficiency from lesser material compared to crystalline photovoltaic panels.[44] Details of the Unisolar photovoltaic panels are further addressed in 'Section 3: Renewable Energy Systems' of this chapter.

Since the South side offers maximum potential for tapping winter solar gain, the required glazing area facing South for the zero energy garage apartment was calculated with the aim of

---

[43] Brown, G. Z., DeKay, Mark. (2000). *Sun, Wind and Light.* (2nd ed.). Wiley Publications.

[44] Amorphous Solar Panels. (2006). Retrieved July 2, 2007, from Solar Voltaic: http://www.solarvoltaic.com/images/doc/solar%20abstract.pdf

decreasing residual heating loads in winter. According to Mark DeKay's *Sun, Wind and Light*, the "South facing glazing area required for winter heat gain should be 15-29% [SSF or solar savings fraction of 0.15 low and 0.29 high] of the floor area" (DeKay, 2000, p. 249). Thus, for the 2nd floor/ apartment level, the required South facing glazing amounts to 97.5 sq.ft- 188.5 sq.ft. The designed solar aperture/ South glazing area for the 2nd floor apartment level of the zero energy garage apartment is 159 sq.ft, an area on the higher side of the recommended values. South facing glazing required for the 634 sq.ft of garage space at the 1st floor level ranges between 95 sq.ft- 184 sq.ft. Translucent garage doors that facilitate a total glazing area of 112 sq.ft provide the required winter solar gain.

Once sunlight is received inside the zero energy garage apartment through the south-facing glazing, thermal mass concrete floors on both the floor levels absorb the heat, store it and release a substantial amount of heat at night. This property of thermal mass floors helps decrease the heating load on the geothermal energy system in winter. Recycled glass chips are mixed with the stained concrete thermal mass floors to provide a terrazzo-like appearance. The concrete slab acts as the thermal mass floor for the garage, which will be specially coated with an eco-friendly material to prevent stains. Thermal mass flooring is further discussed further under 'Building bioclimatic analysis and calculation' part of this chapter.

Another building material that helps reduce heating load in winter and cooling load in summer, is the Structural Insulated Panel [SIP] system that is used to construct the building envelope of the zero energy garage apartment. SIP's are high-performance sandwich OSB panels with foam insulation that offer high R-values and minimal uncontrolled air infiltration, which help keep the zero energy garage apartment warm in winter and cool in summer. SIP's are discussed in detail under 'Building bioclimatic analysis and calculation' and 'Section 4: Materials' of this chapter.

In summer, when heat gain is required to be minimized to decrease the cooling load on the geothermal system, the south facing glazing area should be adequately shaded to limit the undesired high angled solar radiation. This shading element had to be designed in such a way that would permit winter solar gain and restrict summer solar gain. Using data from the *Sun, Wind and Light*, a light, aluminum overhang was designed for the South facing glazing on the 2nd floor/ apartment level as seen in *Figure 3-18: Diagrammatic representation of aluminum overhang*. The horizontal louver is designed such that all high summer solar angles will be blocked from hitting the glazing, but will not cast a shadow on the solar panels on the roof over the garage below. The louvers will let in winter sun [September through April] through the south facing glazing at all times of the months and days. Solar angle in the month of August at 8:30 am is incident at 45 degrees (Dekay, 2000, p. 210). Any incident sunlight with angles greater than 45^0, i.e. summer sun angles in the months between May and August, will be blocked by the louvers that extend outward from the roof to a horizontal distance of 3’9 3/8”. The total length of the horizontal louver projection from the roof is 4’5”. There will, however, be a few minutes/ hours during summer, when the shadow of the horizontal louvers will fall on a part of the photovoltaic panels mounted on the lower roof over the garage. Summer being a time when solar energy production will be maximized, it is expected that the shadow on the photovoltaic panels will not greatly reduce the energy performance of the garage apartment. The zero energy garage apartment’s building performance in terms of the amount of heat gain and heat loss is discussed in the ‘Building bioclimatic analysis and calculation’ part of this chapter.

In the interior space planning, maximally used living spaces are oriented to the South, as seen in *Figures 3-12 and 3-13*. The mechanical room in the garage is oriented towards the South and the West, since the solar energy system batteries need to be stored in warm conditions to prevent them from losing heat. All South facing windows are argon gas filled and double glazed with low-e high solar gain coating. The casement windows are operable to allow summer breezes to cool the house via cross and stack ventilation. Glazing close to the floor is fixed and inoperable.

Figure 3-18: Diagrammatic representation of aluminum overhang.

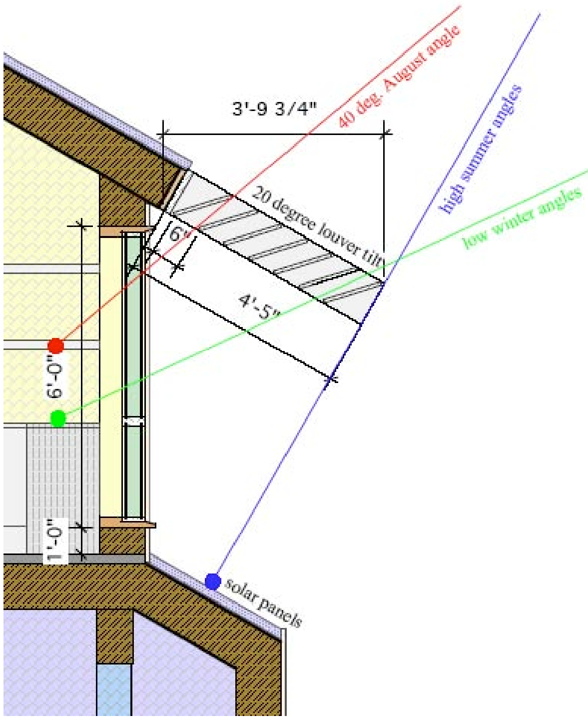


Figure 3-19: Zero energy garage apartment elevation- South.

Figure 3-20: Section towards South.

Client Brief Tally

The clients were presented with a number of different design options, out of which they chose the final design. The design of the zero energy garage apartment meets almost all the requirements requested by the clients. The need for ample storage is met through strategically located cabinets and shelves. An attic space is created above the bathroom on the 2nd floor level to provide for more storage space. Privacy needs for guests are met through the small meeting area near the entrance to the zero energy garage apartment, and through the bedroom that can be optionally closed off. One of the most important features of the zero energy garage apartment is its versatility in adapting to the different situations that the clients may come across through their life time. As *Figures 3-21, 3-22*: *Zero energy garage apartment adaptability* show, the zero energy garage apartment can be configured in a variety of ways depending on client suitability. Although initially designed to facilitate for a B&B, over time, the clients can rent out the 2nd floor apartment and convert the garage on the first floor as a living space for themselves, as illustrated in *Figure 3-23: Lifecycle flexibility of zero energy garage apartment*. During such a scenario, the 4' additional space created in the garage to facilitate the solar energy system, will increase the square footage for comfortable occupancy. The geothermal energy system would have been adequately sized to allow for future use of the garage as a living space. The front house, meanwhile, can be either used by the clients' children or could be rented out.

The clients requested for separate toilet compartments, but this could not be achieved due to limited space availability. The clients said that they like to work in the garage during winter, for which some kind of heating will be preferred. However, this was avoided as heavy infiltration through the garage doors and subsequent increase in heating load on the HVAC system will occur every time the garage doors open. However, the high-performance windows and doors in the garage should help keep the shell of the building air-tight, and hence allow for the clients to work in the garage in winter for a short time without getting too cold.

Figure 3-21: Zero energy garage apartment adaptability.

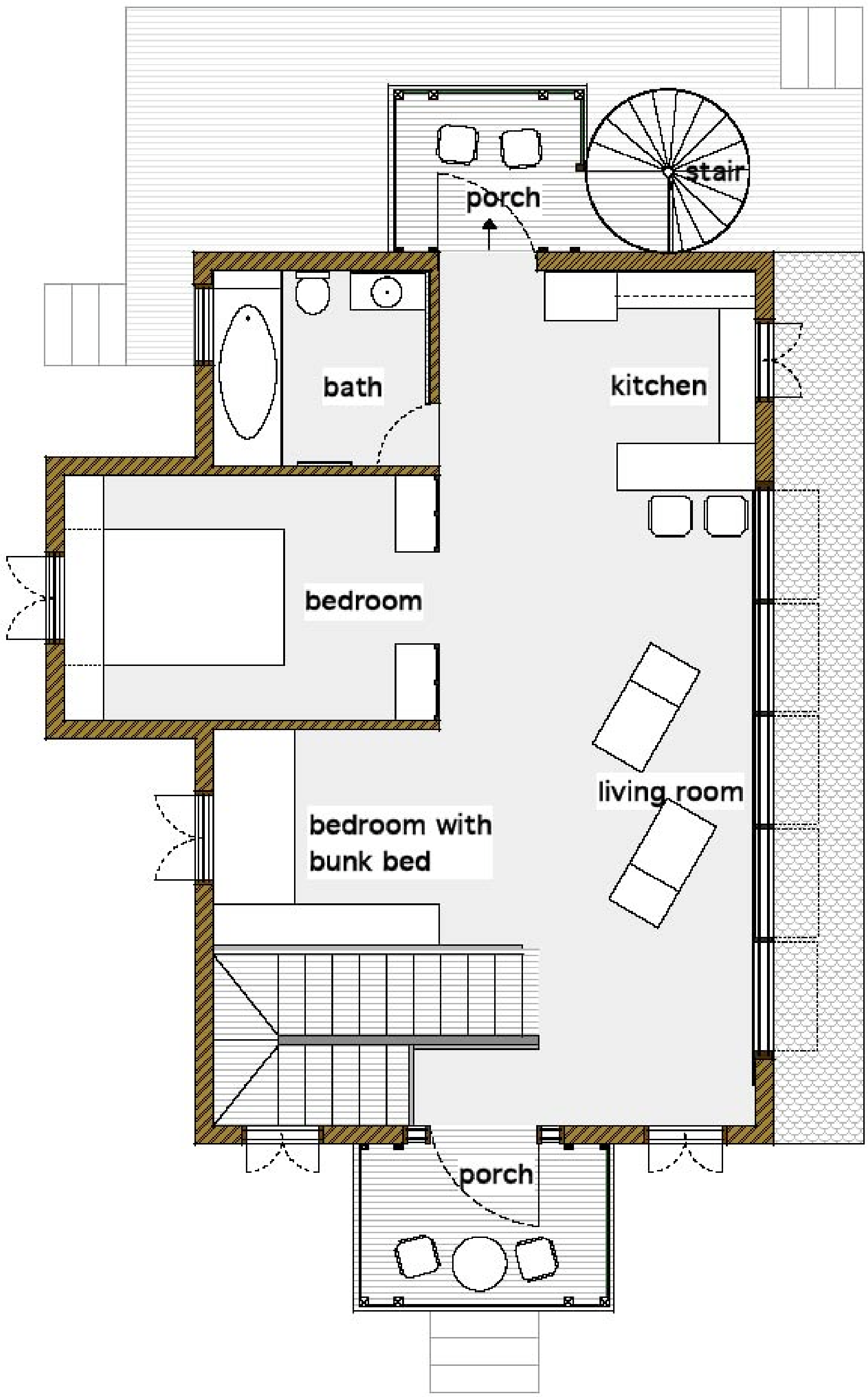


Figure 3-22: Zero energy garage apartment adaptability.

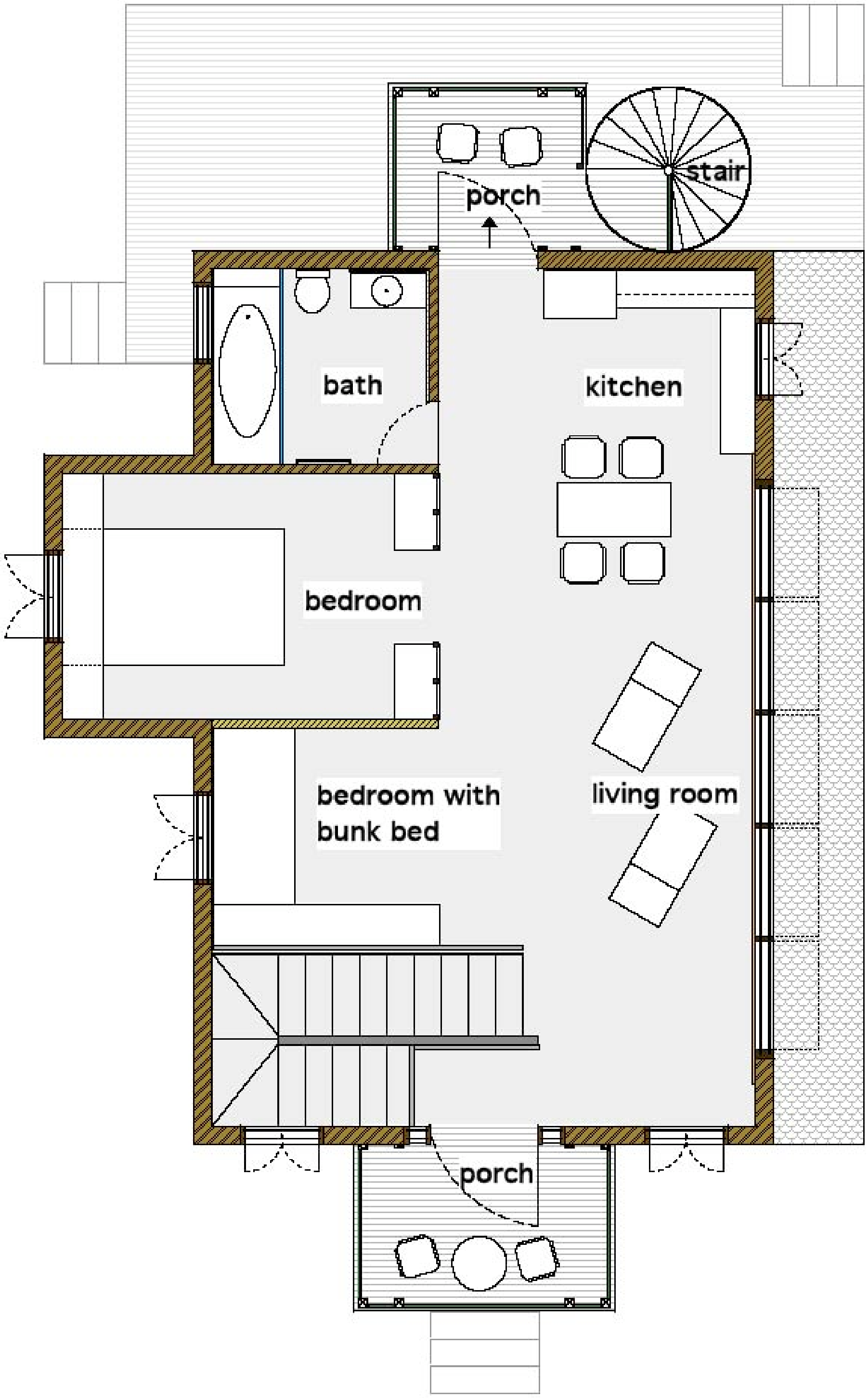
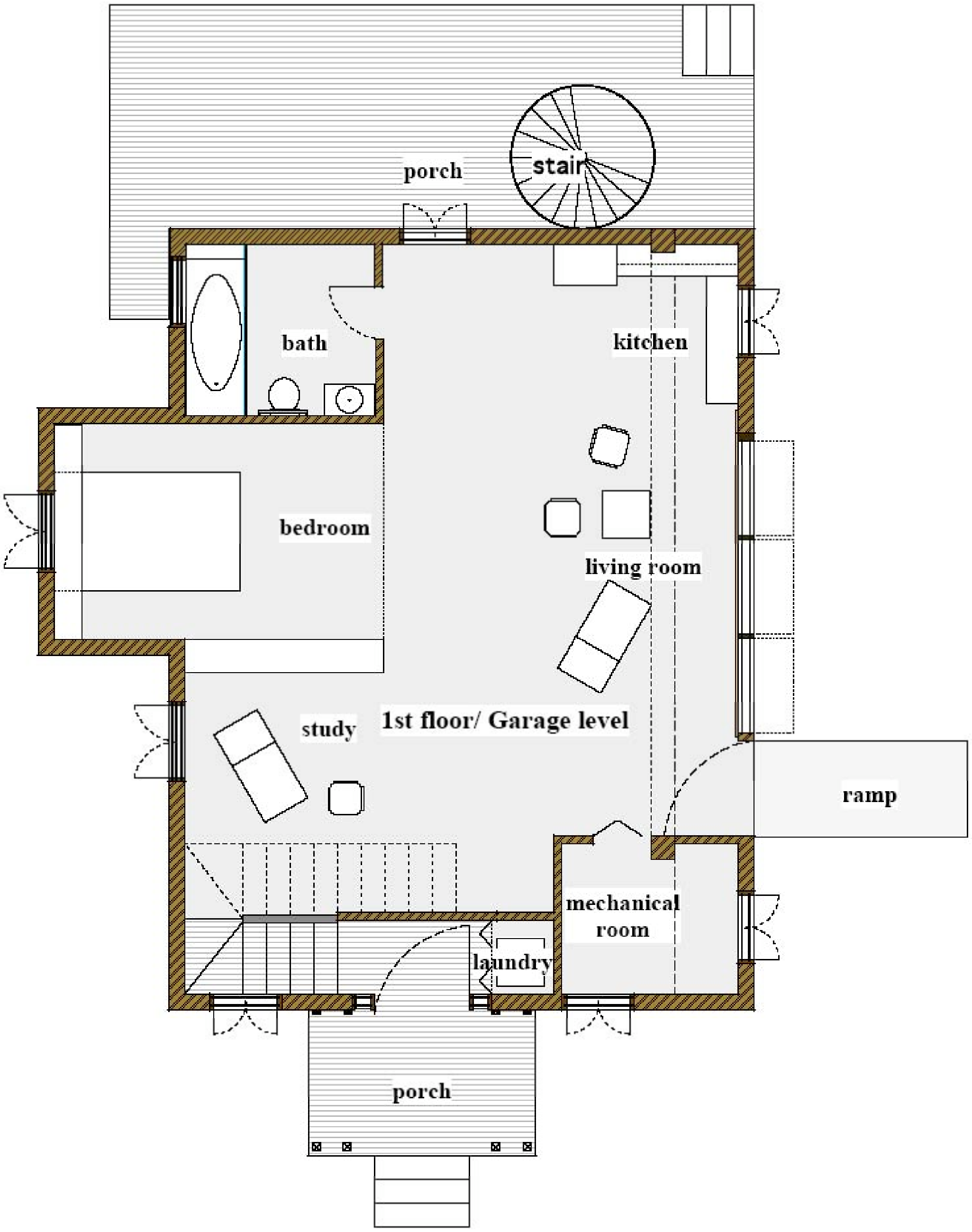


Figure 3-23: Lifecycle flexibility of zero energy garage apartment.



Building Bioclimatic Analysis and Calculations

In order to estimate if the building form and envelope of the zero energy garage apartment would generate the appropriate climatic responses to deliver the necessary energy savings, a building bioclimatic analysis was carried out. Factors that influence the heating and cooling energy requirements of the building, like the amount of heat lost by the building envelope in winter and the amount of heat gained by the building in summer, were calculated as part of the analysis. The required insulation thickness to achieve thermal comfort in the zero energy garage apartment and the amount of thermal mass needed to reduce heating costs, as specified in the *Sun, Wind and Light*, are also listed in this section. The following calculations derived from the *Sun, Wind and Light*, are one method, besides the building energy performance simulations, to try and obtain optimal energy performance from the zero energy garage apartment design. The calculations and simulations helped the designer to evaluate the resources on the site and the structure's response to them, without the inconvenience of on-site measurements. They also help understand the relationship between form, envelope and energy use and are an effective tool for designing with sustainability in focus.

Insulation: Insulation helps reduce heat loss and gain from the interior of a building. In the zero energy garage apartment, expanded polystyrene (EPS) insulation is sandwiched between two structural skins of oriented strand board (OSB). These are called sandwich panels or Structural Insulated Panels [SIP]. SIP's are high-performance panels that ensure an airtight envelope by reducing the amount of air infiltration from and into the zero energy garage apartment. They hence help reduce energy demand to maintain a uniform internal temperature and save costs subsequently. The SIP panels used in the zero energy garage apartment are discussed in detail under 'Section 4: Materials' of this chapter.

The amount of insulation required is directly proportional to the type of climate one is dealing with. *Table 3-1: Recommended residential insulation values for Manhattan, Kansas* and Table *3-2: Recommended insulation values for windows in passive solar heated buildings* list the recommended insulation values for Manhattan, Kansas. The degree of insulation required is expressed in terms of R-value, which is a measure of the capacity of the insulation to impede heat flow.[45] The higher the R-value, the greater is its insulative capacity. U-value, as seen in *Table 3-2*, is a measure of heat transmission through a given thickness of insulating material that will flow in 1 hour through 1 square foot of the structure or material from air to air with a temperature differential of 1°F. U is the inverse of R i.e. U = 1/R.[46]

Table 3-1: Recommended residential insulation values for Manhattan, Kansas. R value expressed in ft^2.^{o}F.h/Btu.

ROOF		FLOOR		WALL	
R value	Thickness	R value	Thickness	R value	Thickness
49	16"	25	8"	25	8"

(Source: DeKay, 2000, p. 214).

Table 3-2: Recommended insulation values for windows in passive solar heated buildings. R value expressed in ft^2.^{o}F.h/Btu. U value expressed in Btu/hr,^{o}F,ft^2.

R value	U value
3.1	0.33

(Source: DeKay, 2000, p. 272).

Thermal mass: Since the thermal mass floor in the zero energy garage apartment will retain the heat incident on it during the day and release it at night and during cloudy periods, its extent/amount is crucial to maintain ambient internal temperatures. As per the schematic design methods of estimating thermal performance of passively heated buildings that is found in *Sun, Wind and Light*, the required thermal mass concrete floor for each floor can be calculated using the formula: surface area of thermal mass floor= [3-6 ft^2 of mass] / unit area in square feet of South-facing glazing (DeKay, 2000, p. 230). Therefore, the required thermal mass concrete floor

---

45 R-value. (September 12, 2005). Retrieved January 8, 2008, from U. S. Department of Energy: http://www.eere.energy.gov/consumer/your_home/insulation_airsealing/index.cfm/mytopic=11340

46 U-value. (May 31, 2006). Retrieved January 8, 2008, from U. S. Department of Energy: http://www1.eere.energy.gov/consumer/tips/windows.html

for each level in the garage apartment ranges between 477- 954 sq.ft. The thermal mass concrete floor available as per the design of the zero energy garage apartment on the 1st floor/ garage level is 622 sq.ft.; and on the 2nd floor/ apartment level is 616 sq.ft. A 3" thick concrete thermal mass has been provided on each of the floors of the zero energy garage apartment. As per *Sun, Wind and Light*, the recommended thickness is 4"-6" (DeKay, 2000, p. 230), but according to experts at Extreme Panel Technologies, 3" thick concrete floors perform with up to 95% the efficiency of 4" thick concrete (personal phone conversation, August 28, 2007). If concrete more than 3" would be poured on the 2nd floor, steel columns will be mandated to support it. As this would complicate the construction of the garage apartment and increase the cost of the overall project, it was avoided (Extreme Panel Technologies, personal phone conversation, August 28, 2007). Thus, by providing 622 sq.ft. of concrete thermal mass flooring on the 1st floor/ garage level and 616 sq.ft of the same on the 2nd floor/ apartment level, the design of the zero energy garage apartment meets the rule-of-thumb criterion for adequate thermal mass.

Building heat loss calculation: The rate of heat loss from a building in winter is one of the factors that determines the amount of energy required to heat the building internally to maintain comfortable conditions. Greater heat loss means that more energy will be required to heat the building. A building loses heat from its roof, walls, skin and via air infiltration. Using methods defined in *Sun, Wind and Light* it was possible to calculate the total heat loss of the zero energy garage apartment from its roof, wall and skin. The calculations also take into account air infiltration standards from a typical, non-SIP building envelope.

Basic calculations (Coates, *Bioclimatic Dwelling Design*, p. 2-20) : U value of roof [1/Rvalue]= 0.02, U value of walls [1/Rvalue]= 0.04.

1) Total area of [opaque and glazed] building envelope [exclusive of South wall]: 1994 sq.ft
2) Total area of glazing exclusive of South wall: 72 sq.ft
3) % of total envelope [exclusive of South wall] in glazing [2/1]= 3.6
4) Total area of opaque building envelope [exclusive of South wall] [1-2]= 1922 sq.ft
5) % of total envelope in opaque building envelope [4/1]= 0.96

Calculations for Area weighted average U-value of opaque skin (Coates, *Bioclimatic Dwelling Design*, p. 2-23):

Opaque roof:

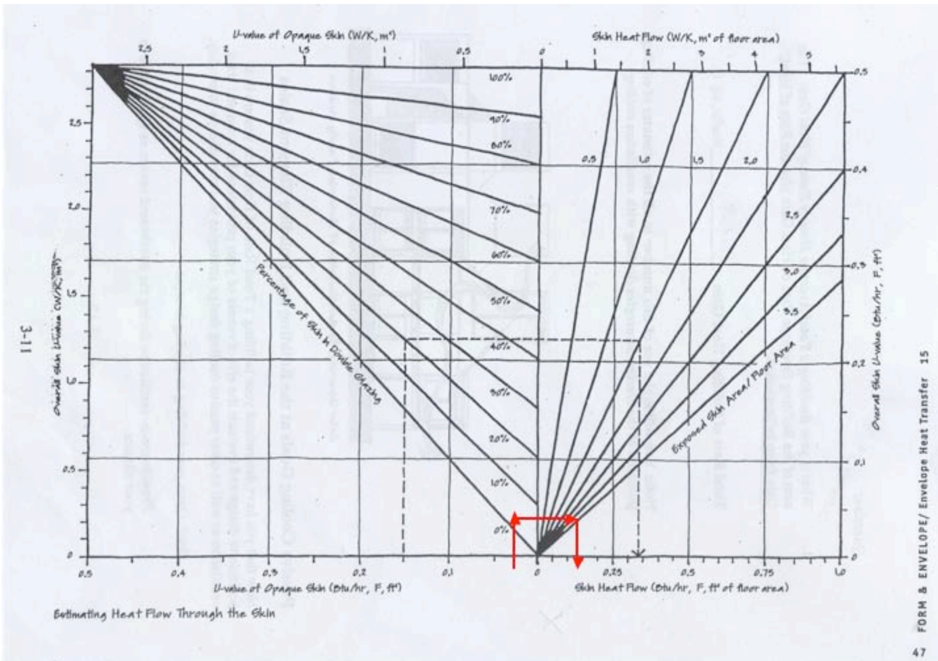
1) Area [A]= 1372 sq.ft
2) % of total opaque [A/iv from previous calculation]: 0.71
3) R-value= 49 $ft^2.^oF.h/Btu$
4) U-value= 0.02 $Btu/hr,^oF,ft^2$
5) % x U= 0.0002 $Btu/hr,^oF,ft^2$

Opaque wall:

1) Area [A]: 550 sq.ft
2) % of total opaque [A/4 from previous calculation]: 0.28
3) R-value= 25 $ft^2.^oF.h/Btu$
4) U-value= 0.04 $Btu/hr,^oF,ft^2$
5) % x U= 0.0004 $Btu/hr,^oF,ft^2$
6) Area weighted average U-value of opaque skin= 0.0006
7) Exposed skin area/ floor area= 3.06

Building skin:

Figure 3-24: Estimating heat flow through the skin.



(Source: Coates, Gary. (n.d.). *Bioclimatic Dwelling Design*. *A Workbook Compilation to Sun, Wind and Light.* p. 2-20)

As obtained from *Figure 3-29*, the Skin heat flow [Btu/hr, ^{o}F, sq.ft. of floor area]= 0.125
Infiltration [Btu/hr, F, sq.ft. of floor area]= 0.09
Therefore, the building's total rate of heat loss [a+b]= 0.215
Total maximum heat loss from the zero energy garage apartment [0.215] x 24 hrs./day= 5.16 [Btu/DD, sq.ft.] (Coates, *Bioclimatic Dwelling Design*, p. 2-22). **Since the maximum permissible heat loss for passively solar heated buildings, as stated as a standard in the *Sun, Wind and Light* is 5.6 Btu/DD, sq.ft., the zero energy garage apartment's heat loss of 5.16 Btu/DD, sq.ft. falls within the safe zone.**

Building heat gain calculation: The rate of heat gain from a building in summer is one of the factors that determines the amount of energy required to cool the building internally to maintain comfort conditions. Higher levels of heat gain mean that more energy is required to cool the building when passive means are inadequate. A building gains heat from its windows, walls, roof and via air infiltration. The following calculations derived from the *Sun, Wind and Light* help determine the total heat the zero energy garage apartment will gain in summer from its envelope and via infiltration.

Heat gain through envelope (DeKay, 2000, p. 66):

Gains through externally shaded windows [window area/ floor area]x 16 [outdoor design temperature]= 3.04 Btu/hr, ft^2 of floor area.

Gains through opaque walls [(opaque wall area x U-value of wall)/ floor area] x 15 [outdoor design temperature]= 0.57 Btu/hr, ft^2 of floor area.

Gains through roofs [(opaque roof area x U-value of roof)/ floor area] x 35 [outdoor design temperature]= 1.48 Btu/hr, ft^2 of floor area.

Therefore, total heat gain through envelope= 5.09 Btu/hr, ft^2 of floor area.

Heat gain from infiltration (DeKay, 2000, p. 66):

Heat gain from infiltration [infiltration load x 16 (outdoor design temperature)]= 0.8 Btu/hr, ^oF, ft^2.

The formula for calculating the total heat gain is: Building envelope rate of heat gain= heat gain through envelope+ heat gain from infiltration.

Building envelope rate of heat gain total (DeKay, 2000, p. 66) **= 5.09+0.80= 5.89 Btu/hr, ft^2 of floor area.**

Section 2: Energy Modeling.

Along with the schematic design calculations related to building bioclimatic analysis, as addressed in Section 1, the thermal performance of the zero energy garage apartment design was simulated using computer software. Energy modeling, or building energy simulation, is the science of estimating the energy interactions between the interior of a building and its external environment. These interactions include the direct purchase of energy from the grid and the exchange of energy due to air infiltration, heat loss and heat gain. Energy modeling also helps in determining the heating, cooling and ventilation loads within a building and the equipment types and sizes needed to meet these loads. The softwares that simulate the building's thermal performance also calculate approximate electricity usage and costs to operate the building's HVAC and non-HVAC equipments. Energy modeling was used as a tool in the design of the zero energy garage apartment in order to determine compliance to building standards and to optimize the economic performance of building components.[47]

After a systematic process of evaluation it was decided that Energy10 and eQuest would be the best programs to simulate the design of the zero energy garage apartment due their accessibility, user friendly interface and rapid output of data. Both softwares have been nationally recognized for their effectiveness and near-accurate output data. Output data generated by the simulation softwares were used as an analytical tool to evaluate the building performance of the zero energy garage apartment during its design and resulted in design changes aimed at increasing it's energy efficiency. The energy calculations were used to predict real-world outcomes of the design of the zero energy garage apartment.

[47] C-2000 Energy Simulation. March 1996. Retrieved December 25, 2007, from IISBE [International Initiative for a Sustainable Built Environment]: http://greenbuilding.ca/C2000/abc-2kes.htm#FUTUREofSIM

Energy-10

Energy-10 is a preliminary design analyzing, energy performance software that is designed to simulate buildings of footprint area less than 10,000 sq.ft. It is a software that can conduct whole-building analysis, evaluate the energy and cost savings that can be achieved by applying energy-efficient strategies such as daylighting, passive solar heating, and high-performance windows and lighting systems. Energy-10 is the result of a collaborative project of the NREL Center for Building and Thermal Systems, the Sustainable Buildings Industry Council (SBIC), Lawrence Berkeley National Laboratory, and the Berkeley Solar Group. It's accuracy has been demonstrated using the BESTEST procedure, developed by NREL's Center for Building and Thermal Systems within the International Energy Agency Solar Heating and Cooling Program Task 12, which has been adopted by the U.S. Department of Energy and the international community as the accepted basis for verifying the credibility of computer simulation programs.[48] The energy performance of the garage apartment was simulated on a regular basis, right from the preliminary design stage. The simulation input and output data provided in this thesis, however, only address the final simulation.

The input data requested by Energy10 is only elementary, since the software is designed to simulate thermal performance during schematic stages of the design process. Location information and weather type were specified as part of the input data. The software also requested information related to the area, volume and the construction type of the zero energy garage apartment. A few specifications of the HVAC system and glazing were also fed in. Input data has been addressed in detail from *Tables C-2* to *C-10* under Appendix C. The simulation output is in the form of comparative bar graphs between a 'reference case' pre-fed into the software and the 'low-energy case', which, in this simulation is the zero energy garage apartment. Figures *3-25: Annual energy use* to *3-30: HVAC rated capacities* depict output graphs generated by Energy10. The annual energy and electric consumption output graphs [Figures *3-*

---

[48] Energy10. (n.d.). Retrieved January 15, 2006, from NREL [National Renewable Energy Laboratory]: http://www.nrel.gov/buildings/energy10.html

25, 3-28] helped verify whether or not the geothermal and solar energy systems were capable of generating the required amounts of energy.

The monthly electric demand peak graph [*Figure 3-29*] was used to estimate the amount of energy in kW that the solar energy system would need to generate during peak hours. The software generated an annual energy cost graph [*Figure 3-26*]. Its subsequent annual cost breakdown graph [*Figure 3-27*] was used to understand the technique by which the software estimated the energy cost of the zero energy garage apartment. The cost breakdown graph also helped identify ways in which the costs incurred to operate and maintain the zero energy garage apartment could be eased. The HVAC rated capacities graph [*Figure 3-30*] generated as an output data by Energy10 was used to continuously test the effectiveness of the passive solar heating and cooling strategies planned for the design of the apartment.

As a drawback, there are a number of building components that cannot be modeled within the current Energy10 version. Since the software is designed to simulate initial estimates of energy performance, the input information it asks for is very basic. The software also assumes certain design parameters and simulates them without offering any user control. This affects the output data as the graphs generated are not precise predictions. Also, since Energy10 does not account for geothermal, or ground source heat pumps, 'fixed COP heat pump' was fed as part of the input data for the HVAC system. The software has some inputting drawbacks related to daylighting. In spite of some drawbacks, the Energy10 software provided excellent guidance towards achieving maximum energy efficiency from the design of the zero energy garage apartment during the schematic stages of design.

Figure 3-25: Annual energy use, clearly shows a steep reduction in heating loads and other energy use loads in case of the zero energy garage apartment in comparison to the software's reference case building. The zero energy garage apartment is depicted by the software as consuming less energy to cool and light the building, and is thus shown to achieve low overall energy consumption compared to the reference case.

Figure 3-25: Annual energy use.

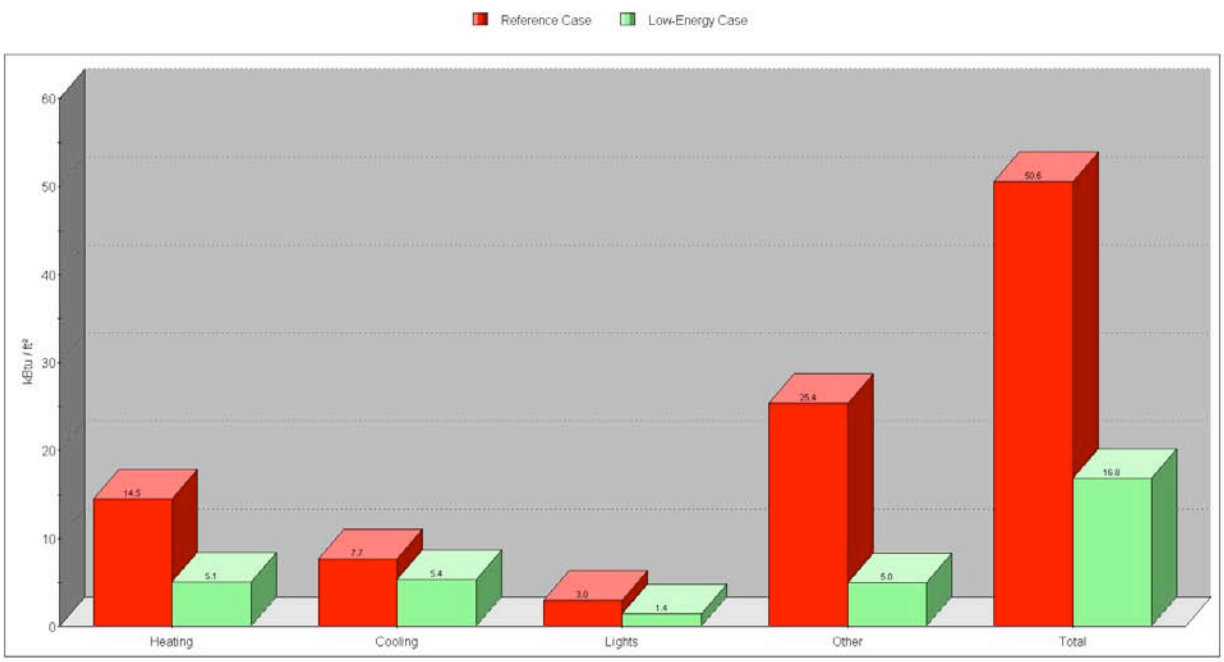


Figure 3-26: Annual energy cost shows the cost of the zero energy garage apartment in $/ft^2 of annual energy usage in kWh. It also depicts the annual energy demand costs, while taking into account zero fossil fuel consumption from the grid. Overall, the graph shows that the zero energy garage apartment performs much better than the software's reference case. The graph below shows that the annual energy cost of the garage apartment is only 1/3rd as compared to the reference case.

Figure 3-26: Annual energy cost.

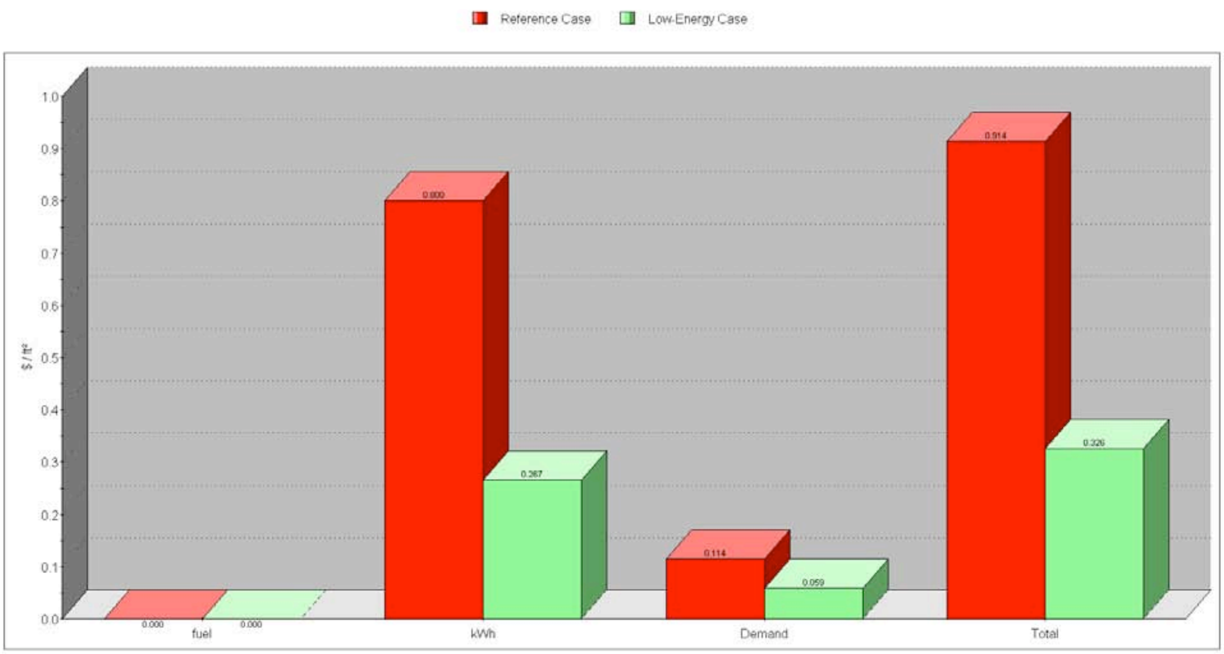


Figure 3-27: Annual cost breakdown depicts the details accounted by the software while estimating annual energy usage by the zero energy garage apartment. In its calculations, it can be seen that the software accounted for hot water electric usage by default. This usage can be negated since hot water is generated supplemental to the normal operation of the ground source heat pump. Once again, the zero energy garage apartment's energy performance is depicted as being superior to that of the software's reference case. In all the parameters that Energy10 accounts for, the zero energy garage apartment shows a reduction of at least 30% in annual costs.

Figure 3-27: Annual cost breakdown.

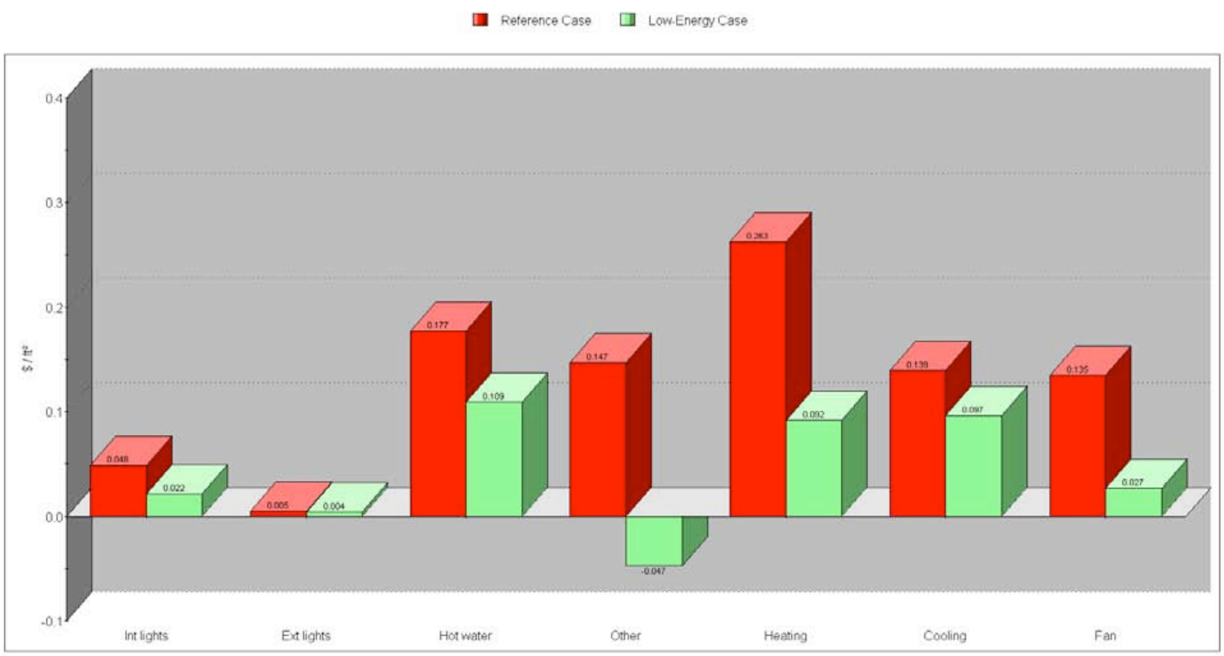


Figure 3-28: Annual electric use breakdown, is a graph similar to that of *Figure 3-31: Annual cost breakdown*, the difference being that this graph accounts for the annual electricity usage in kWh/ft^2 by the different elements of the zero energy garage apartment. In all the parameters accounted for by Energy10, the zero energy garage apartment shows a reduction of 30% and over in annual electric usage, with the exception of exterior lights where the reduction is negligible.

Figure 3-28: Annual electric use breakdown.

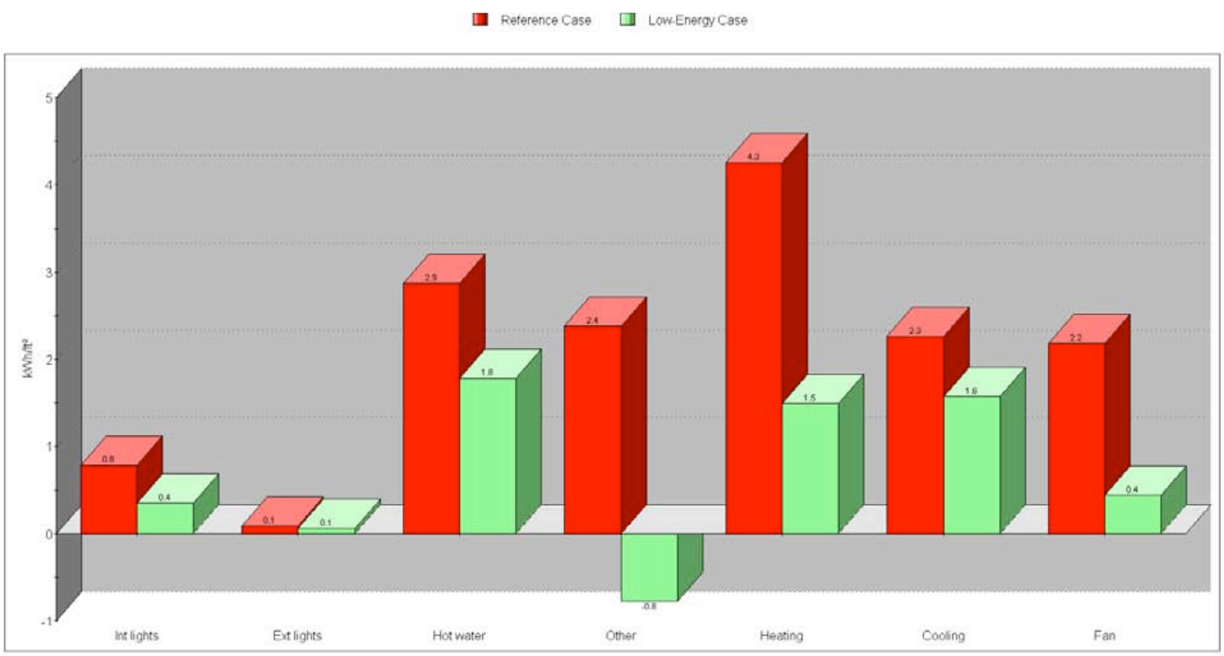


Figure 3-29: Monthly electric demand peaks shows that the monthly electric demand of the zero energy garage apartment is lower than that of the reference case building. From the graph, it can be seen that the software is estimating higher electric demand in winter months to warm the apartment. Passive solar design techniques of using thermal mass and South-facing glazing in the zero energy garage apartment could not be fed into the software, but can be estimated to reduce electric demand further. The zero energy garage apartment cuts down electric demand by approximately 50% during the months that require cooling, and over 45% during the months that require heating.

Figure 3-29: Monthly electric demand peaks.

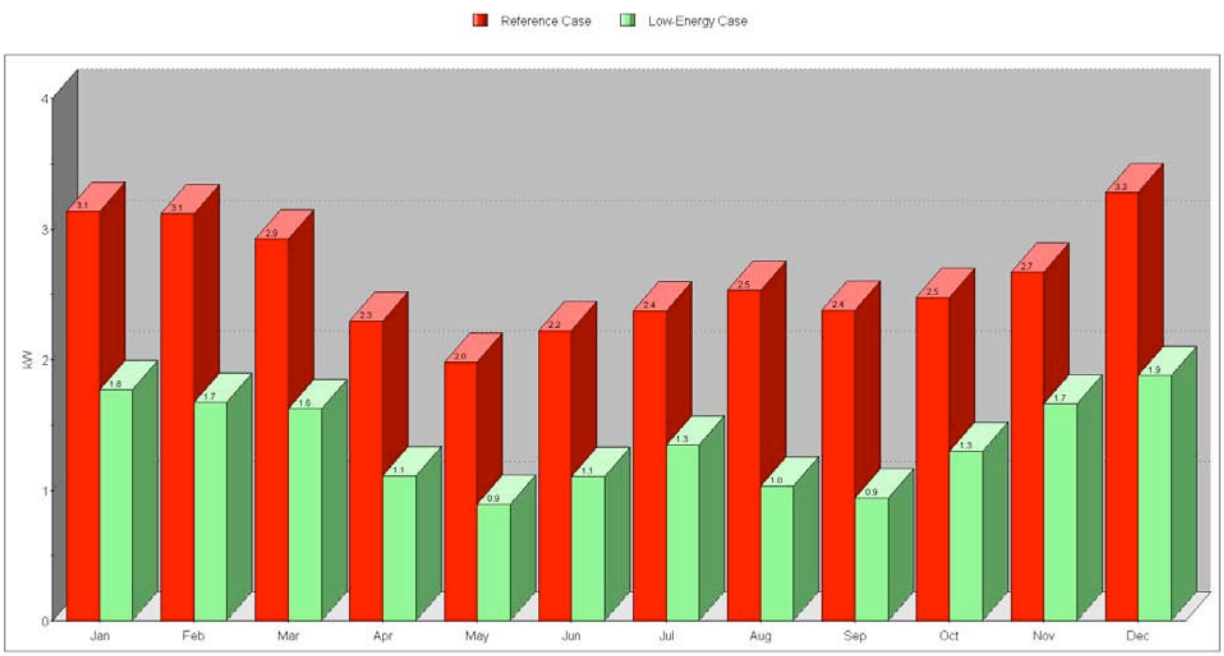
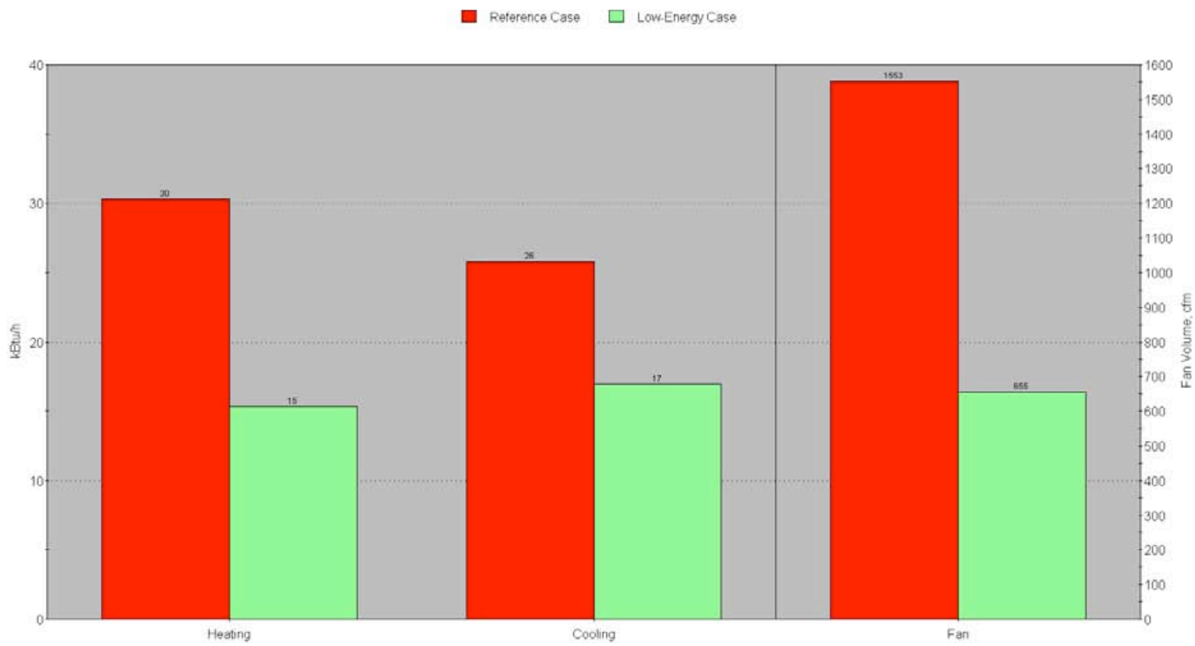


Figure 3-30: HVAC rated capacities shows the loads on the geothermal system to heat and cool the zero energy garage apartment. The zero energy garage apartment shows a 50% reduction in HVAC heating load, 30% reduction in cooling load and a 58% reduction in fan load.

Figure 3-30: HVAC rated capacities.



eQuest

The energy performance simulation software eQuest [version 3.61b] is designed to provide building performance data for both the preliminary and the final stages of design. eQuest is a DOE-2 [Department of Energy] based software. The energy performance of the garage apartment was simulated on a regular basis, right from the preliminary design stage. The simulation input and output data documented in this thesis, however, only address the final simulation.

The input data required by eQuest is extensive in comparison to that fed into Energy10. Input data is illustrated between *Figures C-2* to *C-46* in Appendix C. eQuest begins by requesting information related to the general project, site and weather information. It then moves on to request details related to the building envelope, like the type of construction, window specifications, etc. The software also requires the user to provide building operation schedule data before describing the HVAC and non-HVAC load and system specifications. Inputing all the data for simulating the zero energy garage apartment in such an extensive manner also helped the designer to focus on various aspects of the design of the zero energy garage apartment that were previously not explored. Simulation results for the zero energy garage apartment were generated by eQuest in the form of graphs and pie charts. The output graphs, like those obtained from Energy10, were used to analyze the zero energy garage apartment's energy use patterns. The graphs were then used to modify design elements to help increase the energy performance of the zero energy garage apartment accordingly.

Like Energy10, software drawbacks exist in eQuest also. Since eQuest is programmed to simulate buildings of areas greater than 60,000sq.ft, the output data may not accurately reflect the energy usage of a small building. Errors in eQuest computations of cooking equipment profiles and refrigeration profiles [as seen in the graphs in Appendix C] due to lack of user control further skew the output data. In spite of its drawbacks, eQuest is largely used for assessing buildings regardless of square footage since it is one of the few user-friendly softwares available at no cost. eQuest's backing by the DOE further adds to the validity of the software.

Figure 3-31: Annual electricity consumption by enduse gives a percentage value to the electricity consumption by the different elements of the zero energy garage apartment.

Miscellaneous equipment, space cooling and task lighting account for a major portion of the annual electricity consumption by enduse.

Figure 3-31: Annual electricity consumption by enduse.

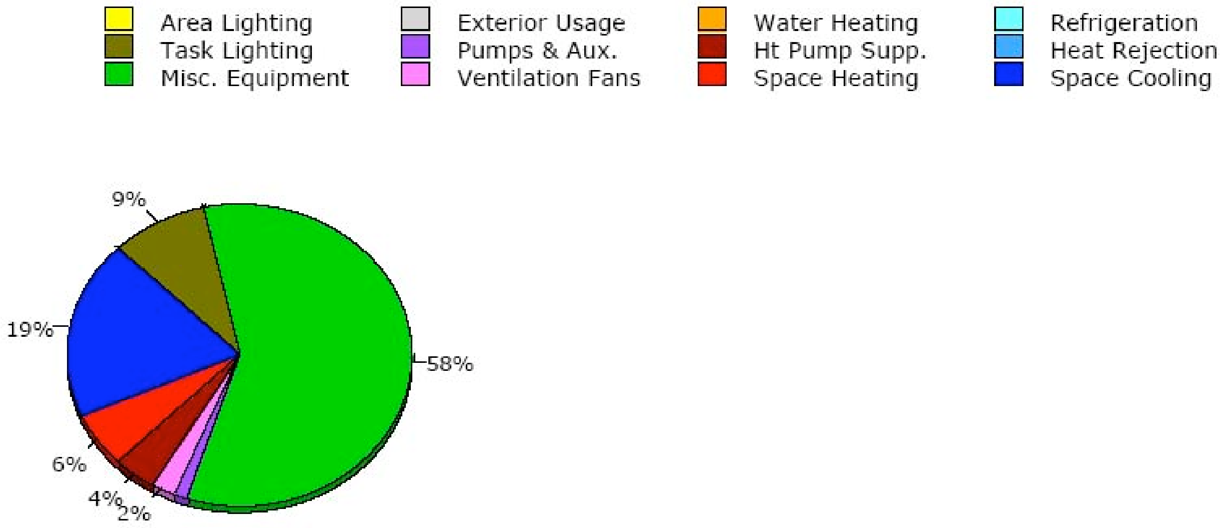


Figure 3-32: Annual peak electricity demand by enduse shows that the geothermal heat pump furnace accounts for 3/4th of the annual peak electricity demand by enduse.

Figure 3-32: Annual peak electricity demand by enduse.

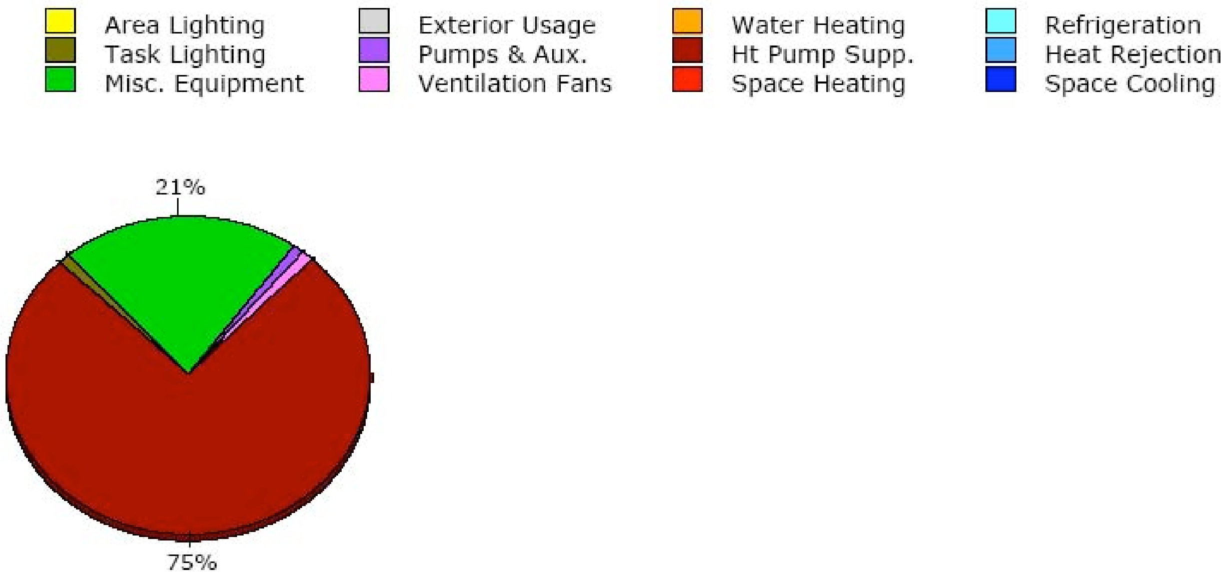


Figure 3-33: Electric demand shows the amount of electricity demanded by the various elements in the zero energy garage apartment on a monthly basis. It is unclear why the software does not account for heating load in the month of November.

Figure 3-33: Electric demand.

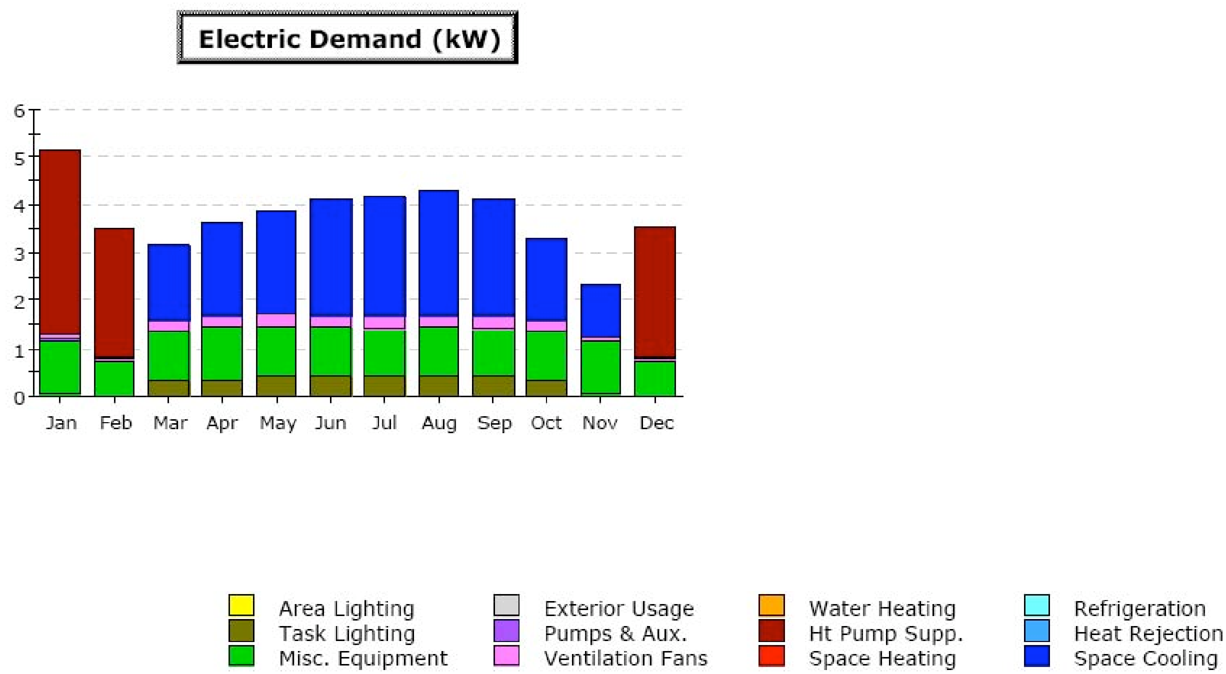
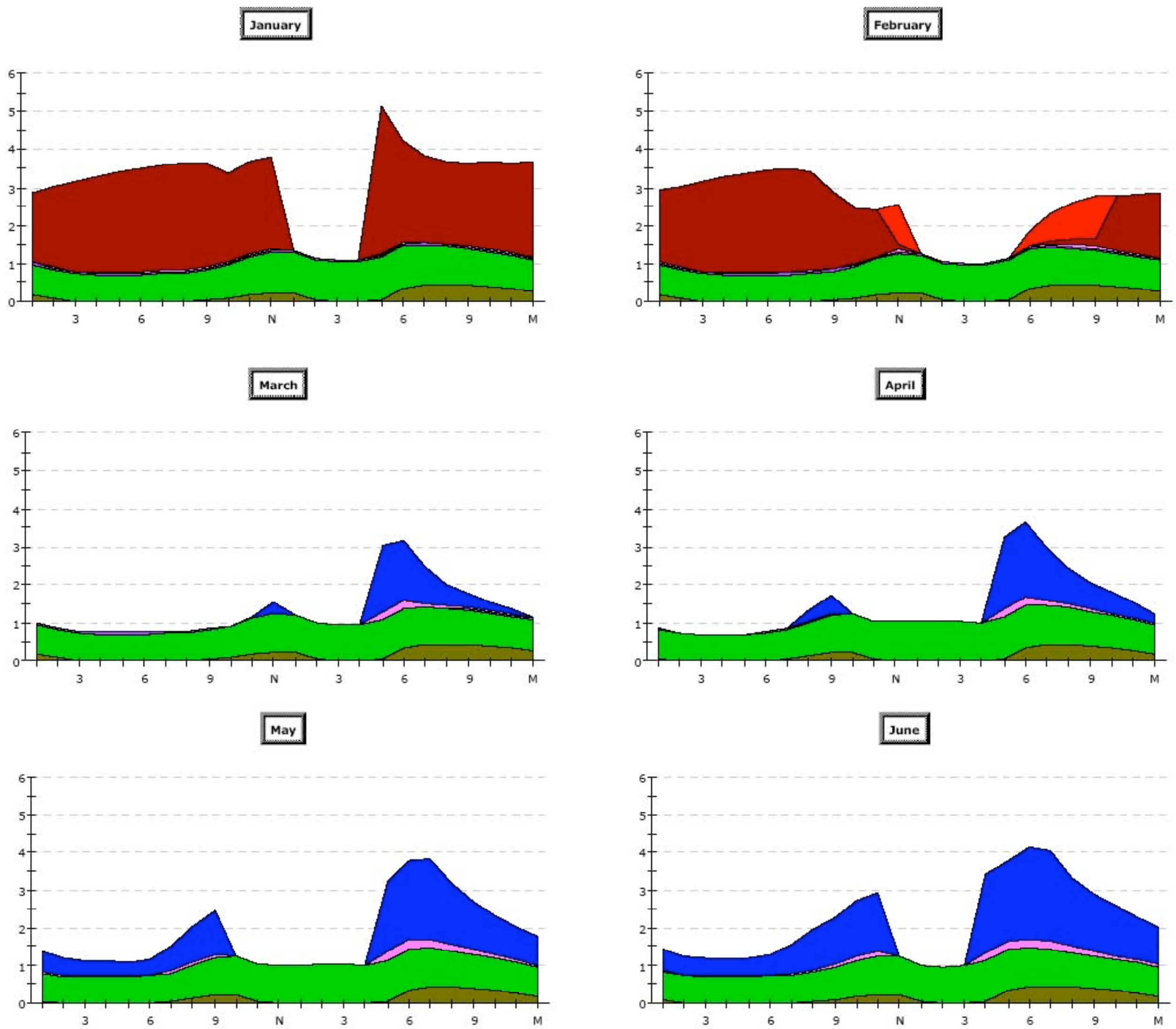


Figure 3-34: Electric loads depicts the loads the solar energy system would need to cater to, and has similar drawbacks as that of *Figure 3-38: Electric demand*.

Figure 3-34: Electric loads in kW.



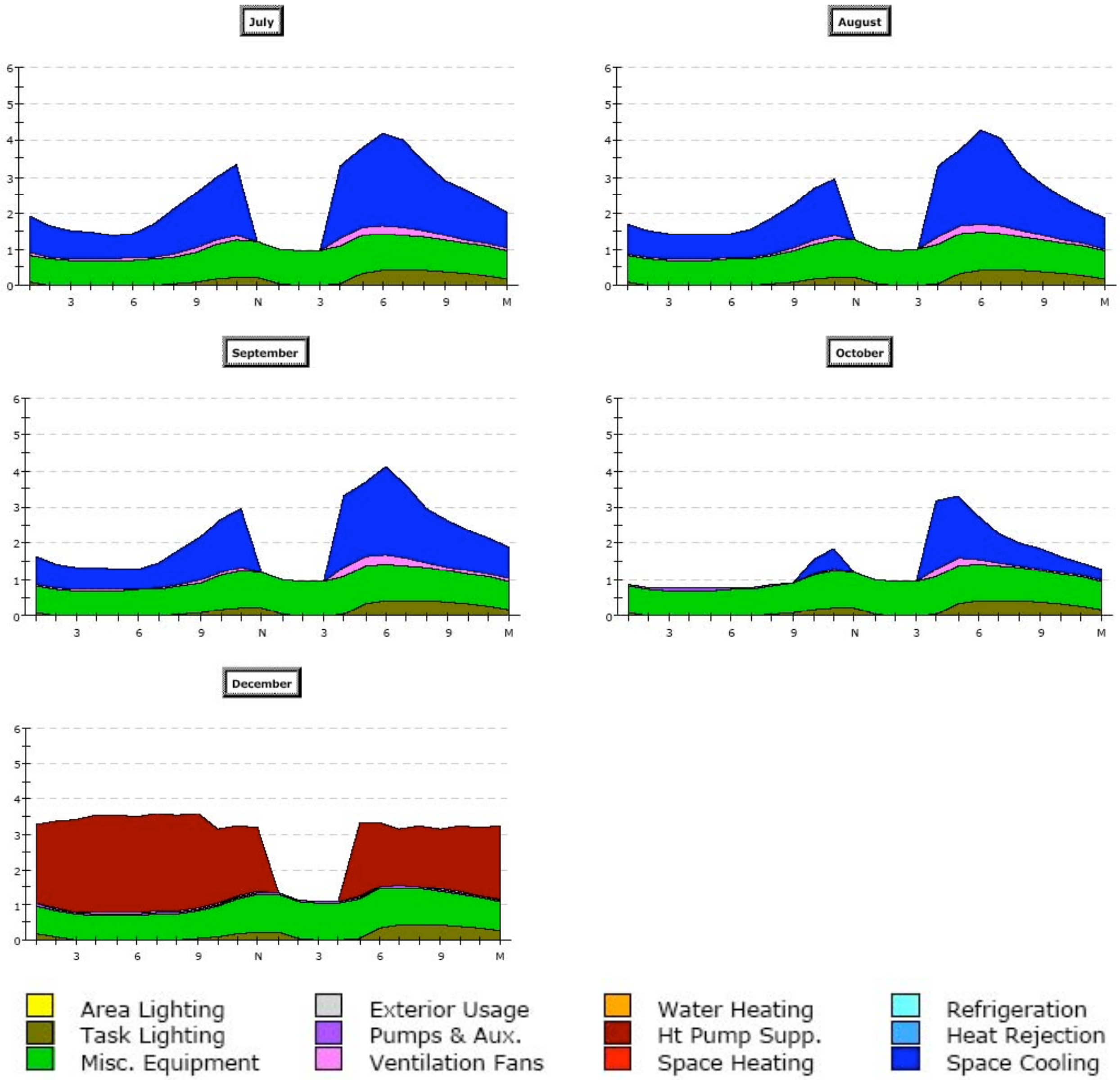
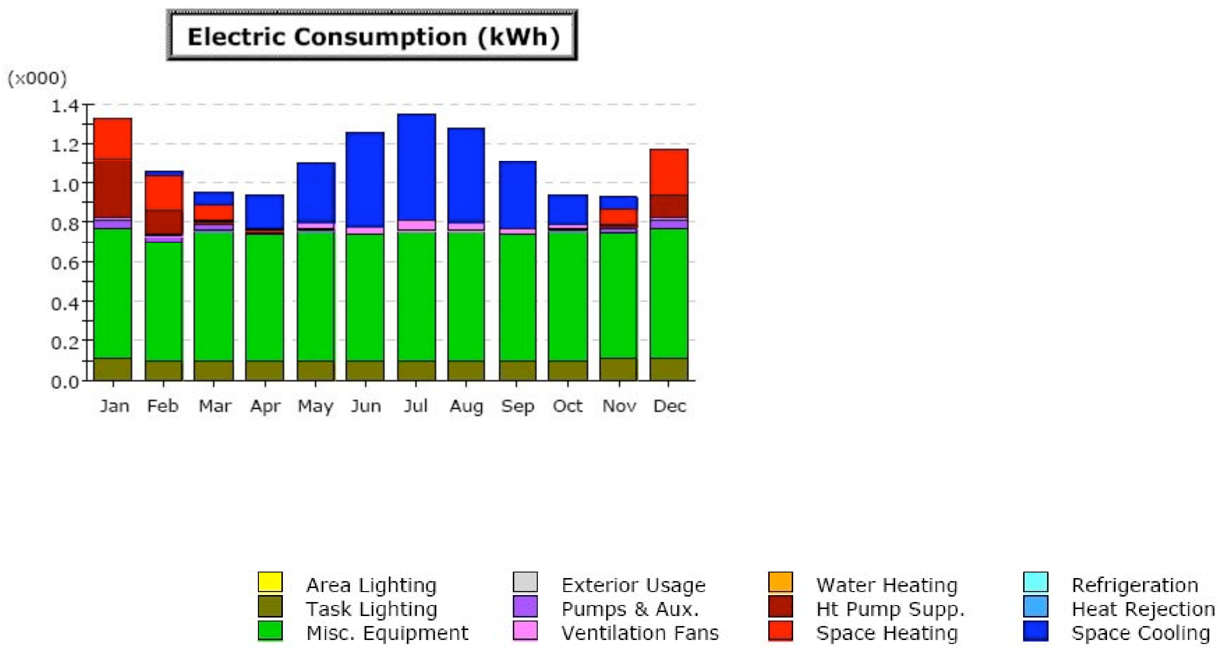

July
August
September
October
December
0
1
2
3
4
5
6
3
6
9
N
3
6
9
M
Area Lighting
Task Lighting
Misc. Equipment
Exterior Usage
Pumps & Aux.
Ventilation Fans
Water Heating
Ht Pump Supp.
Space Heating
Refrigeration
Heat Rejection
Space Cooling

Figure 3-35: Electric consumption in kWh is the most important graph from the eQuest energy performance simulation. It depicts, in kWh, the electric consumption by the zero energy garage apartment throughout the year. As *Figures 3-31*, *3-32 and 3-35* show, miscellaneous equipment and the geothermal heat pump [which provides both heating and cooling] account for a major portion of the electric consumption in kWh. This graph was used to verify whether or not the geothermal system and solar energy system were adequately sized to service the garage apartment to help it reach zero grid energy consumption/ grid energy independence.

Figure 3-35: Electric consumption in kWh.



Summary

Figure 3-25: Annual energy use and *Figure 3-33: Electric demand* were analyzed to compare the results obtained from Energy10 simulation output to that of the eQuest simulation output. According to Energy10 [*Figure 3-25*], the zero energy garage apartment exhibits a 68% reduction in total annual energy use, which is a difference in 34 kBtu/ft^2 between the reference case and the zero energy garage apartment. The total energy use projected by Energy10 for the zero energy garage apartment is 16.8 kBtu/ft^2, as compared to a 50.6 kBtu/ft^2 energy use by the reference case. According to eQuest [*Figure 3-33*], the zero energy garage apartment utilizes under 4 kW energy through 7 months of the year, exceeds a little over 4 kW energy use through 4 months of the year and almost touches 5 kW in the month of January. During months when the energy usage of the garage apartment exceeds energy production by the photovoltaic panels, energy usage must be restricted via techniques such as not using appliances consuming high energy at the same time, etc.

On analyzing the output graphs from both Energy10 and eQuest simulation softwares, data conflict can be observed in annual energy demand for heating and cooling the zero energy garage apartment. Energy10 projects greater heating loads than cooling loads on the geothermal energy system and eQuest projects the opposite. During such conditions of conflict, output data from eQuest was prioritized since the software carries out a much more detailed analysis in comparison to Energy10, which is designed for use during schematic design stages. Even though output results from the simulation softwares may not be accurate, they can definitely be used as part of the study since they help approximate possible future scenarios of energy demand, which could not be computed otherwise. The aim of conducting energy modeling was to understand the possible energy performance scenarios of the zero energy garage apartment, and to cross-check on the geothermal and solar energy system sizing. This aim was definitely achieved through output graphs from both softwares, as they helped visualize and quantify the garage apartment’s energy needs and performance.

Section 3: Renewable Energy Systems

Mechanical systems and the electricity needed for running appliances and fixtures are the most energy expending elements in a building. They are important because they are central to maintaining a comfortable and healthy internal environment. Hence, renewable energy has been used to power mechanical systems and electricity-supplying elements in the zero energy garage apartment in the hope of drastically reducing fossil fuel energy consumption and taking the clients closer to energy security. In the zero energy garage apartment, geothermal energy is used to run the HVAC system and solar energy is used to satisfy all other electrical needs, including that of powering the geothermal system furnace. Since the geothermal energy system provides supplemental hot water throughout the year, water heating has not been separately accounted for. Both the renewable energy systems used in the design of the zero energy garage apartment are elaborately explained in the following pages.

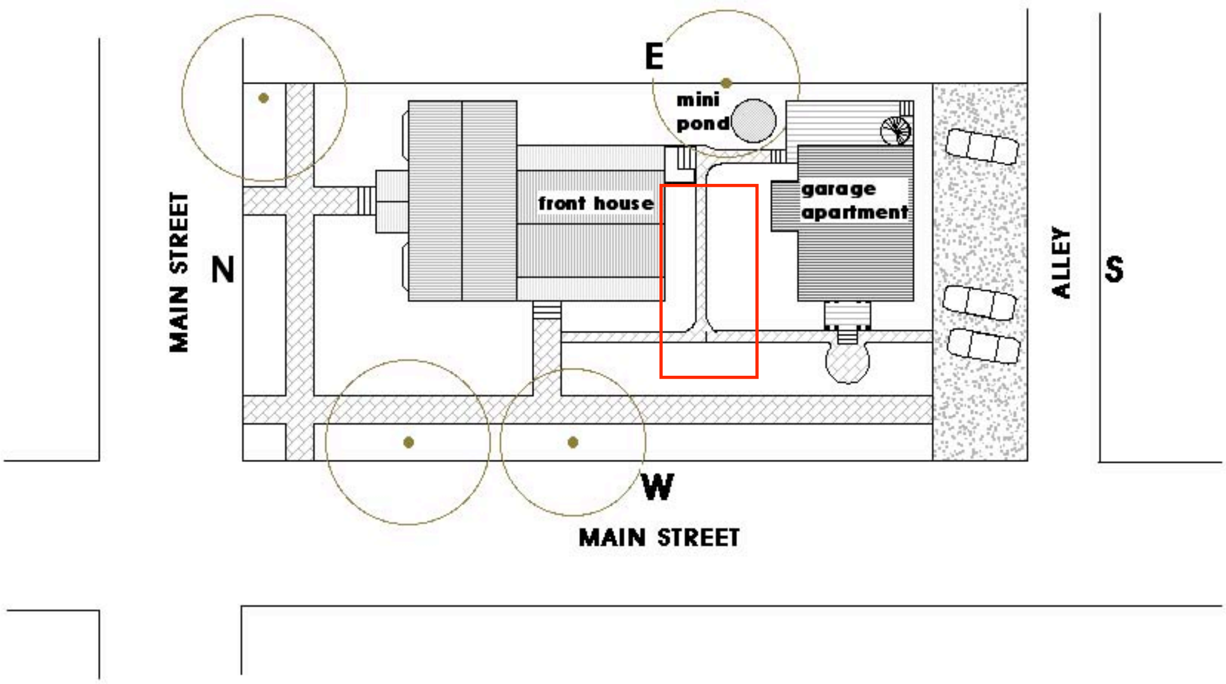
Geothermal Energy System

A geothermal system/ ground-source heat pump is a heating and cooling system that exchanges heat with the earth rather than outdoor air. Below the frost line, the earth is at a constant temperature throughout the year. Heat transfer occurs from a hot body to a cold body, and by using this principle, a ground source heat pump absorbs heat from the ground and uses it to warm the air in a building during winter months, as seen in *Figure 3-37: Heating operation of geothermal heat pump*. This process is reversed in summer months when the pump takes the heat from the building and transfers it back to the ground, as seen in *Figure 3-38: Cooling operation of geothermal heat pump*. The geothermal energy system can reduce greenhouse gas emissions by more than two-thirds, compared to systems that use fossil fuel energy. The system also provides supplemental hot water and room heating temperatures that range well over 100 ^{0}F. The furnace of the geothermal energy system is 4 times as efficient as a gas furnace.[49] Electricity required to run the geothermal system furnace will be supplied by the building integrated photovoltaic energy system. *Figure 3-36: Geothermal piping location for the zero energy garage*

[49] Envision Series. July 2006. Retrieved January 15, 2007, from WaterFurnace: http://waterfurnace.com/marketing/brochures/pdf/WF1585.pdf

apartment shows the area on the property where the geothermal piping would be installed. Since space availability is not a concern on this property, horizontal piping is proposed to be installed for the zero energy garage apartment.

Figure 3-36: Geothermal piping location for the zero energy garage apartment.



Benefits: The geothermal system is generally 2.5 times to 4 times more efficient than other types of air conditioning systems. There are no fluctuations in temperature. The geothermal system does not produce any odor and is hence perfect for people who are sensitive to poor air quality. Unlike other air conditioning systems there is no outdoor unit associated with the geothermal system and hence no weather-related maintenance is required. The system also does not consist of any flues or chimneys. In summary, the geothermal system for this zero energy garage apartment is environmentally responsible since: it does not involve any burning of fossil fuels; it drastically reduces greenhouse gas emissions, and; it completely eliminates the heating system as a potential source of carbon monoxide fumes.[50] *Table 3-3: Heating system comparison*

---

[50] Envision Series. July 2006. Retrieved January 15, 2007, from WaterFurnace: http://waterfurnace.com/marketing/brochures/pdf/WF1585.pdf

compares the geothermal system performance against other combustion based systems and non-combustion heat pumps.

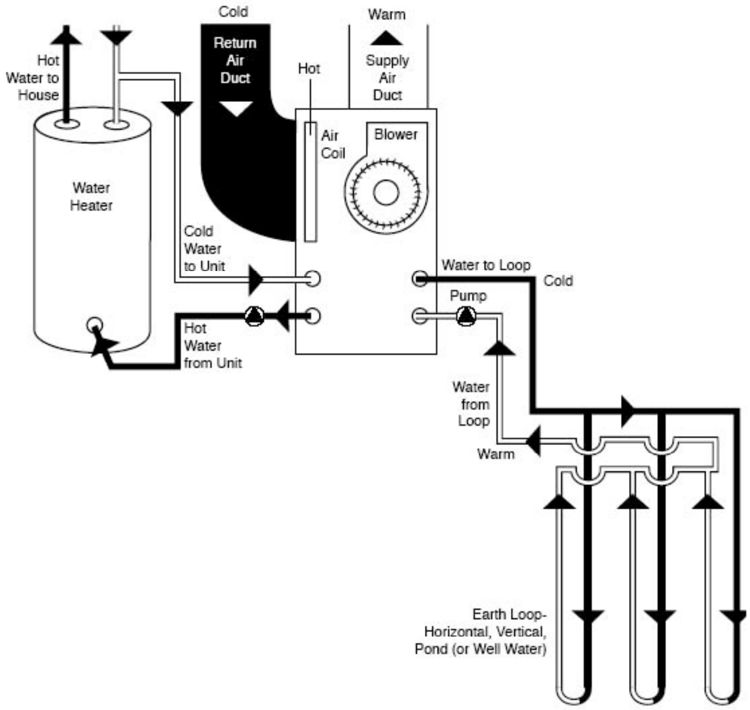
Table 3-3: Heating system comparison.

Heating system	Safety	Installation cost	Operating cost	Maintenance cost	Lifecycle cost
Combustion based	a concern	moderate	moderate	high	moderate
Non- combustion heat pump	excellent	moderate	moderate	moderate	moderate
GeoExchange	excellent	high	low	low	low

(Source: Comparing Heating Systems. (n.d.). Retrieved February 10, 2006, from Alliant Energy: http://www.alliantenergygeothermal.com/stellent2/groups/public/documents/pub/geo_001410.pdf)

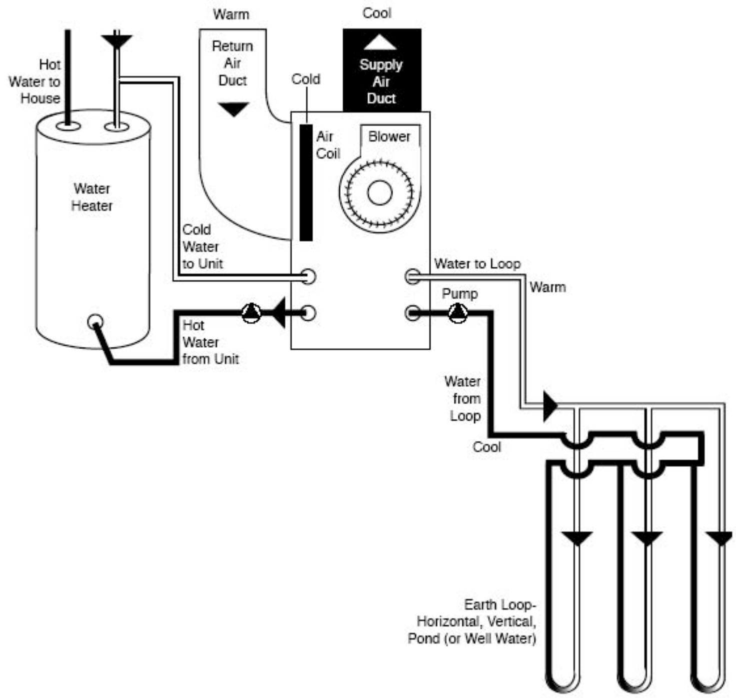
Working: *Figures 3-37: Heating operation of geothermal heat pump* and *3-38: Cooling operation of geothermal heat pump* illustrate the working of the geothermal system proposed for the zero energy garage apartment, as described earlier.

Figure 3-37: Heating operation of geothermal heat pump.



(Source: Homes Built with M2 Panels. (n.d.). Retrieved February 1, 2007, from Allan A Teske: http://allanteske.com/architect_sustainable_design.html)

Figure 3-38: Cooling operation of geothermal heat pump.

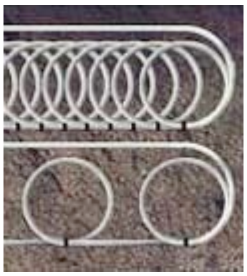


(Source: Homes Built with M2 Panels. (n.d.). Retrieved February 1, 2007, from Allan A Teske: http://allanteske.com/architect_sustainable_design.html)

Components: The closed loop piping system designed for the zero energy garage apartment consists of the following components:

Ground loop circuit: This is comprised of underground piping loops that will be horizontally positioned adjacent to the zero energy garage apartment. Horizontal pipes are less expensive to lay compared to vertical ones. The type of pipes that are proposed to be installed are called compact slinky coils. These coils concentrate heat transfer surface into a smaller volume, require less land area, shorter trenching and are hence highly recommended for residential applications. The compact slinky [*Figure 3-39: Slinky coil pipe system*] will reduce the length of the trench by two-thirds[19]. The trenches for containing the pipes will be dug to a depth of 3-5 feet. The pipes, which will be made of polyethylene and are the same type used for cross-country natural gas lines, do not degrade, corrode or breakdown in ground or water contact.[51] The ground loops are typically joined by thermal fusion [attachment by heat application] and hence minimize the chances of any refrigerant leakage. The Carlson Heating & AC LLC company [based in Clay Center, Kansas] who have been chosen as contactors for the geothermal system design and installation for the zero energy garage apartment, assign a 50 year guarantee for the piping system (Carlson, Bob, personal phone conversation, December 7, 2006).

Figure 3-39: Slinky coil pipe system.



(Source: How It Works: Closed Loop Systems. (n.d.). Retrieved February 1, 2007, from Alliant Energy: http://www.alliantenergygeothermal.com/stellent2/groups/public/documents/pub/geo_how_001212.hcsp)

Refrigerant circuit: R410a is an environment friendly, highly efficient, non-ozone depleting refrigerant and is proposed to be used in the geothermal system. An Envision [ENERGY STAR®] furnace that delivers heating or cooling by generating four units of energy from one unit of electricity is also proposed to be used. Electricity for the furnace will be supplied by the photovoltaic energy system. The Envision water furnace has an efficiency rating of 500%, compared to the most efficient gas furnace, which rates 94%.[52] The water furnace is

---

[51] Geothermal: Bringing Comfort To Your World. (n.d.). Retrieved February 1, 2007, from Alliant Energy: http://www.alliantenergygeothermal.com/stellent2/groups/public/documents/pub/geo_001408.pdf

[52] Owner's Manual. (n.d.). Retrieved March 28, 2007, from WaterFurnace: http://secure.waterfurnace.com/docs/FB507406666/ownersmanuals/OM2006.pdf

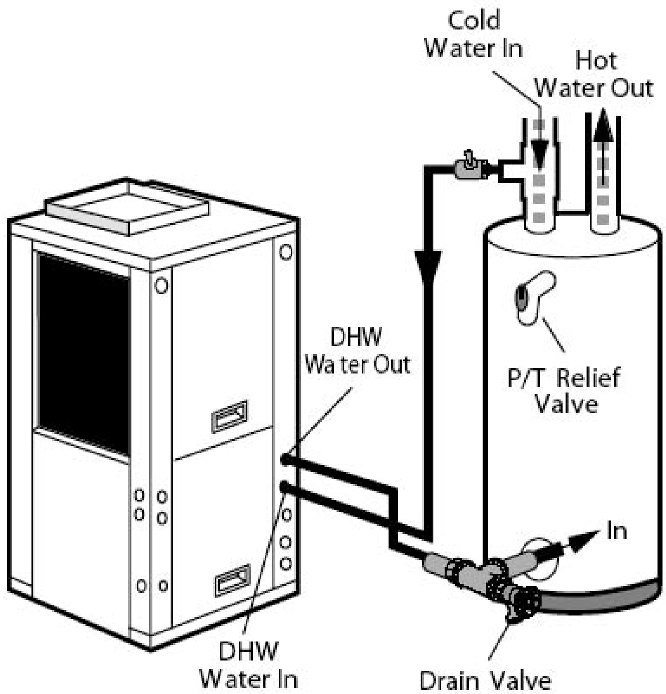
equipped with provisions that indicate system status and fault alerts to the clients via a thermostat.

Hot water circuit: As part of the refrigerant circuit is also a unit called a desuperheater [*Figure 3-40: Desuperheater*] that is a small refrigerant-to-water heat exchanger. It heats water with energy that would otherwise have been given up by the heat pump's condenser. The amount of hot water generated is a function of the model and run time of the geothermal unit. On very hot days and cold days, the hot water generator could produce more hot water than is required for the apartment due to the long run times of the unit.[53] On milder days when the unit has short duty cycles, either the geothermal system has to be kept in operation to generate enough hot water, or electrical energy can be used to maintain the desired temperature in the water heater. A single tank desuperheater is proposed to be installed in the zero energy garage apartment.

---

[53] What It Is: Equipment. (n.d.). Retrieved February 1, 2007, from Alliant Energy: http://www.alliantenergygeothermal.com/stellent2/groups/public/documents/pub/geo_wha_001204.hcsp

Figure 3-40: Desuperheater.



(Source: Homes Built with M2 Panels. (n.d.). Retrieved February 1, 2007, from Allan A Teske: http://allanteske.com/architect_sustainable_design.html)

Air circuit: This will be comprised of ducts that will supply air throughout the conditioned space of the zero energy garage apartment. Other components of the geothermal system include an electronic thermostat, bath venting fan and dryer vent.[54]

System cost: The total installation cost for the geothermal system projected by Carlson Heating & AC LLC amounts up to $6,603 inclusive of taxes and exclusive of tax rebates (Carlson, Bob, personal communication, November 9, 2006). The system is designed to condition the entire second floor unit of the zero energy garage apartment including the staircase block. The conditioned area on the 2nd floor/ apartment level totals up to 680 sq.ft. The

[54] How It Works: Geothermal Concepts. (n.d.). Retrieved February 1, 2007, from Alliant Energy: http://www.alliantenergygeothermal.com/stellent2/groups/public/documents/pub/geo_how_001211.hcsp

geothermal system is also designed to provide the necessary HVAC requirements for the 1st floor/ garage level in case it is converted to a dwelling unit in the future.

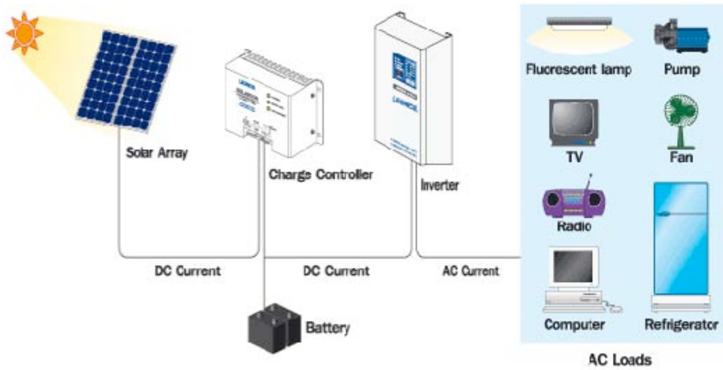
Downside: Installing the geothermal system demands higher upfront costs compared to an equivalent fossil fuel demanding system. However, since the estimated pay-back period for the system is between 2-5 years and the guarantee period lasts 50 years (Carlson, Bob, personal communication, November 9, 2006), the geothermal energy system is an extremely viable option.

Building Integrated Photovoltaic Solar Energy System

Solar technologies convert radiation emitted by the sun into useful electrical energy. This is done by the means of photovoltaic cells or solar cells, which are a non-mechanical device made from silicon alloys. Once the photovoltaic modules convert sunlight into electricity, wires conduct the electricity into a battery, where it is stored until needed. This battery is expected to store energy for a day after which they will require to be recharged. In the zero energy garage apartment, 1 battery will be included as part of the grid-connected solar energy system to store energy. On the way to the battery, the electrical current passes through a controller (regulator), which will shut off the flow when the battery becomes full. Electricity, until this stage, is stored in the form of DC [direct current]. Electricity needed to run the geothermal furnace and the appliances is required to be in the form of AC [alternating current]. This conversion is carried out by an inverter. The inverter's AC output powers the circuit breaker box and the common outlets[55] in the zero energy garage apartment. Since conversion from sunlight to electricity is direct, bulky mechanical generator systems are not required. The modular characteristic of photovoltaic energy allows arrays to be installed quickly and in any size required. *Figure 3-41: Roof integrated solar technology* explains the working of a roof integrated solar energy system.

[55] The Basics. (n.d.). Retrieved February 10, 2007, from Advanced Energy Group: http://www.solar4power.com/solar-power-basics.html

Figure 3-41: Roof integrated solar technology.



(Source: Solar Home Systems. (n.d.). Retrieved November 27, 2007, from Sun'nd: http://www.sun-nrg.org/solar_home_systems.htm)

Description and benefits: The conditions that affected the choice of the photovoltaic system for the zero energy garage apartment include those of aesthetics, cost and power generation optimization. Most roof-integrated photovoltaic panels give an industrial, high tech, modern appearance to a structure. The zero energy garage apartment, due to its conformance to the prevalent architectural character on the property, had to be designed in a minimally visually intrusive manner. Amorphous silicon building integrated photovoltaic panels [BIPV] from Unisolar were chosen to be integrated into the roof of the zero energy garage apartment because of their architecturally clean appearance. These photovoltaic panels, called standing seam roof integrated panels not only tap solar energy with high efficiency, but also offset the cost of roofing materials. In addition, many carriage houses from the turn of the last century used standing seam metal roofs and the clients were interested in making this connection to the past. The panels require low maintenance and have been projected by the manufacturing company to function efficiently for a span of 20 years.[56] The UV stabilized polymer encapsulated roofing laminates have a top coat of Tefzel, which is an exceptionally durable clear Teflon that repels

[56] Report on 5 Years Field Study of Amorphous Solar Panels. 2006. Retrieved February 19, 2007, from Solar Voltaic: http://www.solarvoltaic.com/images/doc/solar%20abstract.pdf

environmental pollutants and self-cleans with rain water.[57]

The roof integrated Unisolar panels comprise of Triple Junction solar cells that use a triple-junction approach — which means that it uses three cells stacked on top of each other [to absorb light of different intensities effectively], each of which is tuned to efficiently convert a different portion of the solar spectrum to electricity. Triple Junction solar cells perform optimally under high concentrations of sunlight as well as low light conditions. This was an important factor to be considered to ensure optimum performance in the cloudy winter conditions in Manhattan, Kansas.

Uni-Solar PVL solar cells are made in a roll-to-roll deposition process on a continuous roll of flexible stainless steel metal and not glass. This makes it shatterproof even against hailstorms, which are frequent in this region of Kansas. Amorphous silicon PV materials typically use less than 1% of semi-conductor material that is consumed in Crystalline products. They are manufactured by techniques suitable for mass production and also require substantially less energy to manufacture. The Galvalume steel on which the laminated photovoltaic panels are bonded on, has been approved by UL [Underwriters Laboratories]. In summary, amorphous silicon panels have exhibited good durability, long term stability and favorable long term performance based on years of tests,[58] and are cost-effective power producers. These benefits offered by the roof integrated Unisolar photovoltaic amorphous silicon panels are the main reasons why they were proposed to be used in the zero energy garage apartment.

System design: Advanced Energy Group, a solar power technical advisory company based in Texas, helped design the solar energy system for the zero energy garage apartment. In response to formulating the energy generation capacity of the solar energy system and sizing the system accordingly, electricity demand was calculated. In the zero energy garage apartment, electrical energy is projected to operate the following:

1) Furnace to operate the geothermal energy system.

---

[57] Solar Electric Roofing Systems. (n.d.). Retrieved August 26, 2006, from Uni-Solar: http://www.scsolar.com/UniSolar.html

[58] Report on 5 Years Field Study of Amorphous Solar Panels. 2006. Retrieved February 19, 2007, from Solar Voltaic: http://www.solarvoltaic.com/images/doc/solar%20abstract.pdf

2) Household appliances- central vacuum system, washer, dryer, refrigerator, microwave, laptop computer, lighting appliances, venting fans in bathroom and dryer room, other minor appliances that could be used- for example cell phone charger, etc.

The photovoltaic solar energy system was designed with the aim of satisfying all these electrical energy requirements. The system proposed for the zero energy garage apartment was designed in consultation with the Advanced Energy Group and can be summarized as follows:

1) Area of photovoltaic module mount: roof.
2) Architectural details: The apartment has a roof angle of 30^0 on the south side where solar modules will be mounted. There are no expected means of shade over the photovoltaic modules, but the possibility has been accounted for. Typically, as specified by the Advanced Energy Group, the maximum roof area required for a 1kW system is 175 sq.ft. For a 4kW system , the maximum roof area required is 700 sq.ft [175 x 4] (Uni-Solar, personal communication, August 26, 2006). This requirement has been met by the South facing roof over the 2nd floor/ apartment level that totals up to 560 sq.ft.; and the roof extension over the 1st floor/ garage level that totals up to150 sq.ft. Hence, the total roof area available on the South for the photovoltaic module installation is 710 sq.ft.
3) Product specifications: Manufacturing Company: Unisolar

   Type: Amorphous silicon building integrated standing seam laminate panels.

   Module: PVL 136 [136 watts] (Uni-Solar, personal communication, August 26, 2006).

   Components of photovoltaic system: UV stabilized polymer encapsulated roofing laminates, Bonding adhesive factory installed on the back of the laminate, Weather-proof Quick Connects for easy and accessible wiring.

   Components of solar energy system: Photovoltaic laminate panels, inverter, charge controller, 1 battery with 1 day energy storage capacity, wires, etc. (Uni-Solar, personal communication, August 26, 2006).

Sizing the solar energy system/ Solar sizing: The initial factors for consideration in sizing a solar photovoltaic system involve determining the solar insolation [sun hours] incident per day in Manhattan, Kansas as shown in *Table 3-4: Insolation*. Insolation, or sunlight intensity is measured in equivalent full sun hours. One hour of maximum sunshine received by a solar panel equals one equivalent full sun hour. Even though the sun may be above the horizon for 14 hours a day, this may only result in six hours of equivalent full sun. The reasons include reflection due to a high angle of the sun in relationship to the solar array and the amount of the earth's atmosphere the sunlight needs to pass through. When the sun is straight overhead, light is passing through the least amount of atmosphere. Early or late in the day sunlight is passing through much more of the atmosphere due to the sun’s position in the sky. Because of these factors, the most productive hours of sunlight are from 9:00 a.m. to 3:00 p.m. Before and after these times, power is being produced, but at much lower levels.[59] “Sizing solar panels involves taking into consideration equivalent full sun hour figures per day and averaging them over a given period” (Dekay, 2000, p.249).

Table 3-4: Solar insolation or sun hours/ day.

State	City	High [kWh/sq.m/day]	Low [kWh/sq.m/day]	Average [kWh/sq.m/day]
KS	Manhattan	5.08	3.62	4.57

(Source: Solar Insolation For U. S. Major Cities. (n.d.). Retrieved January 8, 2007, from Advanced Energy Group: http://www.solar4power.com/solar-power-insolation-window.html)

Load calculation: For calculating the total amp hours per day used by all the AC loads in the zero energy garage apartment, a load calculation workform was used, as shown in *Table 3-5: Load calculation workform*. Next, the minimum continuous watt hours needed was calculated, followed by the potential current surge expected. Potential surge is generally calculated as twice the minimum continuous watt hours needed, but for the zero energy garage apartment, the appliances expected to cause the potential surge have been accounted for with respect to their wattage use. The resultant potential surge value is slightly larger than the value obtained from generalized potential surge calculation. All the above data form the fundamentals in calculating the number of solar modules and the type of inverter and batteries required to support the solar energy system. *Table 3-6: Minimum continuous watts needed* is a calculation of the minimum continuous wattage needed for the AC loads that will be required to be run by the inverter. *Table*

[59] Load Calculations. (n.d.). Retrieved August 26, 2006, from Advanced Energy Group: http://www.solar4power.com/solar-power-sizing.html#loads

3-7: Potential surge is a calculation of the expected appliance electrical surge and the resultant total wattage.

Table 3-5: Load calculation workform.

Description of AC loads run by iverter	Watts x	Hours/ week	Watt hour/ week [WH/ Wk]
Refridgerator microwave	1800 [1200+600]	170 [168+2]	205200
Furnace	4000	84	336000
Lighting appliances	400	35	14000
Laptop	65	35	2275
Dryer	3600	0.3	1080
T.V.	75	14	1050
Central vacuum	1040	1	1040
Washer	1800	0.3	540
Cell phone charger	20	3	60
Venting fan	13	3	39
Others	500	3	1500
Total WH/Wk			**563084**
Inverter loss and battery efficiency correction total WH/Wk x 1.25			703855
Inverter DC input voltage/ DC system voltage 5% voltage drop considered			24
Total amp hours/ week used by AC loads (WH/Wk x 1.25) / (total amp hours / week)			29327
Total average amp hours/ day [(WH/Wk x 1.25) / (total amp hours / week)] / 7 days			**4190**

(Source: Load Calculations. (n.d.). Retrieved August 26, 2006, from Advanced Energy Group: http://www.solar4power.com/solar-power-loads.html)

Table 3-6: Minimum continuous watts needed.

Description of AC loads run by iverter	Watts
Refridgerator microwave	1800
Furnace	4000
Lighting appliances	400
Laptop	65
T.V.	75
Cell phone charger	20
Venting fan	13
Total continuous watts	**6373**

(Source: Load Calculations. (n.d.). Retrieved August 26, 2006, from Advanced Energy Group: http://www.solar4power.com/solar-power-loads.html)

Table 3-7: Potential surge.

Expected appliance surge	Watts
Dryer	3600
Washer	1800
Total potential surge	**5400**

(Source: Load Calculations. (n.d.). Retrieved August 26, 2006, from Advanced Energy Group: http://www.solar4power.com/solar-power-loads.html)

From the output graphs generated by the two energy performance softwares showing peak electric demand, total average amp hours/ day value from *Table 3-5* and on consultation with Bob Dolan, the solar energy system consultant, a 4kW solar energy system is designed to be installed on the roof of the zero energy garage apartment.

Inverter sizing: The inverter to be used in the PV system for the zero energy garage apartment has been calculated in the following manner:

Table 3-8: Inverter details.

Specification	Details	
Module manufacturer	Uni-Solar	
Model	PVL-136	
Temperature unit	°F	
Lowest ambient temperature	55	
Highest ambient temperature	75	
Mounting type	Roof	
Solar module summary	STC rating [Pmp]	136 watts DC
	PTC rating	130 watts
	Max. power voltage [Vmp]	33 volts
	Open circuit voltage [Voc]	46.2 volts
	Max. power current [Imp]	4.13 amps
	Voltage temp. coefficient [Voc]	-0.1023 volts/C
Inverter recommended	PV Powered [brand] PVP 4800-240 V [model number].	
Inverter summary	DC input: Max. power	6000 watts
	Max. VOC	500 volts
	Operating voltage range	200-250 DC
	Max. input current	26.4 amps
	AC output: Max. power	4800 watts
	Nominal voltage	240 volts
	Utility voltage range	214-261 volts
	Max. output current	23 amps
	Overcurrent protection	30 amps
	Nominal frequency	60 Hertz
	General: CEC efficiency rating	96%
	Enclosure	Aluminum NEMA 3R UL 50 Standards
	Dimensions (WxDxH):	15" x 7.5" x 21.75"
	Weight	135 lbs.
	Cooling	Natural Convection
	Warranty	10 Years
	Complies	UL Listed UL 1741, IEEE 519, IEEE 929, NEC 690 Standards

(Source: Inverter Selection. (n.d.). Retrieved August 26, 2006, from Advanced Energy Group: http://www.solar4power.com/solar-power-sizing.html#loads; PVP 4800. (n.d.). Retrieved August 26, 2006, from PVPowered: http://www.pvpowered.com/inverter_pvp4800.php)

Table 3-9: Inverter specification.

Module	Min String	Max String	Min PTC Watts	Max PTC Watts	Max Total Module
PVP 4800-240V	7	10	2600 Watts	5850 Watts	45

(Source: Inverter Selection. (n.d.). Retrieved August 26, 2006, from Advanced Energy Group: http://www.solar4power.com/solar-power-sizing.html#loads; PVP 4800. (n.d.). Retrieved August 26, 2006, from PVPowered: http://www.pvpowered.com/inverter_pvp4800.php)

Battery sizing: Although the zero energy garage apartment is a stand alone, grid-connected system, one battery has been optionally included as part of the design of the solar energy system to provide backup power storage in case of low sun incidence on the photovoltaic panels. *Table 3-10* represents the battery sizing workform recommended by the Advanced Energy Group.

Table 3-10: PVL product specifications- electrical specifications.

Performance	Per cell	PVL-136
Rated power [watts]	6.2	136
Nominal operating voltage	/	24
Operating Voltage [volts]	1.5	33
Operating Current [amps]	4.13	4.13
Open-Circuit Voltage [volts] 25° C	2.1	46.2
Open-Circuit Voltage [Volts] 10°C&1250W/m^2	2.39	52.7
Short-Circuit Current [amps]	5.1	5.1
Short-Circuit Current [amps] 75°C and 1250 W/m^2	6.7	6.7
Fuse and Blocking Diode Rating [Amps]	8	8

(Source: Battery Size Workform. (n.d.). Retrieved August 26, 2006, from Advanced Energy Group: http://www.solar4power.com/solar-power-battery_form.html)

Cost: As projected by Advanced Energy Group, the cost of the solar energy system proposed to be installed in the zero energy garage apartment is as follows:

Price per photovoltaic module: $699 per module

Total cost of photovoltaic roof laminate panels: $13,980 (Uni-Solar, personal phone conversation, September 7, 2006).

Inverter: $2,250 (Uni-Solar, personal phone conversation, September 7, 2006).

1 Battery for storing energy for 1 day: $585 (Uni-Solar, personal phone conversation, September 7, 2006).
Miscellaneous costs [wires, installation, etc]: $3,185 (Advanced Energy Group, personal communication, September 7, 2006).
Total installation cost for 4kW system exclusive of tax credits: $20,000 (Advanced Energy Group, personal communication, September 7, 2006).

Downside: Extremely cloudy winter days stretched continuously for over a few days may result in appliance use restriction.

Zero Energy

'Section 3: Renewable Energy Systems' shows that the geothermal energy system has been sized adequately to provide the heating, cooling and hot water needs of not only the 2^{nd} floor/ apartment level of the zero energy garage apartment, but also the 1^{st} floor/ garage level when it will possibly be converted to a dwelling unit in the future. The solar energy system is sized with a capacity of generating 4kW energy per day, which covers all the electrical needs of the zero energy garage apartment. Both the target energy goals were achieved by analyzing output data from the building energy performance simulations and via constant interaction with the respective energy consultants. The goal of achieving 'zero energy' centers around the principles of energy generation and energy conservation. 100% energy generation is achieved in this thesis project by the geothermal energy and solar energy systems. Energy conservation strategies are designed to reduce energy loads on the two energy generation systems. Passive solar strategies are used in the design of the zero energy garage apartment to help reduce the heating and cooling loads. The byproduct of the geothermal energy system operation, hot water, is used in the zero energy garage apartment to satisfy the daily needs of the client. Daylighting strategies that not only help save light energy consumption, but also help generate adequate winter solar gain are used to reduce heating loads. Rainwater and snowmelt conservation is used to satisfy site irrigation needs. Energy conservation is also achieved in this thesis project through preventive strategies. For example, glazing area has been strategically minimized [and maximized] depending on their climatic responses; and an aluminum overhang has been designed strategically to prevent summer solar gain. To reduce the environmental impact of the zero energy garage apartment, a smaller building footprint and eco-friendly building materials have been used. Building materials are discussed in detail under ‘Section 4: Materials’ of this chapter.

With the goal of energy generation met and that of energy conservation maximized, the garage apartment is expected to function as a zero energy garage apartment, once built. Proof of achieving zero energy can only be obtained from well-documented future energy bills. There exists a post-construction possibility that some unforeseen minor adjustments in the building could be required to be made in order to increase its efficiency. In summary, the ultimate proof of ‘zero energy’ can be obtained only via the built garage apartment’s utility bills throughout the year, over the ages.

Section 4: Materials

Building materials and interior finishes are a critical part of the design process since they have the power to reduce the entire building's environmental impact as well as provide a healthy indoor environment. On research and analysis for choosing the most appropriate materials for the zero energy garage apartment, a material choice framework was established. This framework revolves around the fundamental requirement, put forth by LEED, of choosing materials that are manufactured within a 500 mile radius from the site of construction. The 4 main categories of the material choice framework are using:

1) Products made from environmentally attractive materials: These include products/ materials that can be salvaged from the surrounding areas. Care is taken, however, to avoid salvaged materials that negatively impact the indoor air quality. Products that contain post-consumer, post-industrial and agricultural waste content were also decided to be used. Other naturally or minimally processed products that are either certified or rapidly renewable were decided to be used.
2) Products that are green because of what isn't there: This category mostly includes products that reduce material use. It also includes using alternatives to products that carry heavy environmental impacts. For example, products containing ozone-depleting substances, PVC, polycarbonate and preservative-treated wood were avoided.
3) Products that reduce environmental impacts during construction and operation: These are the products that help conserve energy and water; and help prevent pollution or reduce waste. For example, products that exhibit good durability and require low maintenance, water conserving toilets, showerheads and faucet aerators, etc.
4) Products that contribute to a safe, healthy indoor environment: This includes products with no off gassing and products that don't release significant pollutants into the building, among others.[60]

---

[60] 2001. *Building With Vision.* Volume 2. Watershed Media.

Table 3-11: Material palette for zero energy garage apartment summarizes the material palette used in the zero energy garage apartment. Every material/ product is assigned a ‘reference number’, which can be used to obtain detail information about the product from the ‘material details’ section listed below the table.

Table 3-11: Material palette for zero energy garage apartment.

Reference number	Elements	Material	Application	Finish	Color	Brand	Manufacturing plant location
EN1	**Envelope**	SIP	Structure	Drywall, paint	ref: Finishes	Extreme Panel Technologies	Cottonwood, Minnesota
WI1	**Windows**	Aluminum, glass,	2nd floor, garage	Original	Original	Pella Windows and Doors	Story City, Iowa
DO1	**Doors**	Aluminum,glass,polystyrene insulated	Storm doors	Original aluminum, glass	Original	Pella Window and Doors	Sioux Center, Iowa
		Duracast	Inner- Entrance doors	Original	To match fibercement siding	Pella Window and Doors	Wylie, Texas
		Aluminum,glass,polystyrene insulated	Garage Door	Original aluminum	Original	Ankmar LLC	Kansas City, Missouri
				Frosted glass	Original	Ankmar LLC	Kansas City, Missouri
RO1	**Roofing**	Aluminum panels	Roof, some siding	Original	Original	Metal Sales Manufacturing Corp	Independence, Missouri
SI1	**Siding**	Fibercement	Almost entire exterior	Original	To match front house	James Hardi, Inc.	Waxahachie, Texas
RO1		Aluminum	Part side on North	Original	Original	Metal Sales Manufacturing Corp	Independence, Missouri
SI1	**Decking**	Fibercement	East, West	To match fibercement siding	To match fibercement siding	James Hardi, Inc.	Waxahachie, Texas
CO1	**Flooring**	Concrete	Garage	Coated, polished	Charcoal	N/A	Project site
CO1		Concrete	2nd floor	Polished	To match AL-3 Enviroglas plank	N/A	Project site
FL1		Glass chips	2nd floor	Polished	Glass chips to match AL-3, mirror chips	Enviroglas	Plano, Texas
	Finishes						
FI1	Drywall	Gypsum, paper	Walls, floors, ceilings	1/2" Drywall	Original	Fiberock from USG	Southard, Oklahoma
FI2	Painting	N/A	2nd floor, access area walls and ceilings			Kelly- Moore Paints	Hurst, Texas
			Study room accent wall		Moab red tuscon gold blend 1	Kelly- Moore Paints	Hurst, Texas
			Bedroom		Hand paintedw/ tinted sealer	Kelly- Moore Paints	Hurst, Texas
			Bathroom		Kentucky blue	Kelly- Moore Paints	Hurst, Texas
			All other living areas, access area		Rio grade pecan	Kelly- Moore Paints	Hurst, Texas
			Garage walls, ceiling		Kentucky blue	Kelly- Moore Paints	Hurst, Texas
CO1	Tiles	Concrete	Bathroom wall, kitchen backsplash	Original	Original	N/A	Project site
		Concrete	Bathroom floor	Original	Original	N/A	Project site
CO1	**Fixtures**		**Kitchen**				
		in-situ Concrete/salvaged	Counter top	Polished	Charcoal	N/A	Project site
			Bathroom				
		in-situ Concrete/salvaged	Bathtub/shower cubicle	Polished	Charcoal	N/A	Project site
		in-situ Concrete	Bathtub/shower tile	Matt polish	Gorsuch Grey	N/A	Project site
	Storage	Cabinets	All storage requirements	Stained	Mahogany/Black	Salvaged	Salvaged

Note: Materials, if chosen from manufacturing plant distances beyond 500 miles, were chosen on the basis of either superior quality or non-availability in the 500 mile radius. Salvaged materials like used doors and windows for the garage, cabinets and other materials will be sourced appropriately from the Boulder, Colorado based company called ReSource, which is run by the Center for Resource Conservation. The associated website is www.resourceyard.org/. Other available salvaged materials will be sourced from Straw, Sticks and Bricks as available in time. The associated website is www.strawsticksandbricks.com/. Salvaged materials will also be obtained from other sources for paving purposes, etc., but care will be taken to avoid any materials that are harmful to the environment. Any lumber/ wood used in the project, for example the framing members over the roof of the garage and wood for stairs, will be FSC certified.

Material Details [on basis of reference numbers from Table 3-16]

EN1 Structural Insulated Panels [SIP] [Extreme Panel Technologies]: SIP's, as shown in *Figures 3-42: SIP panel* and *3-43: Sample SIP construction*, are high-performance building panels for foundations, floors, walls and roofs. The recommended R-value for the building envelope for Manhattan, Kansas is 49, as mentioned in the "Building Bioclimatic Analysis and Calculations" section of this Chapter. 8" thick SIP Panels will be used to construct the garage apartment (Extreme Panel Technologies, personal phone conversation, January 15, 2007). The wall and roof SIP panels consist of 7/16" OSB [oriented strand board] on both sides with expanded polystyrene in the middle for insulation. Floor panels consist of 5/8" treated plywood with expanded polystyrene in the middle. Glulam splines will be installed in every floor panel 4' on center for easy installation. For electrical needs, chases or channels will be built into the foam cores of the SIP panels that will work like conduits.[61] In SIP panel construction, plumbing is usually installed in interior walls and floors and not in exterior walls. This mandated the use of an interior wall instead of separators for the bathroom in the garage apartment. For exterior wall vent pipes, chases will be formed in the foam cores. Since the 2nd floor contains a

[61] From the Structural Insulated Panel Association. (n.d.). Retrieved February 4, 2008, from Extreme Panel Technologies: http://www.extremepanel.com/faq_frameset.htm

3” thick thermal mass concrete floor, wooden truss members on the roof of the 1st floor/ garage level will be used for additional structural support. For information on SIP CAD drawings, please visit the ToolBase services website: http://www.toolbase.org/TechInventory/TechCAD.aspx?ContentDetailID=975

Benefits: SIP’s perform better than traditional systems because they are manufactured in a controlled environment characterized by uniform fabrication of components without gaps or air pockets. They offer a relatively high R-value per inch of thickness. SIP’s are designed for efficient field installation that reduce air infiltration, and contain few thermal breaks or penetrations in the panels. Panels can be completely pre-cut to in the manufacturing plant, including rakes and eaves, bevel cuts and openings for windows, doors and skylights. Factory-cut panels help shorten construction time, minimize the potential for mistakes, reduce site scrap and get the building structure enclosed in a shorter amount of time. OSB in the SIP’s does not contain any formaldehyde or urethane binding agent. OSB reduces dependence on old growth lumber since it is made from sustainable, short rotation trees like poplar, etc. It also uses wood chips instead of large cross-sections of wood. Throughout the manufacturing and installation processes, OSB scraps can be used for a variety of applications. It is a strong composite system and both the OSB and insulation exhibit excellent performance under fire. Throughout it’s life, the insulation does not produce any off gassing. The insulation utilizes recyclable materials. Overall, SIP’s exhibit at least 50% savings in heating and cooling costs compared to typical frame constructed buildings.[62]

Drawbacks: Expanded polystyrene is derived from environmentally hazardous chemicals. Polystyrene recycling is viewed, at present, as an uneconomical venture. Few recycling plants are available in the country. However, there is promise for future large scale polystyrene recycling. Plumbing and wiring require advanced planning. The interior finish, although flat, mandates gypsum wall installation to meet fire code requirements.[63]

Maintenance: Possible future insect damage needs to be checked for. Proper siding installation with reduce the maintenance of SIP’s.

---

[62] From the Structural Insulated Panel Association. (n.d.). Retrieved February 4, 2008, from Extreme Panel Technologies: http://www.extremepanel.com/faq_frameset.htm

[63] Ibid.

Durability: If maintained and constructed properly, long-term durability will be achieved. SIP's have proven to perform well against earthquakes and hurricanes in the past.

Figure 3-42: SIP panel.

(Source: Introduction. (n.d.). Retrieved February 4, 2008, from Extreme Panel Technologies: http://www.extremepanel.com/introduction_frameset.htm)

Figure 3-43: Sample SIP construction.

(Source: Introduction. (n.d.). Retrieved February 4, 2008, from Extreme Panel Technologies: http://www.extremepanel.com/introduction_frameset.htm)

WI1 Windows: Although double-hung windows are characteristic of the front house, they are not intended to be duplicated on the garage apartment since they are less energy efficient due to a slight centrally horizontal gap necessitated to make them operational. Hence, Energy Star rated polystyrene insulated casement windows will be used to better the energy saving performance of the windows. U-value is the rate of heat loss of a window assembly. The insulating value is indicated by the R-value, which is the inverse of the U-value. The lower the U-value, the greater a window's resistance to heat flow and the better its insulating value. The recommended U-value for Manhattan, Kansas is U≤0.40. The Solar Heat Gain Co-efficient [SHGC] is the fraction of incident solar radiation admitted through a window. While windows with lower SHGC values reduce summer cooling and overheating, they also reduce free winter solar heat gain. Hence, SHGC for moderate air conditioning requirements has been chosen for windows in the garage apartment, with a value of 0.55. The recommended SHGC value for Manhattan, Kansas is 0.55 or less. The highest SHGC value was chosen for the windows in the garage apartment to help maximize solar heat gain in winter and minimize solar heat gain in summer. Heat loss and gain occur by infiltration through cracks in the window assembly. The lower the air leakage value [AL], the less air will pass through cracks in the assembly. AL is an extremely important factor to increase the performance of the window. The recommended AL for Manhattan, Kansas is 0.30 or less.[64]

The specification for windows used on both floors of the zero energy garage apartment are direction specific. On the West façade, double paned casement windows with Argon gas fill and low-e [low solar gain] coating are proposed to be used. The windows on the West will also be tinted and operable. On the North façade, triple paned casement windows with Argon gas fill and low-e [low solar gain] coating are proposed to be used. The windows on the North will also be operable. On the East façade, double paned casement windows with Argon gas fill and low-e [low solar gain] coating are proposed to be used. The windows on the East will also be operable. On the South façade, double paned casement windows with Argon gas fill and low-e [high solar gain] coating are proposed to be used. The windows on the South will be combination of

---

[64] Wichita, Kansas. (2004). Retrieved March 17, 2007, from Efficient Windows Collaborative: http://www.efficientwindows.org/city_all.cfm?new=N&prodtype=WN&id=71

operable and inoperable. Windows proposed on the South and North façades let in more light compared to those on the East and West facades.

Benefits: High performance windows produce less condensation and reduce fading. They provide for increased light and view, while reducing energy loads of the zero energy garage apartment[65]. Tax credits can be claimed for high-performance windows.

Challenges: High initial costs.

Maintenance: Regular cleaning and checking for damages.

Durability: Long-term (Pella Windows, personal phone conversation, January 15, 2007).

DO1 Doors: Recommended U-value and SHGC co-efficient for Manhattan, Kansas for doors are the same as those of the windows.[66]

Benefits: High-performance doors, like high-perfromance windows produce less condensation and reduce fading. They provide for increased light and view, while reducing energy loads of the zero energy garage apartment. Tax credits can be claimed for high-performance windows.

Challenges: High initial costs.

Maintenance: Regular cleaning and checking for damages.

Durability: Long-term.((Pella Windows, personal phone conversation, January 15, 2007).

RO1 Aluminum roofing/ siding panels: *Figure 3-44: Aluminum roofing panel installation- Top view* and *Figure 3-45: Aluminum roofing/ siding panel installation- North elevation* indicate the areas on the zero energy garage apartment where aluminum roofing and aluminum siding are proposed to be used.

Benefits: Aluminum roofing/ siding panels contain high recycled content. Although metal has a very high embodied energy in its initial production, its ability to be recycled over and over makes it a good choice for energy conservation. According to a recent survey, the recycled content of domestically produced, flat-rolled aluminum products used in commercial construction ranges from 80 to 85 percent. At the end of their useful life, aluminum roofing and

---

[65] Wichita, Kansas. (2004). Retrieved March 17, 2007, from Efficient Windows Collaborative: http://www.efficientwindows.org/city_all.cfm?new=N&prodtype=WN&id=71

[66] Ibid.

siding panels can be repeatedly recycled into roofing and siding products without loss of quality. Producing aluminum from recycled material requires only 5 percent of the energy required to produce aluminum from bauxite ore, and every ton of recycled aluminum saves four tons of bauxite. In addition, using recycled aluminum instead of raw materials reduces air pollution generation by 95 percent, and water pollution by 97 percent (Building With Vision, p. 20).

Challenges: Contains high-embodied energy. (Building With Vision, p. 20).

Maintenance: Requires cleaning every 6 months to prevent corrosion and oxidation. The panels may need to be sanded occasionally as the product ages. They can be occasionally painted on, if required. The panels are susceptible to dents if corrosion not treated, but they can be repaired (Metal Sales Mfg. Corp., personal phone conversation, March 17, 2007).

Durability: The panels are extremely durable. They should be well-maintained to prevent damage in the long run (Building With Vision, p. 20).

Figure 3-44: Aluminum roofing panel installation in the zero energy garage apartment- Top view.

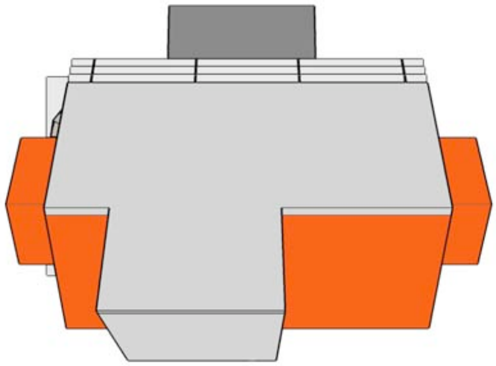


Figure 3-45: Aluminum roofing/ siding panel installation in the zero energy garage apartment- North elevation.

SI1 Fiber-cement siding/decking: Fiber-cement siding, as shown in *Figure 3-46: Fiber-cement siding for the zero energy garage apartment*, is a wood fiber blend with Portland cement to create faux wood siding and roofing materials. It is available in smooth and textural panels, planks and shingles.[67]

[67] Home Siding Products and Styles. (n.d.). Retrieved March 17, 2007, from James Hardie: http://www.jameshardie.com/developer/products_siding.shtml

Benefits: It's relatively low cost and carries a 50-year warranty by the manufacturing company.

Challenges: Wood-fiber raw material used for the product is presently sourced from outside the American continent due to lack of wood species that can tolerate both processing-related heat and the alkalinity of cement. The panels carry high-embodied energy due to energy-intensiveness of cement manufacture (Building With Vision, p. 20). The manufacturing plant is located 526 miles away from the job site, which is greater than the 500 mile radius restriction.

Maintenance: Must be installed carefully to prevent moisture intrusion. (Building With Vision, p. 20).

Durability: The panels exhibit resistant to weather and insect damage. They are also engineered to be rotting, splitting, delaminating, warping, buckling and swelling resistant.[68]

Figure 3-46: Fiber-cement siding for the zero energy garage apartment[28].

Home Siding Products and Styles. (n.d.). Retrieved March 17, 2007, from James Hardie: http://www.jameshardie.com/developer/products_siding.shtml

CO1 Concrete: Concrete used on the project will contain varied levels of blast furnace slag and fly ash. The amount of recycled content will satisfy code requirements. Concrete is also used to construct the foundation for the zero energy garage apartment.

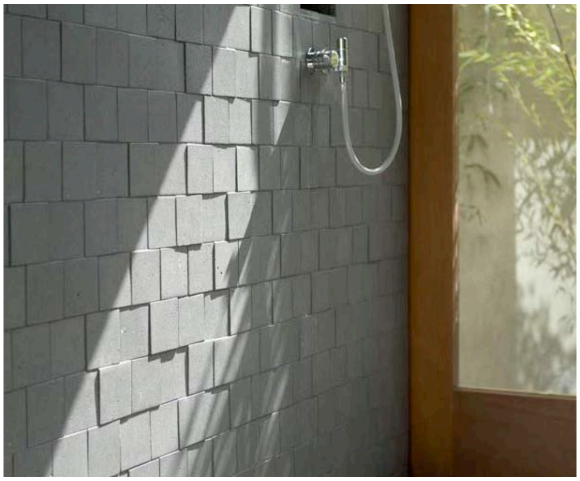
Maintenance: Protection against chipping and floor repolishing may be required in time.

Durability: Concrete ages with beauty and exhibits long-term durability.

---

[68] Home Siding Products and Styles. (n.d.). Retrieved March 17, 2007, from James Hardie: http://www.jameshardie.com/developer/products_siding.shtml

Figure 3-47: Sample concrete bathroom tiles.



(Source: Gallery. (n.d.). Retrieved March 17, 2007, from Syndecrete: http://www.syndecrete.com/main.html)

Figure 3-48: Sample concrete bathtub.

(Source: Gallery. (n.d.). Retrieved March 17, 2007, from Syndecrete: http://www.syndecrete.com/main.html)

Figure 3-49: Sample concrete sink.

(Source: Gallery. (n.d.). Retrieved March 17, 2007, from Syndecrete: http://www.syndecrete.com/main.html)

FL1 Recycled glass chips- 2nd floor, access area: The glass chips will be mixed with stained concrete on the floor for an inexpensive terrazzo-style finish, as shown in *Figure 3-50: 2nd floor/ apartment level flooring*.

Benefits: The glass chips contain 75% recycled glass content and hence helps conserve natural resources. They contribute to a safe, healthy indoor environment. They help save energy and water during regular maintenance. They can be quantified as using regional materials. The glass chips help in construction waste management after the life of the building.

Maintenance: No specification.

Durability: Extremely durable.[69]

[69] EnviroGLAS Product Overview. (n.d.). Retrieved January 17, 2007, from EnviroGLAS: http://www.enviroglasproducts.com/products.asp

Figure 3-50: 2nd floor/ apartment level flooring.

(Source: EnviroGLAS Product Overview. (n.d.). Retrieved January 17, 2007, from EnviroGLAS: http://www.enviroglasproducts.com/products.asp)

FI1 Drywall: Benefits: The USG Fiberock drywall is the only available one in the market that is made from 95% certified, recycled materials. It contains the maximum recycled gypsum content. The panel surface will not delaminate when wet. The panels provide a smooth, paintable surface that can be finished with ceramic tile.

Maintenance: Embossed pattern on back of panel facilitates easy drainage of incidental water.

Durability: The panels don't lose their strength when cut and can be exposed to weather for up to 12 months after application.[70]

FI2 Paint: Benefits: E coat from Kelly-Moore Paints contains 50% Minimum Post Consumer Waste. It is a water-based paint with low odor & low VOC.

Maintenance: It offers simple water clean-up, resists outdoor elements and offers good washability indoors.[71]

Durability: Long term.

[70] Products. (n.d.). Retrieved March 17, 2007, from USG: http://www.usg.com:80/USGSearch/search_results.jsp

[71] Products. 2006. Retrieved March 17, 2007, from Kelly-Moore Paints: http://www.kellymoore.com/site/products

Section 5: Cost Estimation

The following *Table 3-12* illustrates the partial cost estimation break-ups for the zero-energy garage apartment.

Table 3-12: Zero energy garage apartment partial cost estimation beak-up.

Material/ system	Cost $
SIP panels [excluding labor cost]	18,000
Windows, Doors [excluding labor cost]	13,721
Aluminum overhang/ louver [excluding labor cost]	2,000
Aluminum roofing, siding [excluding labor cost]	5,040
Fibercement siding, decking [excluding labor cost]	5,000
Flooring- concrete [excluding labor cost]	4,000
Flooring- EnviroGlas [excluding labor cost]	500
Drywall [excluding labor cost]	1,000
Paint [excluding labor cost]	1,300
Cabinets [excluding labor cost for finishing, if required]	1,000
Geothermal system [inclusive of labor cost]	6,603
Solar energy system [excluding labor cost]	20,000
Total up-front cost [excluding land/ property costs, design costs and construction labor costs]	**78,164**
10% contingencies for unforseen spendings during construction.	**85,980.40**

The prices mentioned in *Table 3-12* for SIP; windows and doors; aluminum roofing and siding; concrete flooring; geothermal system and solar energy system are listed as projected by the respective manufacturing/ installing companies. The prices mentioned for fiber cement siding, decking; Enviroglas flooring; drywall and paint were calculated with respect to the rates per sq.ft mentioned by the respective manufacturing companies. The project cost calculation illustrated in *Table 3-12* does not include land/ property costs, design costs and construction labor costs. A 10% contingency in unforeseen cost escalation during construction of the project has been included in the project cost calculation. All the above-mentioned costs are subject to time and can be expected to change. The material costs listed in *Table 3-12* should not in any way be assumed as a complete material price. Actual costs will vary. If the actual total cost of the project after including construction labor costs and subtracting benefits from tax credits [*Table 3-*

13] is unacceptable for the clients, phased installation of the solar photovoltaic panels can be considered. It should be noted that out of the total tax credits listed below, there exists a maximum cap on the amount of tax credits that can be claimed.

Table 3-13: Federal tax credits available as until December 2007.

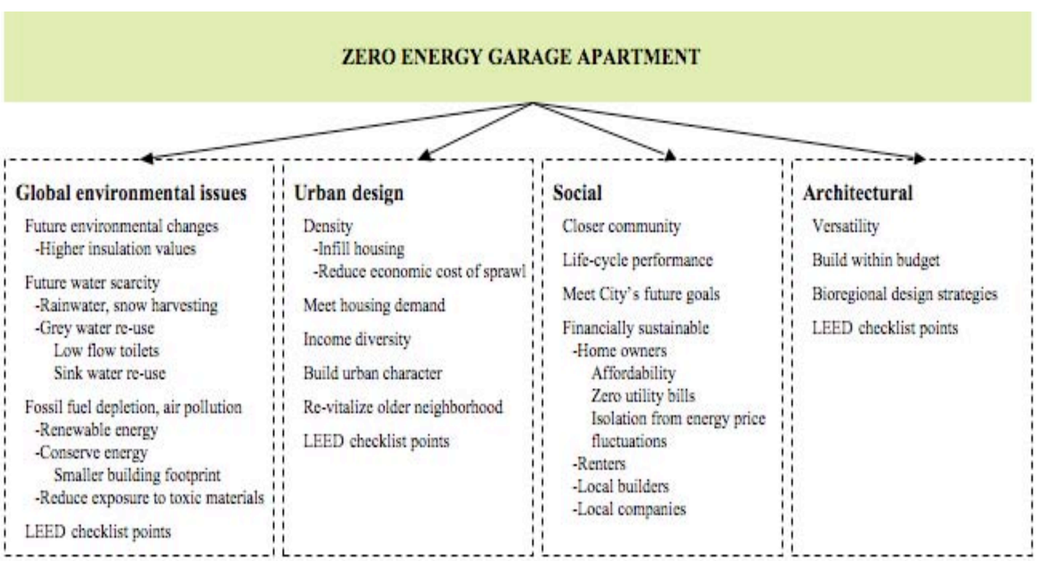
Product category	Product type	Tax credit [$]
Windows, doors	Exterior windows	200
	Exterior doors	500
	Storm door	500
Roofing	Metal roofs	500
Insulation	Insulation	500
HVAC	Geothermal heat pump	300
Solar energy system	Photovoltaic system	2,000
New home	New energy efficient home	2,000
	New energy saving home	1,000
Total available Federal tax credits		**7500**

(Source: Federal Tax Credits for Energy Efficiency. (n.d.). Retrieved April 25, 2007, from Energy Star: http://www.energystar.gov/index.cfm?c=products.pr_tax_credits)

CHAPTER 4 - Conclusion

The ‘zero energy building’ is a relatively new concept amongst the common masses and architects alike. Although a lot of educational sources like the internet and magazines document a variety of information on achieving ‘zero energy’ buildings, much of the information leads the reader to believe that it may either be a utopian concept at the grass roots level, or may be achievable only at a high cost. This thesis has demonstrated, through the design of the zero energy garage apartment, the simplicity involved in achieving such an energy target. The key here is on-site energy generation, building energy conservation and a radical reduction in energy consumption. The zero energy garage apartment designed in this thesis extends beyond technological precision in energy performance to show that such buildings need to be integrated with environmental, urban design and social issues as shown in *Figure 4-1: Zero energy garage apartment design matrix*.

Figure 4-1: Zero energy garage apartment design matrix.



While designing the zero energy garage apartment with the method described in this thesis, drawbacks were encountered at certain instances. Although the producers of the energy modeling softwares used in this thesis say that their products are capable of simulating building performance with near-accurate data generation, in reality this is not so. It was found that these softwares can only be used to make calculated guesses of a building’s energy performance and cannot be used to authenticate it. This drawback can be attributed to the fact that the simulation softwares are still at the early stages of development. Perhaps this will change for the better when concrete proof of achieving true zero energy performance can be established from the analysis of a building’s energy bills over an extended period of time. The results of such real world experiences can then be incorporated into the software design to achieve accurate results.

In the process of designing the zero energy garage apartment, a need for better technology to obtain higher efficiency levels from renewable energy systems was felt. For example, batteries to store the electricity generated from the photovoltaic panels are currently extremely bulky, expensive and toxic to the larger environment. They also face the drawback of losing a high percentage of stored energy over a short period of time. Moreover, the solar energy system itself costs almost 25% of the total cost of the project and hence renders the system inaccessible to the poorer sections of society.

In addition to a need for improvements in the elements of the photovoltaic energy system, there is also a need for advancements in technologies used to make maximum use of the energy generated. For example, hot water generation is a major part of the energy consumption in a residence. With the geothermal energy system generating hot water supplemental to its operation, installing separate systems that generate hot water can be completely eliminated. It would be ideal if similar synergies could be developed in other aspects of the building energy systems.

The Structural Insulated Panels [SIP] proposed for use in the zero energy garage apartment can be highly recommended. Apart from their several environmental and energy conserving benefits, their quick on-site assembly and a relatively affordable price make them a viable option for constructing high performance building envelopes. SIP panel construction is not labor-intensive and does not demand highly skilled labor, which should help to reduce fabrication costs, especially if demand for such systems increased significantly in the future.

Currently, Kansas does not recognize the potential of net metering as part of a more decentralized, and diversified electrical energy grid. Net Metering is a consumer-based renewable energy incentive, which as described by the Energy Policy act of 2005, is a “service to an electric consumer under which electric energy generated by that consumer from an eligible on-site generating facility and delivered to the local distribution facilities may be used to offset electric energy provided by the electric utility to the electric consumer during the applicable billing period".[72] If net metering was permitted in Kansas, the clients for this project could sell excess energy generated by the solar energy system to the utility company. This would greatly improve the economic viability of the zero energy garage apartment and, in turn, might encourage more home owners to build similar high-performance residences.

If built, the zero energy garage apartment could be used as a case in point to encourage the State of Kansas to provide incentives for such environmentally responsible designs. There are no renewable energy tax credits available for a homeowner in Kansas, except those available from the Federal Government. If the State will provide incentives for building high-performance, low-impact buildings like the zero energy garage apartment, it will help people visualize the benefits of building zero energy homes. It will also help eradicate the false notion that environment friendly homes are less affordable.

In the very near future, it is necessary that zero-energy/ low energy consumption buildings be built in large numbers to actually make a measurable difference in the mitigation of global warming and a reduction in the use of non-renewable fossil fuels. To further help reduce human-induced climate change, greater use of renewable energy will lessen non-renewable energy demand and consumption. The resultant isolation of consumers from fluctuating energy costs will lead to a stronger economy. Such isolation will also provide consumers better tolerance from energy grid disruptions and adverse climatic impacts. Some of the worst affected will be the vulnerable groups of people who are socially or economically disadvantaged. It is hence evident, that architecture can play a crucial role in being part of the solutions to mitigate human-induced global climate change and the fossil fuel shortages in the age of peak oil and gas.

Finally, this thesis can be used to launch further analysis to understand the life cycle performance that a zero energy house of the future will demand. Until now, the focus of zero energy buildings has largely been laid on technical specifications. It is important to move further

---

[72] Net Metering. (n.d.). Retrieved January 6, 2007, from Wikipedia: http://www.energystar.gov/index.cfm?c=products.pr_tax_credits)

and begin addressing the other responsibilities of a high performance building than just energy security.

References

Brownell, Blaine. (2005). *Transmaterial: A Catalog of Materials that Redefine our Physical Environment*. (1st ed.). Princeton Architectural Press.

Carmona, Matthew, Heath, Tim, Taner, OC, & Tiesdell Steve. (2003). *Public Places Urban Spaces*. (1st ed.). Architectural Press.

Coates, Gary. Bioregional Design Strategies Lecture Notes.

Davis, Sam. (1997). *The Architecture of Affordable Housing*. (new ed.). University of California Press.

Dean, Angela. (2003). *Green by Design.* (1st ed.). Gibbs Smith, Publisher.

Morley, Michael. (2000). *Building with Structural Insulated Panels (SIPs): Strength and Energy Efficiency Through Structural Panel Construction.* (1st ed.). Taunton.

Roaf, Sue. (2003). *Ecohouse*. (2nd ed.). Architectural Press.

Roberts, Jennifer. (2005). *Redux*. (1st ed.). Gibbs Smith, Publisher.

Ryker, Lori. (2005). *Off the Grid*. (1st ed.). Gibbs Smith, Publisher.

Sassi, Paola. (2006). *Strategies for Sustainable Architecture*. (1st ed.). Taylor & Francis.

Spiegel, Ross & Meadows, Dru. (2006). *Green Building Materials: A Guide to Product Selection and Specification.* (2nd ed.). Wiley Publications.

Stang, Alanna, & Hawthorne, Christopher. (2005). *The Green House: New Directions in Sustainable Architecture*. (1st ed.). Princeton Architectural Press.

(2006). *Green Building: Project Planning and Cost Estimating*. (2nd ed.). R. S. Means Company.

(2006). *The ASHRAE GreenGuide.* (2nd ed.). Butterworth- Heinemann Publishers.

Websites:

How the Science House Works. (n.d.). Retrieved May 27, 2006, from Science Museum of Minnesota: http://www.smm.org/sciencehouse/about/

Compare Materials. (2004). Retrieved June 10, 2006, from Minnesota Building Materials Database: http://www.buildingmaterials.umn.edu/guide1.html

Products. (n.d.). Retrieved on December 25, 2006, from Straw, Sticks & Bricks: http://www.strawsticksandbricks.com/index.php?main_page=products_all

Projects. (n.d.). Retrieved August 26, 2006, from Studio 804: http://www.studio804.com/2008/projects.html

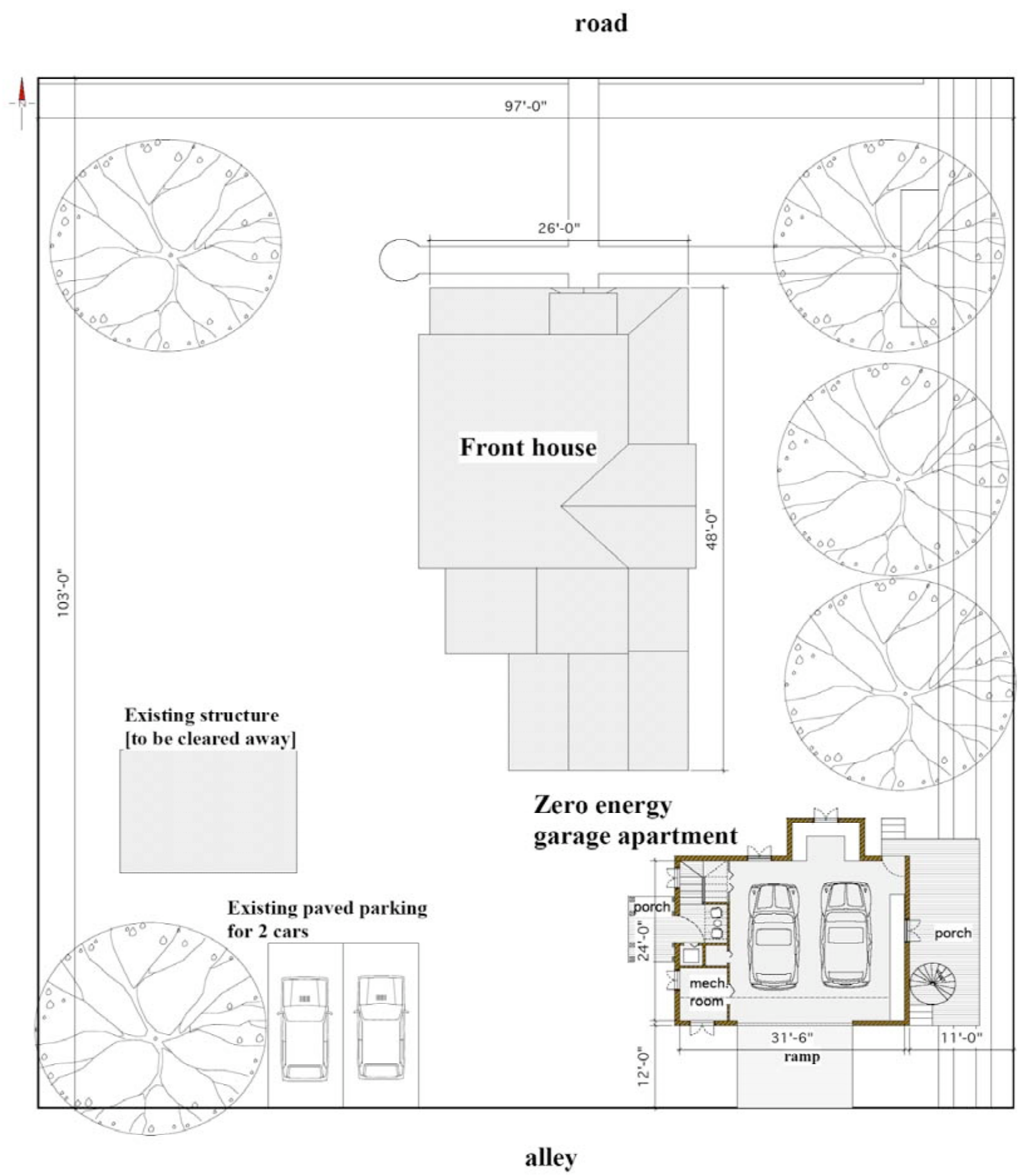
A Sourcebook for Green and Sustainable Building. (n.d.). Retrieved November 19, 2006, from Sustainable Sources: http://www.greenbuilder.com/sourcebook/

Science House: A Resource Center for Educators. (n.d.). Retrieved February 12, 2007, from The Science Museum of Minnesota: http://www.smm.org/sciencehouse/about/

Appendix A - Current status of zero energy garage apartment

Towards the final stages of the design of the zero energy garage apartment, the clients purchased a similar, new historically significant property that is located close to the original property on which the zero energy garage apartment was designed. It was projected that the originally designed property could be sold in the future with the possibility of the clients moving in to the new property. The clients expressed a desire to relocate the garage apartment on to the newly purchased property. The only changes made in the design of the zero energy garage apartment at the new location were those of the surrounding landscape and the color of the exterior siding and decking. The most recent progress was the submittal of new site drawings to the client for laying the plumbing and electrical lines on site. The new site plan is as illustrated in *Figure A-1*.

Figure A-1: Zero energy garage apartment updated site plan.



Appendix B - City requirements and codes

Urban Visual Code and architectural guidelines:

i. For alley garage apartments/ covered parking
ii. There shall only be one alley garage apartment per lot.
iii. The maximum alley garage apartment occupancy is 3 tenants.
iv. The alley garage apartment shall not exceed 1.5 stories.
v. The maximum height of the alley garage apartment shall not exceed 25’-0”.
vi. The alley garage apartment’s height shall not exceed the height of the front house.
vii. The allowable area for the Alley Garage Apartment Footprint is equal to the Maximum Building Footprint [sf] minus the Front House Building Footprint [sf].
viii. The alley garage apartment setback shall be 10’-0”, and carport setback shall be 0’-0”.
ix. The alley garage apartment’s roof pitch must be the same as that of the front house.
x. It is recommended that the alley garage apartment’s roof style be consistent with that of the front house.

Parking:

i. A total area no more than 25 times the lot width.
ii. It is required that each family unit has at least 3 parking spots; and 1 for each bedroom for rental units.
iii. Minimum of 8’-0” width per car stall.
iv. No front yard parking.

Driveways:

i. No driveway shall be wider than 10’-0”.
ii. Each driveway will have at least a 3’-0” setback from the property line and from the house.
iii. The driveway must extend past the back of the house.
iv. If using two-pad driveway the pads shall be a maximum of 3’-0”, and the middle shall be a grass strip[5].

Appendix C - Tables and Figures

Table C-1: Value Matrix Programming Document

VALUES	GOALS	NEEDS	IDEAS	VALUE ASSIGNMENT OF GOAL
HUMAN				
FUNCTIONAL				
General				
	o Please confirm the number of apartments needed and number of people allowed to occupy each one.			**1 apartment, 2 people**
	o Provide an exercise room or space for exercise equipment.		o Provide for an easily accessible mini-exercise room.	4
	o Provide sound proofing between studios.		o Use sound-proofing materials and strategically locate storage spaces between rooms to avoid sound transmission across rooms.	4
	o Provide adequate amount of built-in storage - located where it is most needed.	o Storage for clothes, shoes, coats and other necessities.	o Locate built-in storage cabinets in such a way as to allow easy access.	1
	o Provide a space which has proper provision for technological equipment to enable guests to stay connected to the world.		o Use electronic communication methods and systems, such as internet and telephones.	1
	o Provide a facility that incorporates the proper adjacencies to enable efficiency.		o Design wet areas so that they can share plumbing, etc.	1
	o Provide for privacy requirements of the guests.		o Provide blinds/curtains over windows, provide facilty for do-not-disturb signs, etc.	1

	o Provide even and adequate artificial lighting and daylighting.			1
	o Provide a vending machine.		o Provide the machine at the lobby/gathering space.	4
	o Provide an adequate number of electrical outlets to support laptops, charging cell phones, etc.			1
	o Provide a laundary room.			1
Kitchen	o Provide a large counter space.			**No.** kitchen counter is for minimal use.
	o Provide a separate dining area.			**4.** Maybe a little island or counter if space permits.
	o Provide a refridgerator.			1
	o Provide cabinets for storage.			1
Living Room Area	o Provide a physical seperation between living area and kitchen.		o Provide an opaque/ transparent seperation-wall between kitchen and living areas.	4
	o Provide living room furniture like sofas, coffee table, etc.			3
Bathroom	o Provide separate toilet compartments.	o To allow for more efficient use.	o Provide a seperating opaque wall and a door between toilet and bath area.	1
	o Provide built-in storage.	o To store towels, toiletries, etc.	o Provide a linen closet.	1
	o Provide a small dressing/make-up area.			2
	o Provide a whirlpool tub/ jacuzzi.			2
SOCIAL	o Provide a facility which fosters social interaction.	o For interaction between guests among guests and visitors.	o Provide a small centrally accessible gathering space preferably near the interior entrance.	4
	o Provide a central area for posting of information common to everyone.	o For posting any common legal/security/instructional information.	o Provide a board in a central area accessed by guests constantly.	4
	o Provide a learning, educating environment.	o Increase peoples awareness towards Manhattan's history, etc.	o Provide a small centrally accessible library area and an area that will educate guests about the eco-friendliness of the backhouse.	1
PHYSICAL	o Provide a thermally comfortable environment.			1

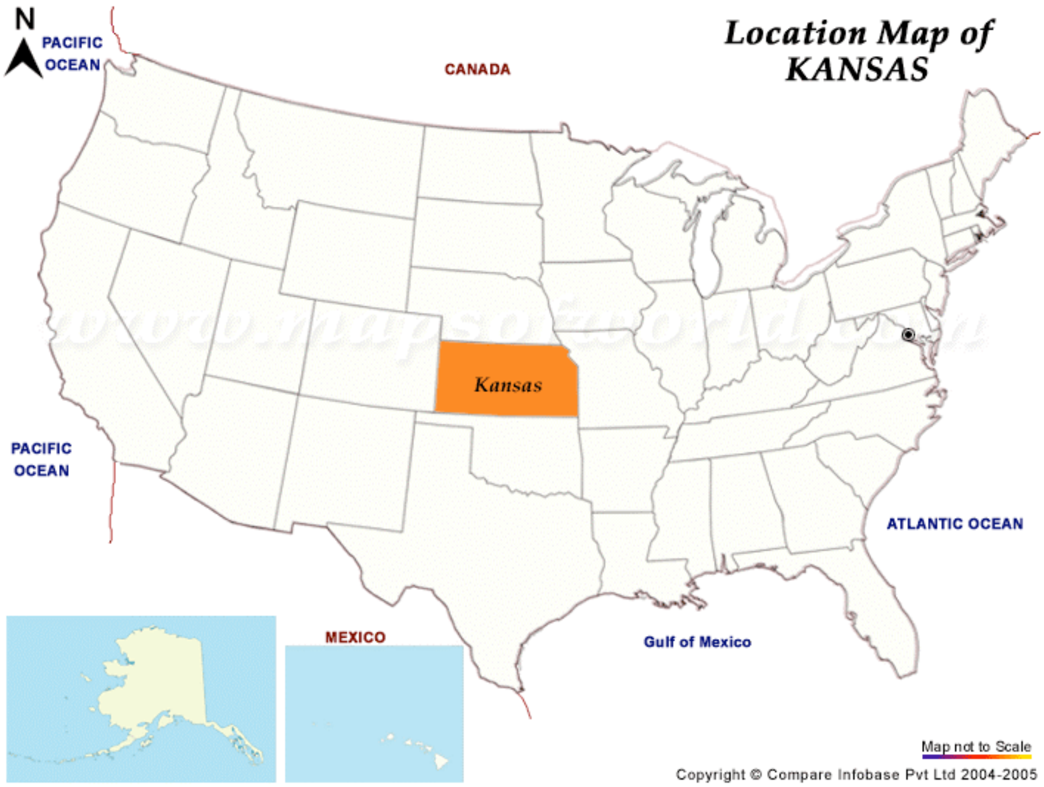
	o Provide ergonomic equipments / furniture.			3
	o Provide comfortable and adequate daylighting.		o Use materials like glass effectively to let in sunlight.	1
	o Provide a facility with a healthful, non-toxic environment.		o Utilize materials with low voc's (volatile organic compounds).	1
PSYCHOLOGICAL	o Provide a facility which encourages a feeling of a connection to nature.		o Use windows to provide views.	1
	o Provide a psychologically pleasing environment.		o Use of psychologically pleasing colors.	1
			o Ensure that all design elements are at human scale.	
			o Ensure that the facility has spaces/areas to relax/unwind.	
	o Improve the perceived safety of guests in the space.		o Place security systems with camera at entrance to the backhouse.	2
	o Provide a facility which incorporates a mixture of privacy / and interaction.		o Design living room areas as areas that allow for interaction with visitors.	1. Bedroom could be optionally closed off. Acoustic seperation not necessary.
	o Provide a facility which can be orderly, efficient, and high performing.		o Implement a simple design strategy.	1
ENVIRONMENTAL				
CLIMATE	o Provide a facility with balanced heating and cooling throughout.			1. Garage heated but not necessarily cooled.
	o Design the alley garage apartment to be climatically efficient.	o To help save energy bills.	o Design the alley garage apartment by incorporating bioregional design strategies.	1
RESOURCES	o Conserve natural resources.		o Utilize recycled and renewable resources as much as possible.	1
			o Utilize natural lighting to reduce heat load caused by lighting and electricity usage.	
WASTE	o Reduce the amount of material that is sent to landfill.		o Use new materials that can be recycled in future.	1
CULTURAL				
LEGAL	o Provide a facility which meets all current applicable building codes.			1

	o Please list any legal issues involved with constructing the backhouse.			None.
TECHNOLOGICAL				
MATERIALS				
	o Provide a facility which uses economic and common materials.			**2**
	o Use eco-friendly, cost-effective materials.			**1**
	o All materials specified should be current running lines and be available on a short lead time.		o Select quick ship finishes, materials and furniture.	Range of options preferable before final choice.
	o Use solid surface counter-tops in the kitchens.			**1**
	o Use ceramic tiles in bathrooms.			**1**
SYSTEMS				
	o TV Cable cabability for the apartment.			**1**
PROGRESSIONAL				
GROWTH				
	o Provide for future expansion/ growth.	o Probability of change of use in the future.	o The alley garage apartment should accommodate for flexibility in spaces. o The design should allow for estimated future changes to be made with minimum cost/ effort.	**4**
CHANGE				
	o Provide a facility which is flexible enough to allow rearrangement of rooms.			**4**
	o Create a single flexible footprint that allows for growth.			
PERMANENCE				
	o Provide a space which will last for many years.	o To facilitate re-sale.	o Implement a "timeless design" strategy.	**1**
ECONOMIC				
CONSTRUCTION				
	o Construction cost should be kept to a minimum.		o Create value through design. o Use well priced materials. o A cost life cycle of materials would be beneficial to see how cost could be saved over the life of a high quality material.	Quality of construction is primary.
OPERATIONS				
	o Provide a facility in which the various groups are placed such that operations are most efficient.	o Layout must support all the systems to work as a team.		**4**
	o Provide an energy-saving HVAC system.			**1**

ENERGY				
	o Provide a facility which minimizes energy costs.	o Facility must meet stringent energy regulations.	o Use state of the art systems for energy efficiency. o Providing maintenance information for all materials specified will reduce the need to replace finishes later on.	1
MAINTENANCE				
	o Provide a facility which can be kept clean and well maintained.		o Specify low maintenance materials.	1
AESTHETICS				
FORM				
	o Provide "aesthetically pleasing" forms, which respect the existing forms in the fronthouse.			Compliment it. should not be identical.
	o Provide a facility in which the various forms express the functions of the spaces that they enclose.			3
	o Provide an architectural "feature" to express the visitor entrance and draw the guests to it.			1
	o The exterior and interior of the building should bear similarity to the existing fronthouse.		o Maintain existing architectural features and interior aesthetics.	1
	o Provide high ceilings.			9'-10' ceilings. Do not compromise on efficiency.
	o Increase access to nature.		o Provide balconies/sun rooms.	1
SPACE				
	o Provide a facility which uses the sense of space to enhance the living space.		o Design on the principles of effectively planning "small spaces" to accommodate all facilities and yet look spacious.	1
	o Facilitate a neat living space.		o Provide sufficient storage.	**1.** Ample built-in storage required.
	o Provide a facility which provides natural light and an outside view.		o Provide dormers on roofs. o Provide bay/ corner windows that also facilitate as 'window places'.	Windows should be proportional to those in the fronthouse.
	o Provide a fireplace.			No.
	o Design the backyard.	o For climate control and local food production.	o Design edible landscape/ garden rooms.	1
			o Design play-free areas in the backyard.	4
COLOUR				
	o Provide a facility which uses color to enhance the space.			Use only accent colours.

	o Provide a facility in which color is used to help define spaces.	o To assist in wayfinding.		1
	o Provide a facility in which color psychology is used to enhance the mood.			1
	o Use carpets that are multicolored to hide dirt.			No carpets.
MEANING				
	o Provide a design which is consistent with Manhattan's historic buildings.			Should be sympathetic to the fronthouse.
SAFETY				
STRUCTURAL				
	o Provide a safe flooring system with correct slip resistances.			1. Especially on stairs and entryway.
FIRE				
	o Provide a facility that meets all current fire code regulations with regard to materials, construction assemblies, etc.			1
	o Provide a facility that is "user-friendly" with regard to exiting paths, fire safety issues, etc.			1
CHEMICAL				
	o Use materials that have no off-gassing or are done in the factory.		o Implement "green" materials and finishes.	Wherever possible.
PERSONAL				
	o Improve the safety of guests on the site.		o Install security equipment for proper surveillance.	Possibility to be explored at later stage.
	o Provide safety of individuals during emergency exiting.		o Design according to current fire regulations.	1
CRIMINAL				
	o Provide protection for equipment and the space from vandalism and/or theft.		o Utilize intrusion detection devices.	Provide lockable storage in garage for gardening equipment.

Figure C-1: Location map, Manhattan, Kansas.



Energy10 software output:

Table C-2: Energy10 simulation summary.

Description:	Reference Case	Low-Energy Case
Scheme Number:	none / Not Saved	none / Not Saved
Library Name:	Local Only	Local Only
Simulation status, Thermal/DL	out of date/NA	out of date/out of date
Weather file:	Kansasct.et1	Kansasct.et1
Floor Area, ft^2	680	680
Surface Area, ft^2	2278	2278
Volume, ft^3	6120	6120
Total Conduction UA, Btu/h-F	325	153.6
Average U-value, Btu/hr-ft^2-F	0.143	0.067
Wall Construction	10 in sip, R=36.6	steelstud 6 poly, R=19.2
Roof Construction	pv_roof_r40, R=39.8	flat r-38, R=38.0,etc
Floor type, insulation	Crawl Space, Reff=9.7	Slab on Grade, Reff=33.3
Window Construction	4060 double, alum, U=0.70	4060 low-e al/b, U=0.31
Window Shading	None	40 deg latitude
Wall total gross area, ft^2	918	918
Roof total gross area, ft^2	680	680
Ground total gross area, ft^2	680	680
Window total gross area, ft^2	288	240
Windows (N/E/S/W:Roof)	3/0/7/2:0	3/2/3/2:0
Glazing name	double, U=0.49	double low-e, U=0.26
Operating parameters for zone 1		
HVAC system	Fixed COP Heat Pump	Fixed COP Heat Pump
Rated Output (Heat/SCool/TCool),kBtu/h	33/15/20	33/15/20
Rated Air Flow/MOOA,cfm	680/0	680/0
Heating thermostat	65.0 °F, no setback	65.0 °F, setback to 60.0 °F
Cooling thermostat	78.0 °F, no setup	78.0 °F, setup to 83.0 °F
Heat/cool performance	COP=3.5,EER=18.0	COP=3.5,EER=18.0
Economizer?/type	no/NA	yes/fixed dry bulb, 60.0 °F
Duct leaks/conduction losses, total %	2/0	2/0
Peak Gains; IL,EL,HW,OT; W/ft^2	0.20/0.04/0.66/0.36	0.15/0.03/0.66/0.36
Added mass?	none	340 ft^2, 8in cmu
Daylighting?	no	yes, continuous dimming
Infiltration, in^2	ELA=122.1	ELA=33.0

Photovoltaics System Summary:

Description:	Reference Case	Low-Energy Case
PV System Definition Status:	Undefined	Applied
Total PV Array Area, ft^2 / m^2	--	182 / 17
Total PV Rated Output, kW	--	2
Total Inverter Rated Capacity, kW	--	4
Total PV System First Cost, $	--	14963

Table C-3: Energy10 simulation summary.

Description:	Reference Case	Low-Energy Case
Scheme Number:	1 / Not Saved	**2 / Not Saved**
Library Name:	Local Only	**Local Only**
Simulation status, Thermal/DL	valid/NA	**valid/valid**
Weather file:	Kansasct.et1	**Kansasct.et1**
Floor Area, ft^2	680	**680**
Surface Area, ft^2	2278	**2278**
Volume, ft^3	6120	**6120**
Total Conduction UA, Btu/h-F	325	**153.6**
Average U-value, Btu/hr-ft^2-F	0.143	**0.067**
Wall Construction	10 in sip, R=36.6	**steelstud 6 poly, R=19.2**
Roof Construction	pv_roof_r40, R=39.8	**flat r-38, R=38.0,etc**
Floor type, insulation	Crawl Space, Reff=9.7	**Slab on Grade, Reff=33.3**
Window Construction	4060 double, alum, U=0.70	**4060 low-e al/b, U=0.31**
Window Shading	None	**40 deg latitude**
Wall total gross area, ft^2	918	**918**
Roof total gross area, ft^2	680	**680**
Ground total gross area, ft^2	680	**680**
Window total gross area, ft^2	288	**240**
Windows (N/E/S/W:Roof)	3/0/7/2:0	**3/2/3/2:0**
Glazing name	double, U=0.49	**double low-e, U=0.26**
Operating parameters for zone 1		
HVAC system	Fixed COP Heat Pump	**Fixed COP Heat Pump**
Rated Output (Heat/SCool/TCool),kBtu/h	30/19/26	**15/13/17**
Rated Air Flow/MOOA,cfm	1553/0	**655/0**
Heating thermostat	65.0 °F, no setback	**65.0 °F, setback to 60.0 °F**
Cooling thermostat	78.0 °F, no setup	**78.0 °F, setup to 83.0 °F**
Heat/cool performance	COP=3.5,EER=18.0	**COP=3.5,EER=18.0**
Economizer?/type	no/NA	**yes/fixed dry bulb, 60.0 °F**
Duct leaks/conduction losses, total %	2/0	**2/0**
Peak Gains; IL,EL,HW,OT; W/ft^2	0.20/0.04/0.66/0.36	**0.15/0.03/0.66/0.36**

Added mass?	none	**340 ft², 8in cmu**
Daylighting?	no	**yes, continuous dimming**
Infiltration, in²	ELA=122.1	**ELA=33.0**

Results:		
Energy cost	0.400$/Therm,0.054$/kWh,2.470$/kW	**0.400$/Therm,0.054$/kWh,2.470$/kW**
Simulation dates	01-Jan to 31-Dec	**01-Jan to 31-Dec**
Energy use, kBtu	34395	**11457**
Energy cost, $	622	**222**
Saved by daylighting, kWh	-	**161**
Total Electric (**), kWh	10080	**3358**
(** less Sellback, if any)		
Internal/External lights, kWh	534/58	**240/44**
Heating/Cooling/Fan+Aux, kWh	2898/1537/1483	**1015/1072/300**
Heat Pump/Elec. Res., kWh	2898/0	**1015/0**
Hot water/Other, kWh	1949/1620	**1210/-523**
Peak Electric, kW	3.3	**1.9**
Fuel, hw/heat/total, kBtu	0/0/0	**0/0/0**
Emissions, CO2/SO2/NOx, lbs	13547/80/41	**4513/27/14**
Construction Costs	111005	**128176**
Life-Cycle Cost	136812	**136703**

Photovoltaics System Summary:

Description:	**Reference Case**	**Low-Energy Case**
PV System Definition Status:	Undefined	**Applied**
Total PV Array Area, ft² / m²	--	**182 / 17**
Total PV Rated Output, kW	--	**2**
Total Inverter Rated Capacity, kW	--	**4**
Total PV System First Cost, $	--	**14963**

Table C-4: Energy use/ cost comparison.

Description:	Reference Case	Low-Energy Case
Scheme Number:	1	2
Library Name:	ARCHIVELIB	ARCHIVELIB
Simulation status, Thermal/DL	valid/NA	valid/valid
Weather file:	Kansasct.et1	Kansasct.et1
Floor Area, ft²	680	680
Surface Area, ft²	2278	2278
Volume, ft³	6120	6120
Total Conduction UA, Btu/h-F	325	153.6
Average U-value, Btu/hr-ft²-F	0.143	0.067
Wall Construction	10 in sip, R=36.6	steelstud 6 poly, R=19.2
Roof Construction	pv_roof_r40, R=39.8	flat r-38, R=38.0,etc
Floor type, insulation	Crawl Space, Reff=9.7	Slab on Grade, Reff=33.3
Window Construction	060 double, alum, U=0.70	4060 low-e al/b, U=0.31
Window Shading	None	40 deg latitude
Wall total gross area, ft²	918	918
Roof total gross area, ft²	680	680
Ground total gross area, ft²	680	680
Window total gross area, ft²	288	240
Windows (N/E/S/W:Roof)	3/0/7/2:0	3/2/3/2:0
Glazing name	double, U=0.49	double low-e, U=0.26
Operating parameters for zone 1		
HVAC system	Fixed COP Heat Pump	Fixed COP Heat Pump
Rated Output, kBtu/h		
Heat	30	15
Sensible Cool	19	13
Total Cool	26	17
Rated Air Flow,cfm	1553	655
MOOA,cfm	0	0
Heating thermostat	65.0 °F	65.0 °F
Setback	no setback	setback to 60.0 °F
Cooling thermostat	78.0 °F	78.0 °F
Setup	no setup	setup to 83.0 °F
Heat performance	COP=3.5	COP=3.5
Cool performance	EER=18.0	EER=18.0
Economizer?	no	yes
Type	NA	fixed dry bulb, 60.0 °F
Duct Leaks, total %	2	2
Conduction losses, total %	0	0
Peak Gains;W/ft²		
Internal Lights	0.2	0.15
External Lights	0.04	0.03
Hot Water	0.66	0.66
Other (Plug loads)	0.36	0.36
Added mass?	none	340 ft², 8in cmu
Daylighting?	no	yes, continuous dimming
Infiltration, in²	ELA=122.1	ELA=33.0

Results:	Reference Case	Low-Energy Case
Energy cost		
$/Therm	0.4	0.4
$/kWh	0.054	0.054
$/kW	2.47	2.47

Simulation dates	01-Jan to 31-Dec	**01-Jan to 31-Dec**
Energy use, kBtu	34395	**11457**
Energy cost, $	622	**222**
Saved by daylighting, kWh	-	**161**
Total Electric, kWh	10080	**3358**
Internal Lights, kWh	534	**240**
External Lights, kWh	58	**44**
Heating, kWh	2898	**1015**
Cooling, kWh	1537	**1072**
Fan, kWh	1483	**300**
Elec. Res. kWh	2898	**1015**
Heat Pump, kWh	0	**0**
Hot water, kWh	1949	**1210**
unregulated/process loads	1620	**1620**
Peak Electric, kW	3.3	**1.9**
Fuel		
hw kBtu	0	**0**
heat, kBtu	0	**0**
total, kBtu	0	**0**
Annual Emissions		
CO2, lbs	13547	**4513**
SO2, lbs	80	**27**
NOx, lbs	41	**14**
Construction Costs	111005	**128177**
Life-Cycle Cost	136812	**136703**

Table C-5: PV system summary.

Description:	Reference Case	Low-Energy Case	
PV System Definition Status:	Undefined	Applied	
Total PV Array Area, ft² / m²	--	182 / 17	
Total PV Rated Output, kW	--	2	
Total Inverter Rated Capacity, kW	--	4	
Total PV System First Cost, $	--	14963	
Array 1			
BIPV Type / Rated Power, kW		--	Roof-Integrated / 2.0
No. of Modules		--	7
Area(ft²)/Azimuth/Tilt		--/--/--	182 / 0 / 0
PV Simulation Results:			
PV System Output, kWh		--	2143
PV Sellback, kWh		--	0
PV Output by Array			
Array 1, kWh		--	2143

Table C-6: Peak load summary.

Description:	Reference Case	Low-Energy Case
Design-day Sizing Results		
Combined Zones:		
Rated heating output, kBtu/h	30	15
Rated sensible cooling output, kBtu/h / ton	19/2	13/1
Rated total cooling output, kBtu/h / ton	26/2	17/1
Rated Air Flow, cfm	1553	655
Zone 1		
HVAC System:		
Cooling System	Fixed COP DX Comp	Fixed COP DX Comp
Heating System	Fixed COP Heat Pump	Fixed COP Heat Pump
Autosize On?/Oversize factor	Yes / 1.2	Yes / 1.2
Rated heating output, kBtu/h	30	15
Heating load, kBtu/h	25	13
Rated sensible cooling output, kBtu/h	19	13
Sensible cooling load, kBtu/h	20	13
Rated total cooling output, kBtu/h	26	17
Total cooling load, kBtu/h	21	14
Rated air flow, cfm	1553	655
Cooling Peak month/hour	NA / 4 p.m.	NA / 6 p.m.
Dry bulb/wet bulb temperatures, °F	96/74	96/74
Hourly Simulation Results		
Peak Heating Zone Heat Flow, kBtu/h	25	15
Heating Peak, hour, month/day	8:00, 12/17	1:00, 12/26
Peak Cooling Zone Heat Flow, kBtu/h / ton	24/2	15/1
Cooling Peak, hour, month/day	16:00, 8/5	1:00, 7/5
Peak Heating Metered Use, kBtu/h	7	4
Heating Peak, hour, month/day	8:00, 12/17	1:00, 12/26
Peak Cooling Metered Use, kW		1
Cooling Peak, hour, month/day	14:00, 10/31	1:00, 7/5
Peak Building Metered Electric Use, kW	3	2
Building Electric Peak, hour, month/day	14:00, 10/31	1:00, 7/5

Table C-7: PV summary.

Description:	Reference Case	Low-Energy Case	
PV System Definition Status:	Undefined	Applied	
Total PV Array Area, ft² / m²	--	182 / 17	
Total PV Rated Output, kW	--	2	
Total Inverter Rated Capacity, kW	--	4	
Total PV System First Cost, $	--	14963	
Array 1			
BIPV Type / Rated Power, kW		--	Roof-Integrated / 2.0
No. of Modules		--	7
Area(ft²)/Azimuth/Tilt		--/--/--	182 / 0 / 0
PV Simulation Results:			
PV System Output, kWh		--	2143
PV Sellback, kWh		--	0
PV Output by Array			
Array 1, kWh		--	2143

Table C-8: Cost summary report.

Scheme Name:	Reference Case	Low-Energy Case	Difference
Construction	111005.29	128176.6	-17171.31
fixed	102000	102000	0
EE strategies	0	20463.46	-20463.46
HVAC installation	9005.29	5713.13	3292.15
Mortgage payment	10184	11759	-1575
HVAC replacement	6753.96	4284.85	2469.11
Annual fuel	0	0	0
Annual electric	621.75	221.66	400.09
Annual maintenance	340	340	0
Life Cycle Cost Results	Reference Case	Low-Energy Case	NetPresentValue
capital	21673	25026	-3353
property taxes	8014	9254	-1240
mortgage	104843	121061	-16218
utilities	28598	10207	18391
maintenance	12274	12274	0
HVAC replacement	11756	7458	4298
tax deductions	-50346	-48577	-1769
Life-Cycle Cost	136812	136703	109
Internal Rate of Return, IRR,	6.03%		
Simple Payback, years	0		
Benefit / Cost Ratio	1		

Table C-9: Cost summary report.

Scheme Name:	Reference Case	Low-Energy Case	Difference
Construction	111005.29	128176.6	-17171.31
fixed	102000	102000	0
EE strategies	0	20463.46	-20463.46
HVAC installation	9005.29	5713.13	3292.15
Mortgage payment	10184	11759	-1575
HVAC replacement	6753.96	4284.85	2469.11
Annual fuel	0	0	0
Annual electric	621.75	221.66	400.09
Annual maintenance	340	340	0
Life Cycle Cost Results	**Reference Case**	**Low-Energy Case**	**NetPresentValue**
capital	21673	25026	-3353
property taxes	8014	9254	-1240
mortgage	104843	121061	-16218
utilities	28598	10207	18391
maintenance	12274	12274	0
HVAC replacement	11756	7458	4298
tax deductions	-50346	-48577	-1769
Life-Cycle Cost	136812	136703	109
Internal Rate of Return, IRR,	6.03%		
Simple Payback, years	0		
Benefit / Cost Ratio	1		

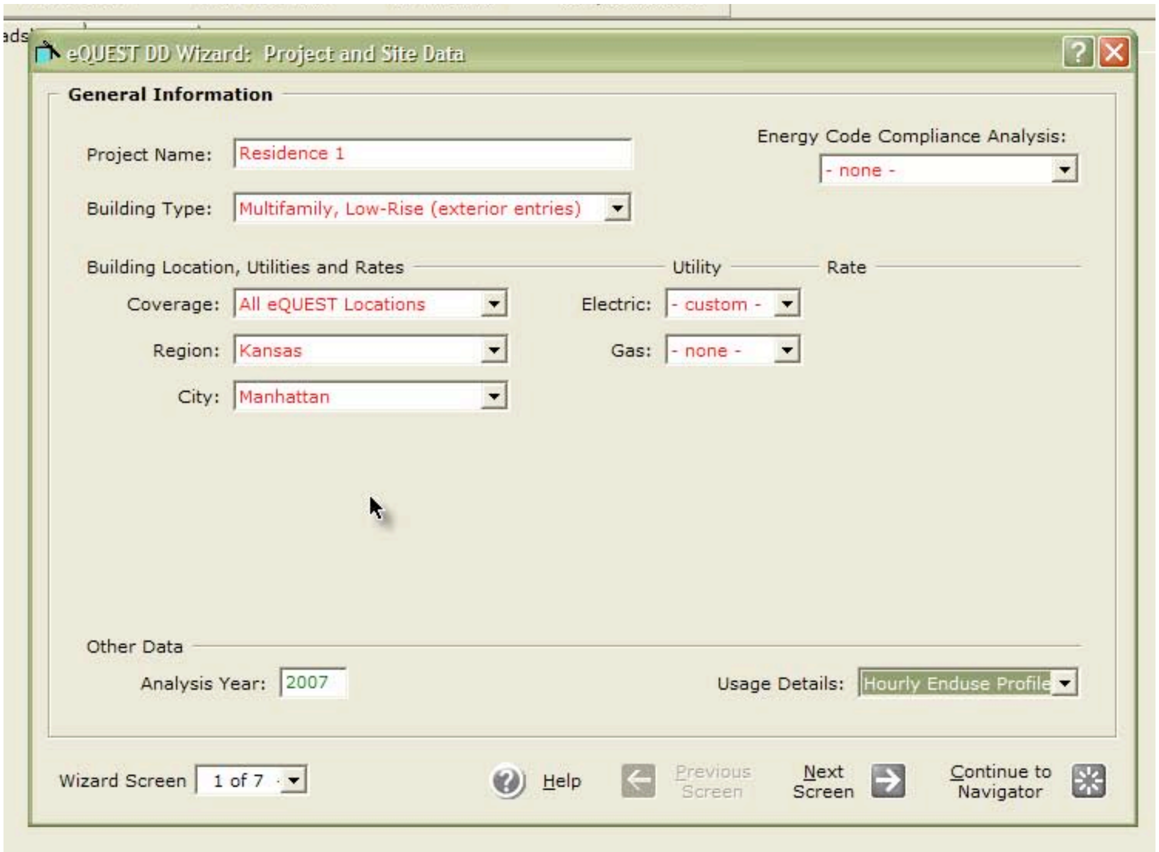
Table C-10: Cost breakdown.

HVAC Costs	Reference Case	Low-Energy Case	Difference
fixed	1360	1360	0
heating	666	338	-328
cooling	2321	1526	-794
distribution	4658	2490	-2168
Total	9005	5713	-3292

eQuest software input:

<u>Project/ site/ utility</u>

Figure C-2: General project and site information.



The garage apartment is a versatile space that will function as a B&B and a future single-family residence with a maximum occupancy of 2 people at all times. In the "building type" information requested by eQuest in *Figure C-2: General project and site information*, "multi-family, low-rise [exterior entries]" was the choice that came closest to the type of space designed in this thesis.

Figure C-3: Season definitions.

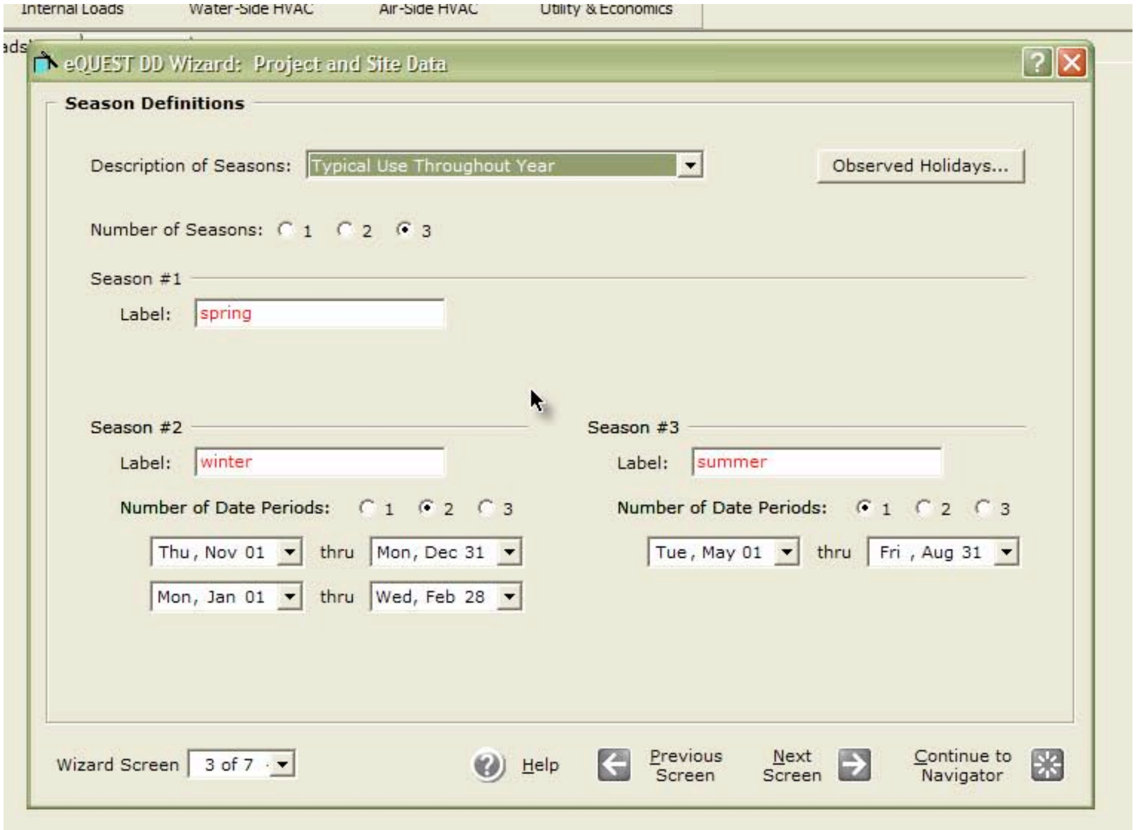
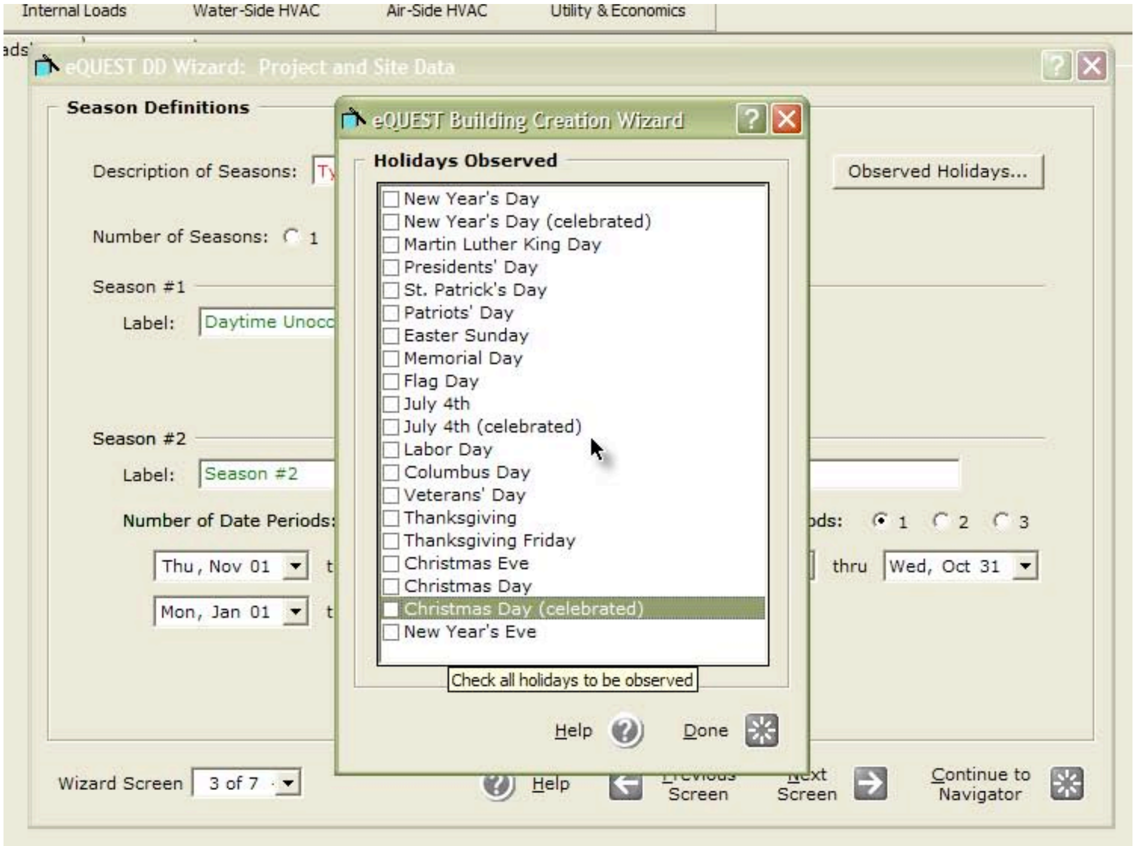


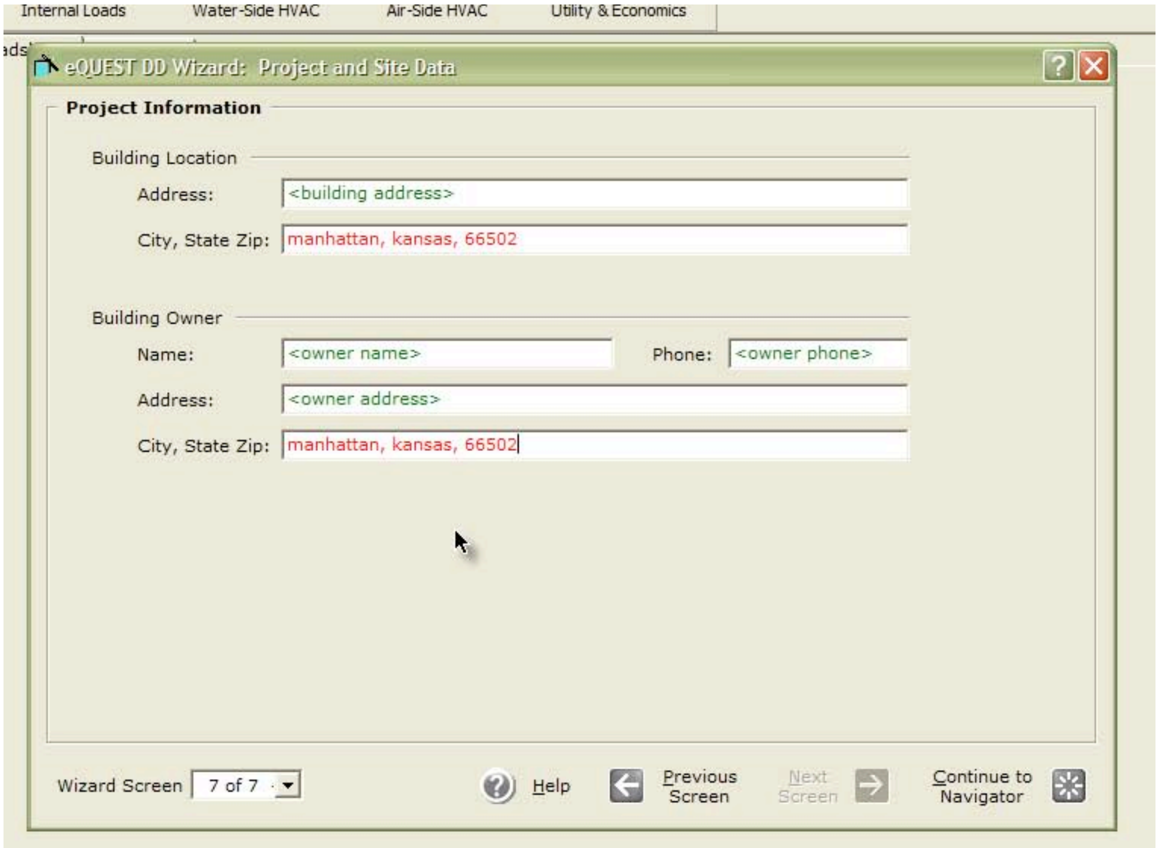
Figure C-4: Holiday definitions.



Although the garage apartment, as a B&B, is not expected to function during Thanksgiving, *Figure C-4: Holiday definitions* has been programmed otherwise to simulate its future function as a single-family residence.

General shell information

Figure C-5: Project information.



Project name and address have been retained for privacy reasons.

Building shell

Figure C-6: General shell information.

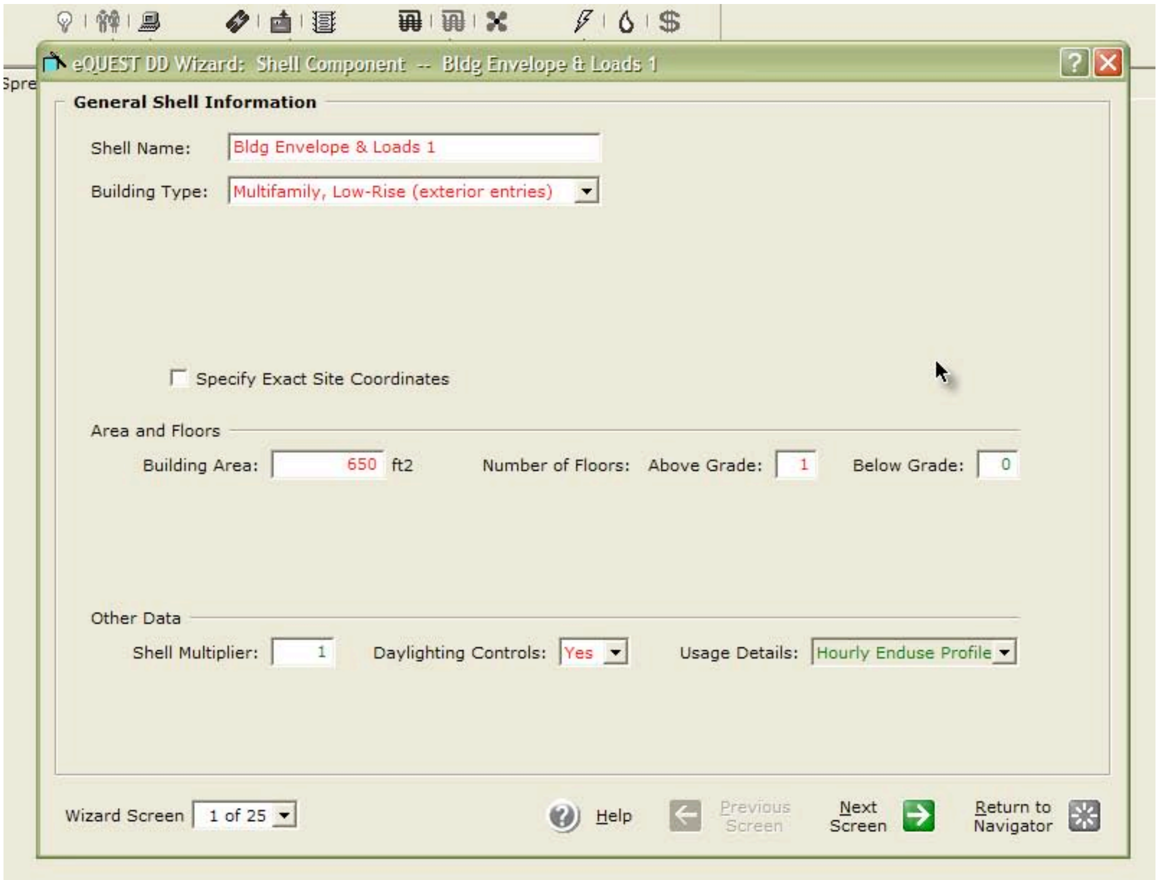
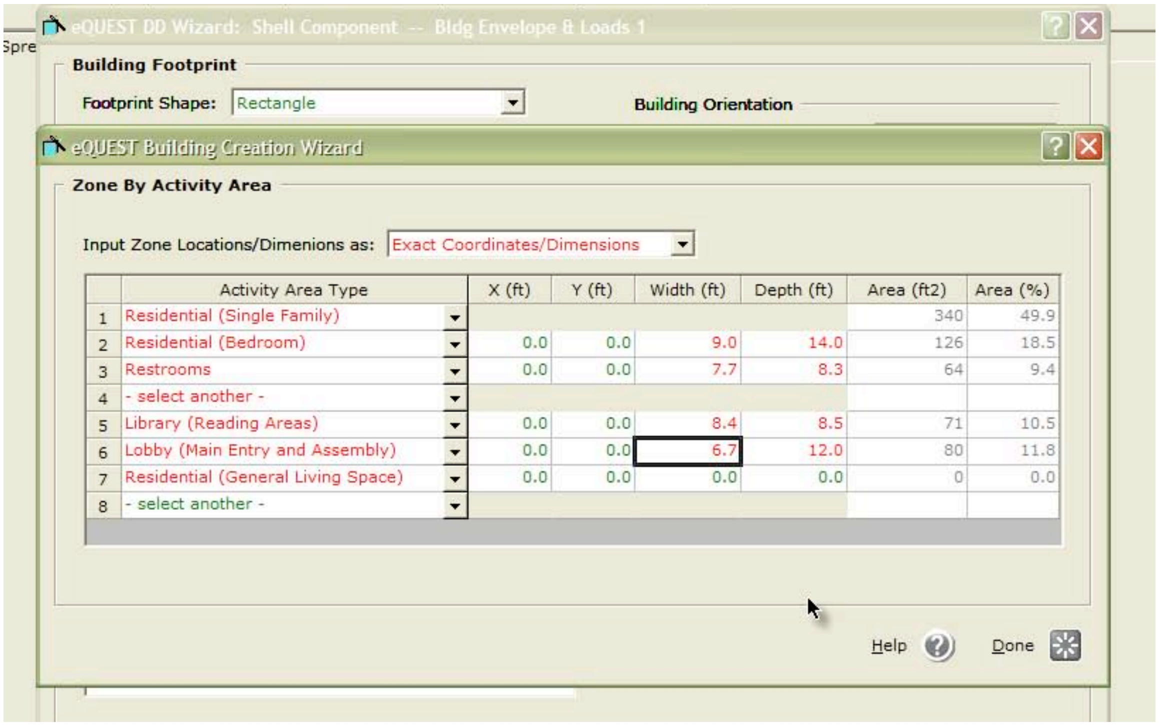


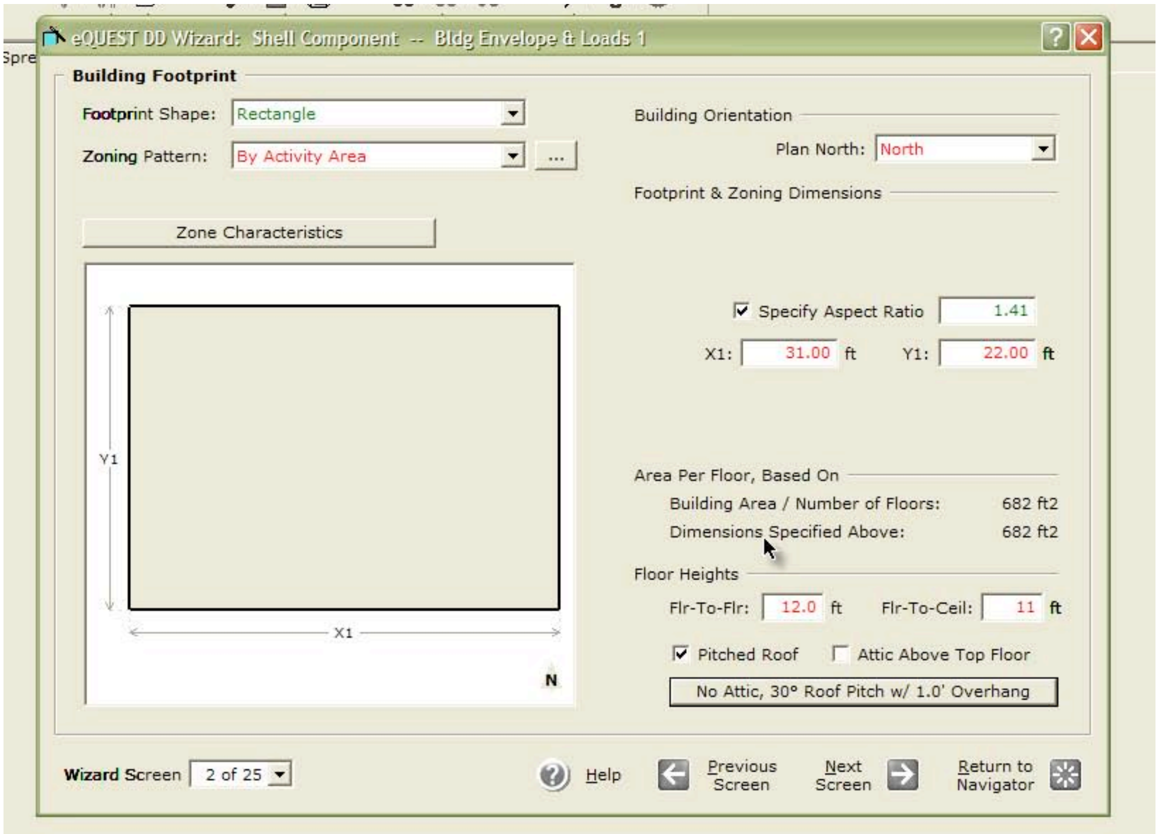
Figure C-7: Zoning by activity area definition.



General living space area was automatically computed by eQuest under the "Residential [single family]" section, and hence no value was entered in the "Residential [general living space]" section.

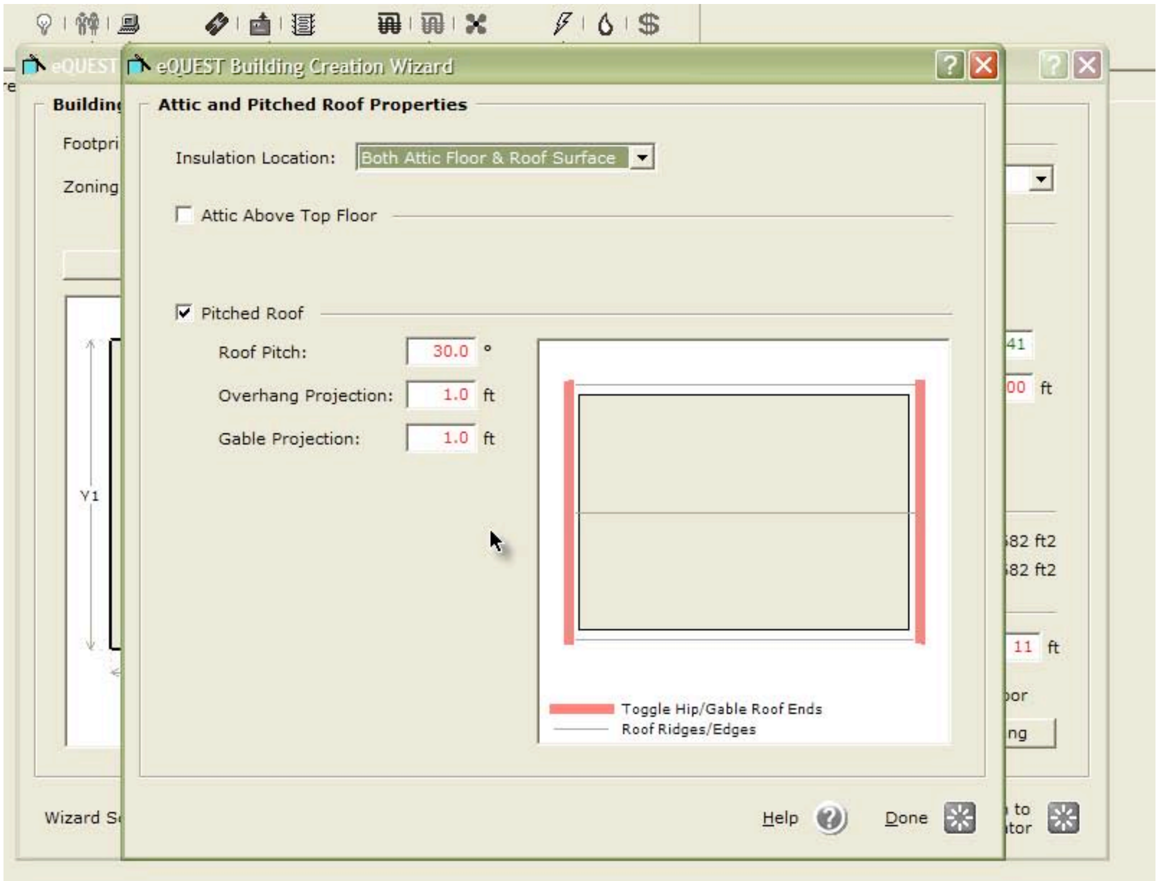
Building footprint

Figure C-8: Building footprint data



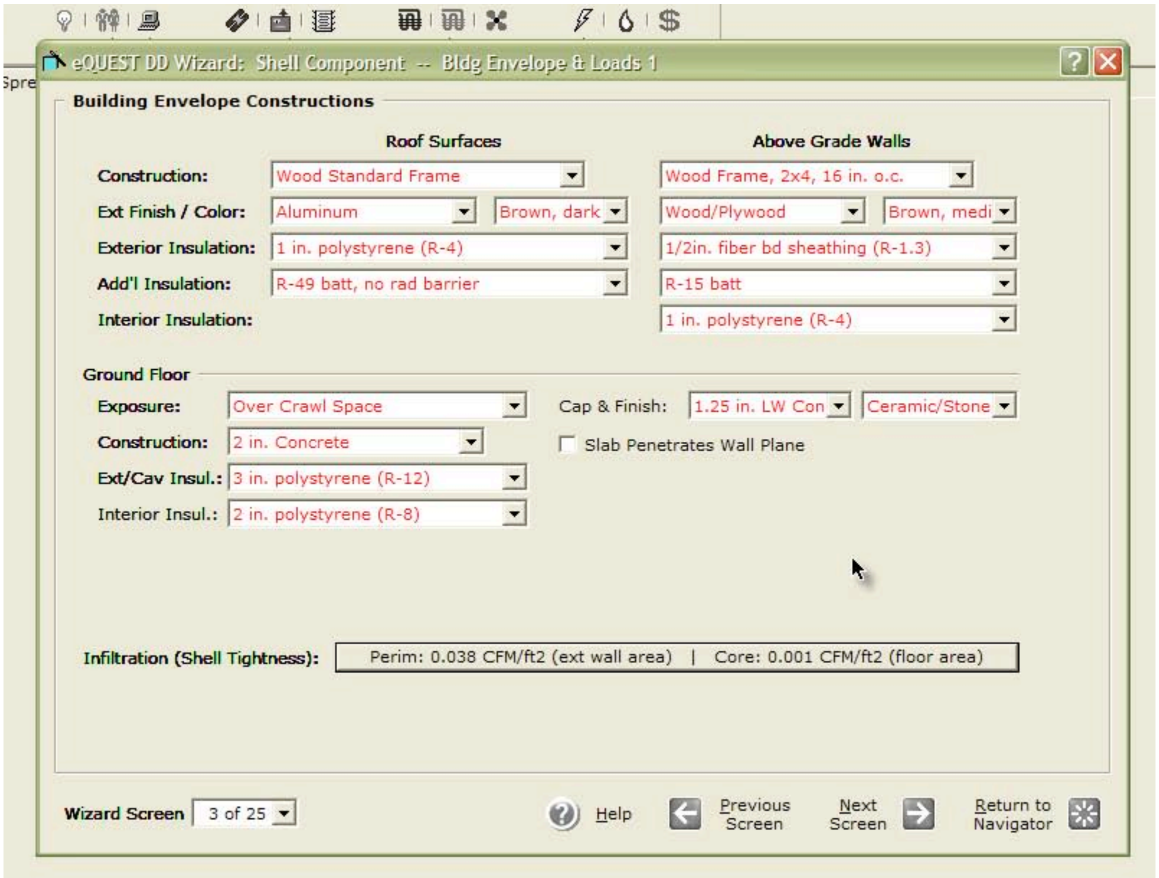
The building footprint form could not be inputted as is, and hence a rectangle with the area of the conditioned space of the garage apartment was inputted.

Figure C-9: Attic and pitched roof properties.



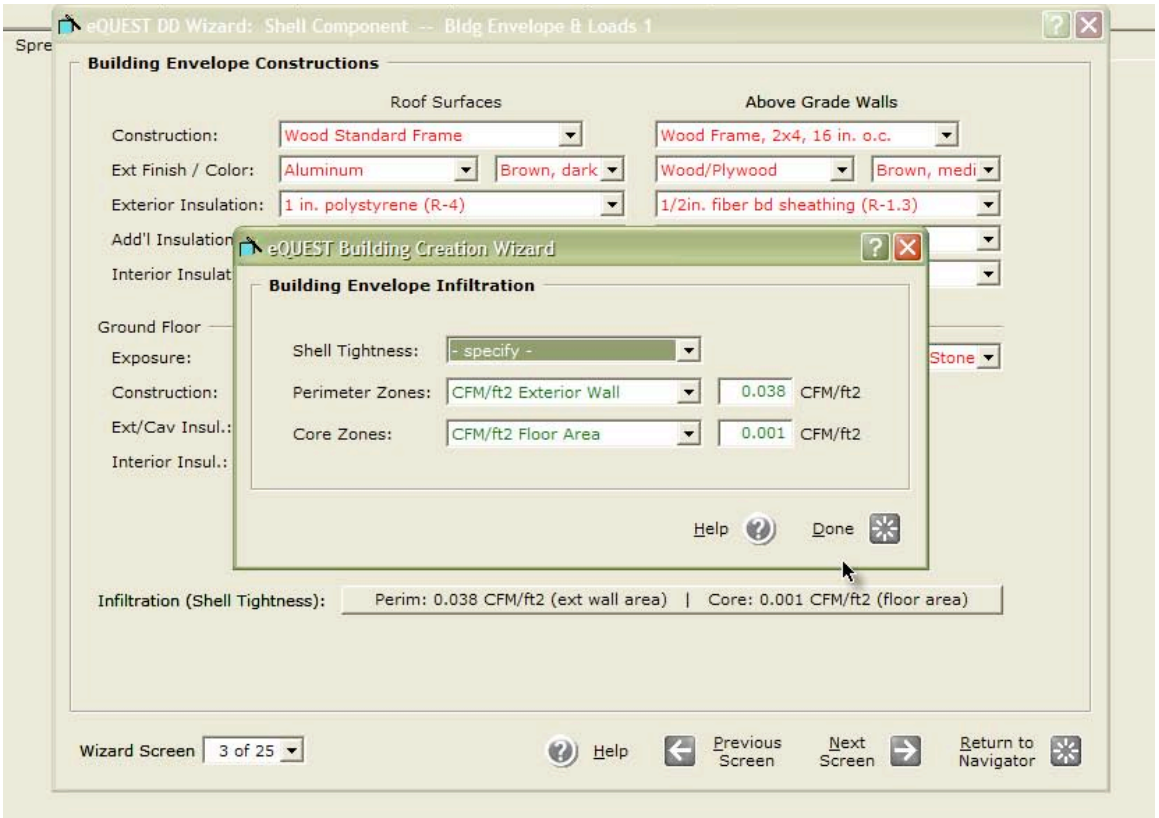
Building envelope constructions

Figure C-10: Building envelope constructions.



Construction of the roof surface and above grade walls could not be specified as SIP construction, since no such option was listed in the software.

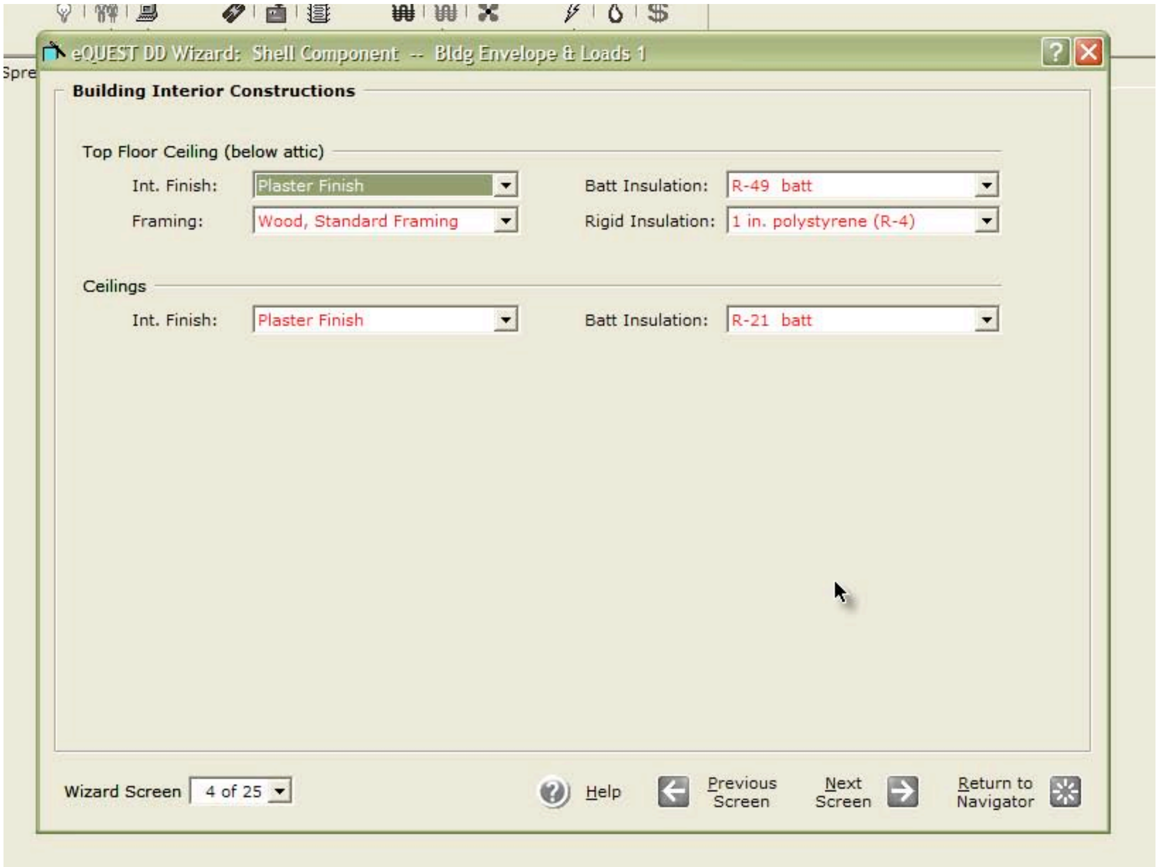
Figure C-11: Building envelope infiltration data.



The building envelope infiltration values were retained as specified by eQuest.

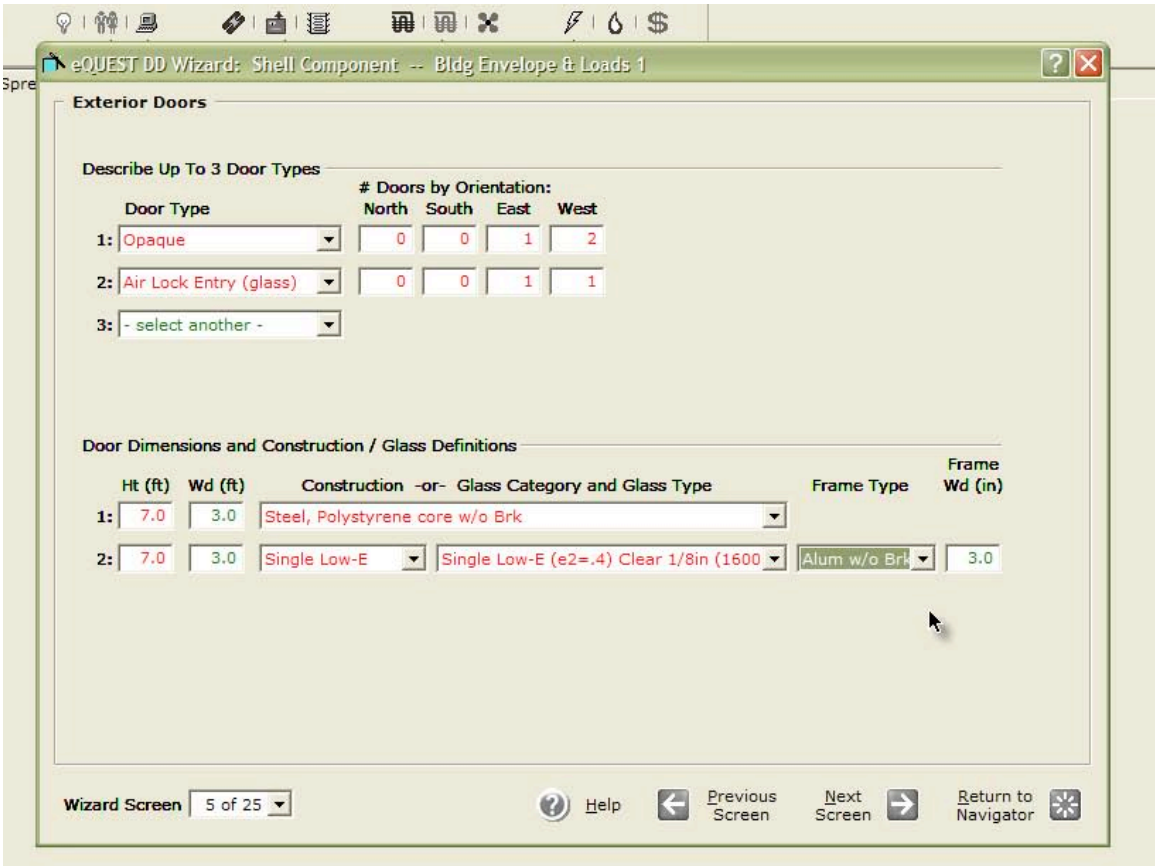
Building interior constructions

Figure C-12: Building interior construction data.



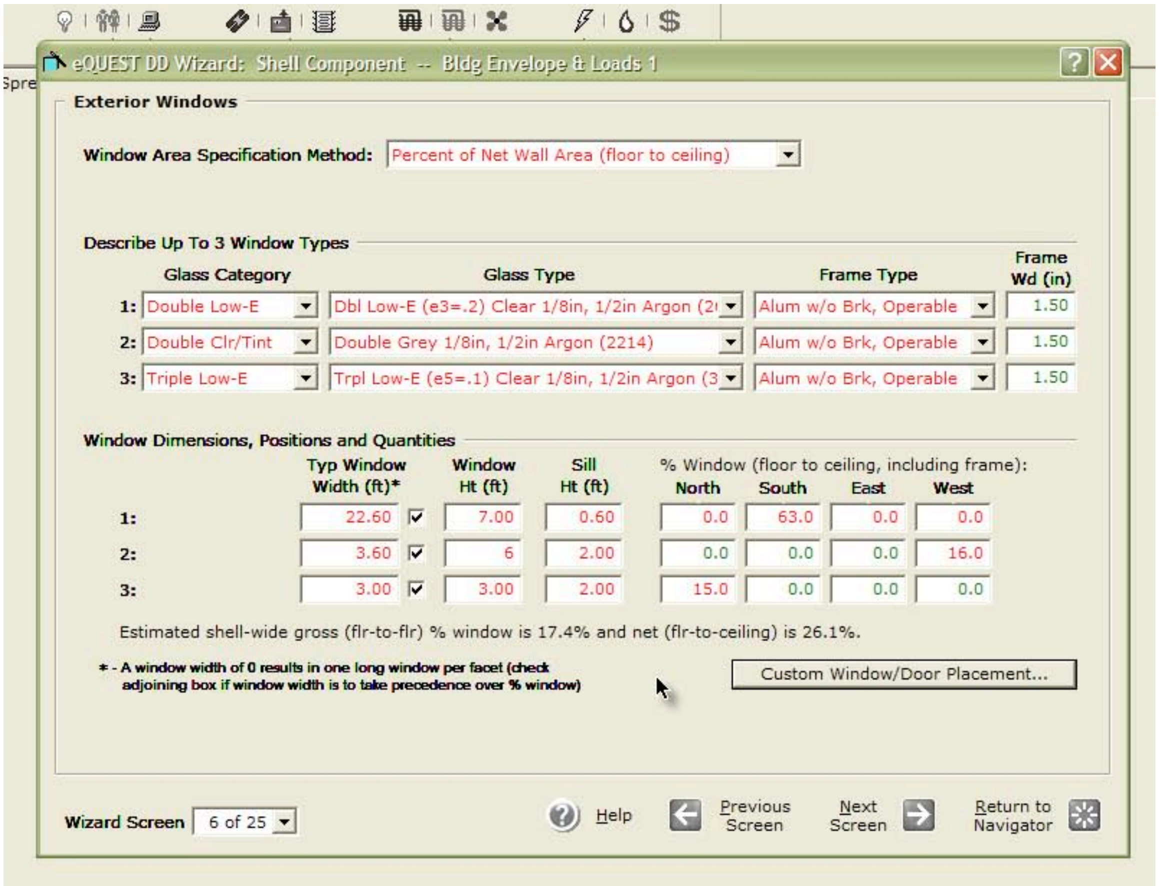
Exterior doors

Figure C-13: Exterior door information.



Exterior windows

Figure C-14: Exterior window information.



Since only 3 window types could be listed, double low-e windows and double tint windows of size 3’x3’ could not be listed; and a triple glazed window of size 3’6”x3’6” could not be listed.

Exterior window shades and blinds

Figure C-15: Exterior window shades and blinds information.

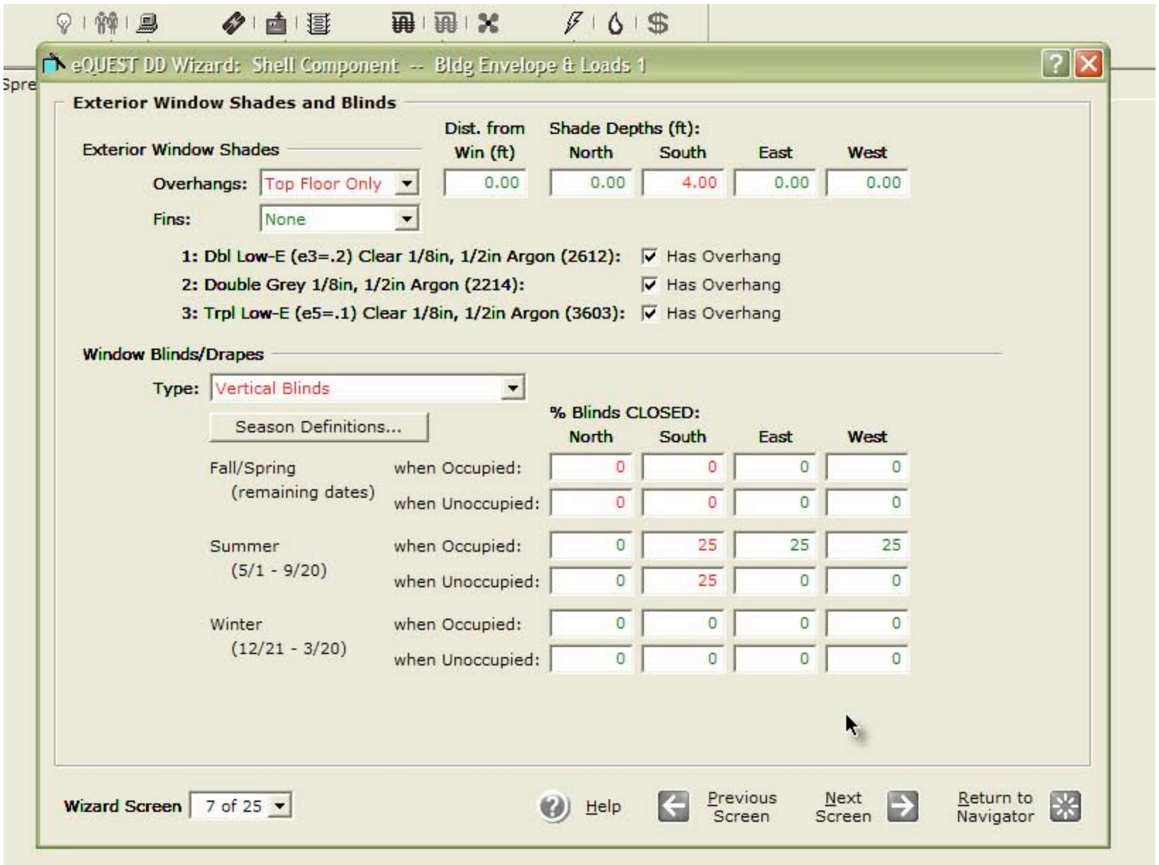
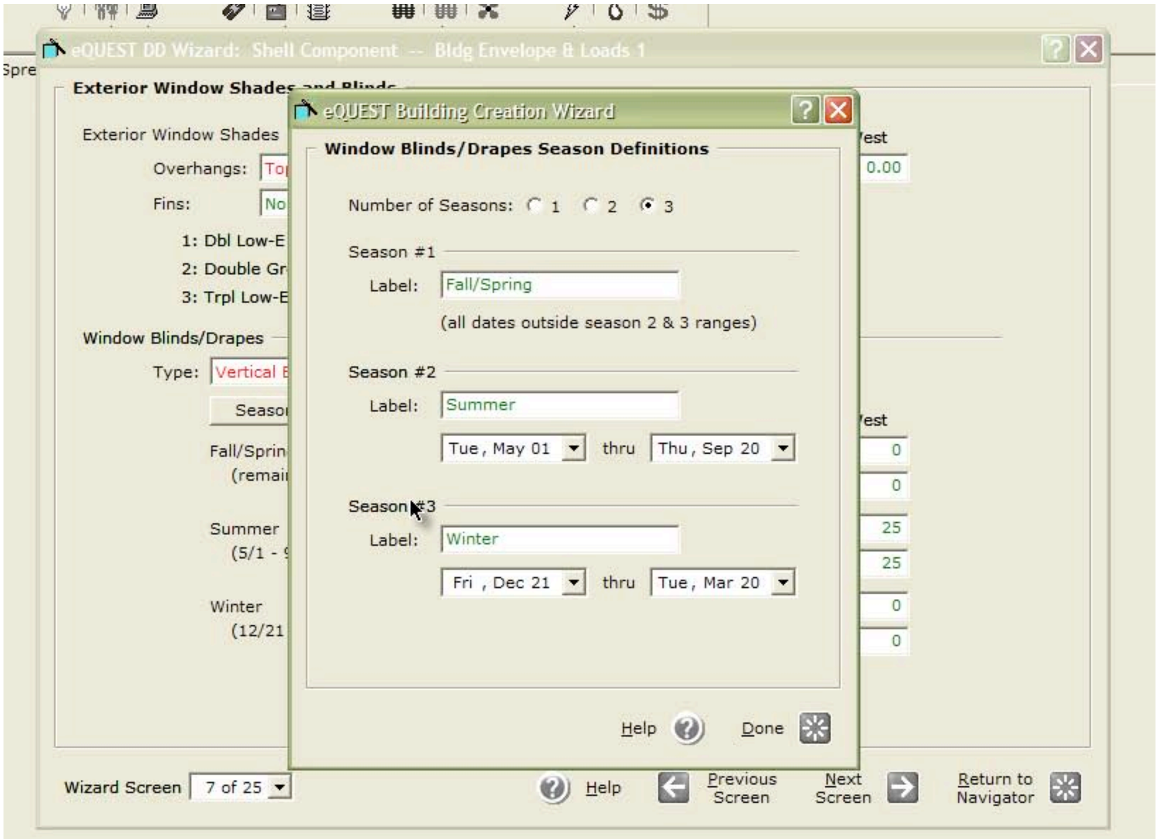
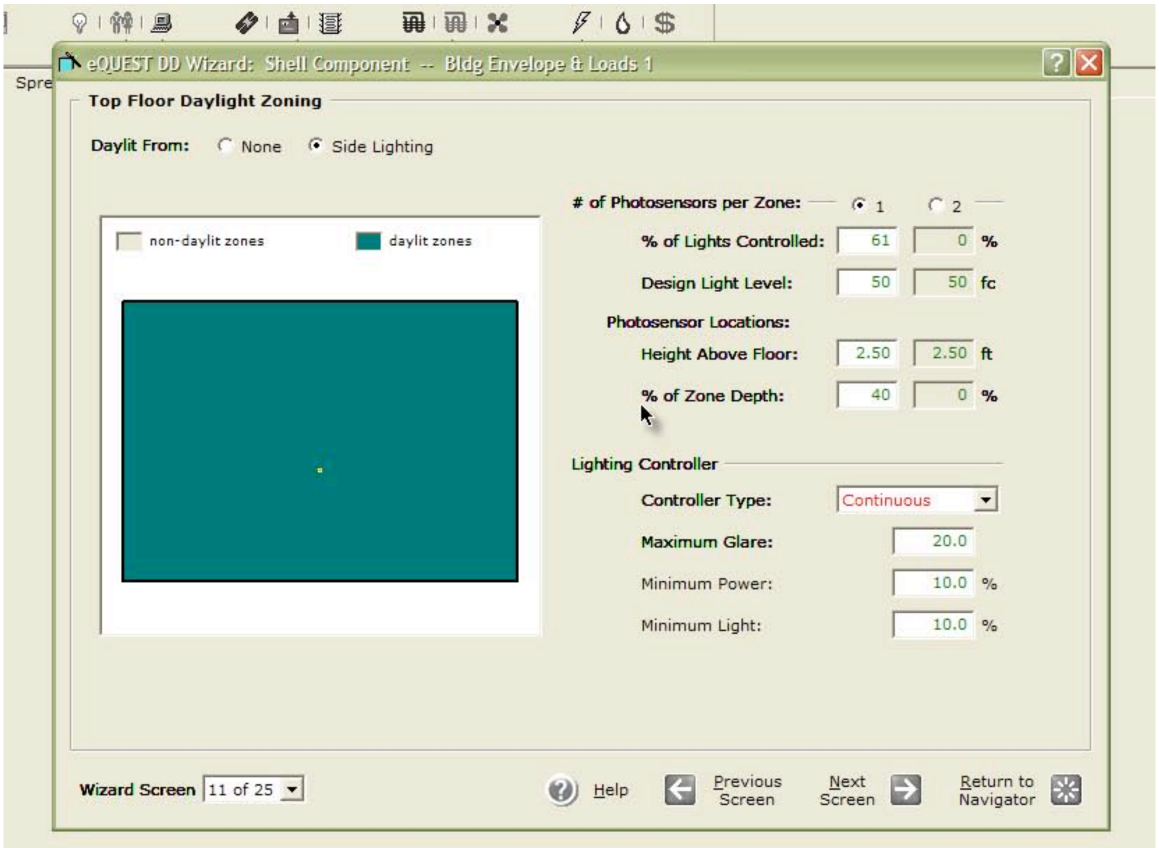


Figure C-16: Exterior windows shades and blinds seasonal definitions.



Top floor daylight zoning

Figure C-17: Top floor daylight zoning data.

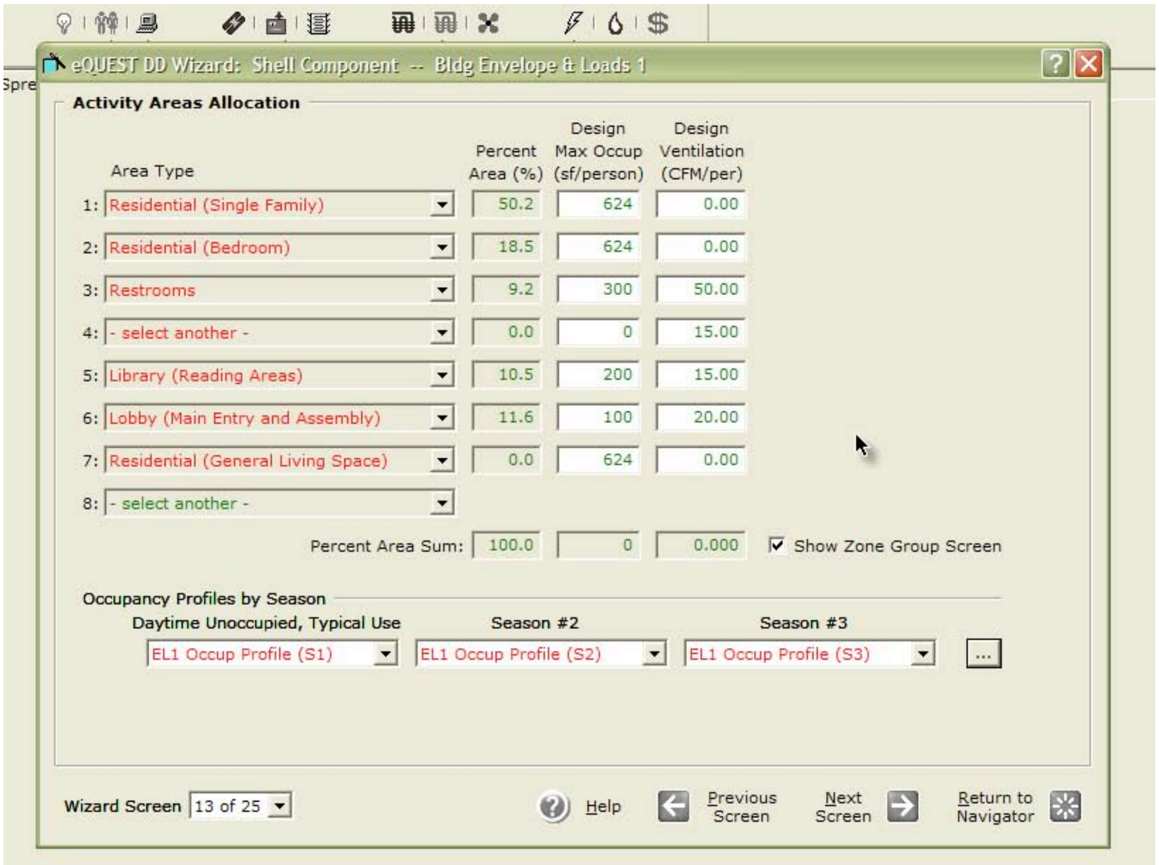


Building operation schedule

Figure C-18: Building operation schedule.

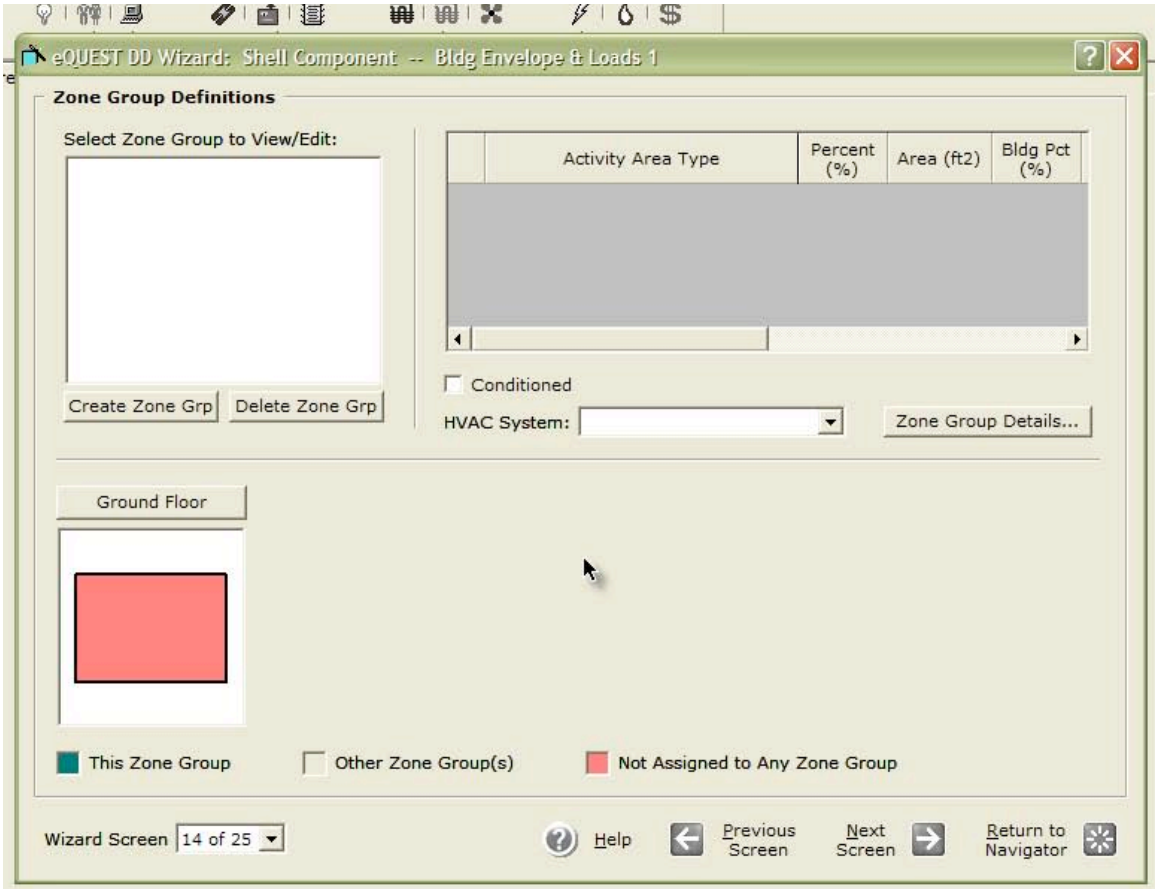
Activities area allocation

Figure C-19: Activities area allocation.



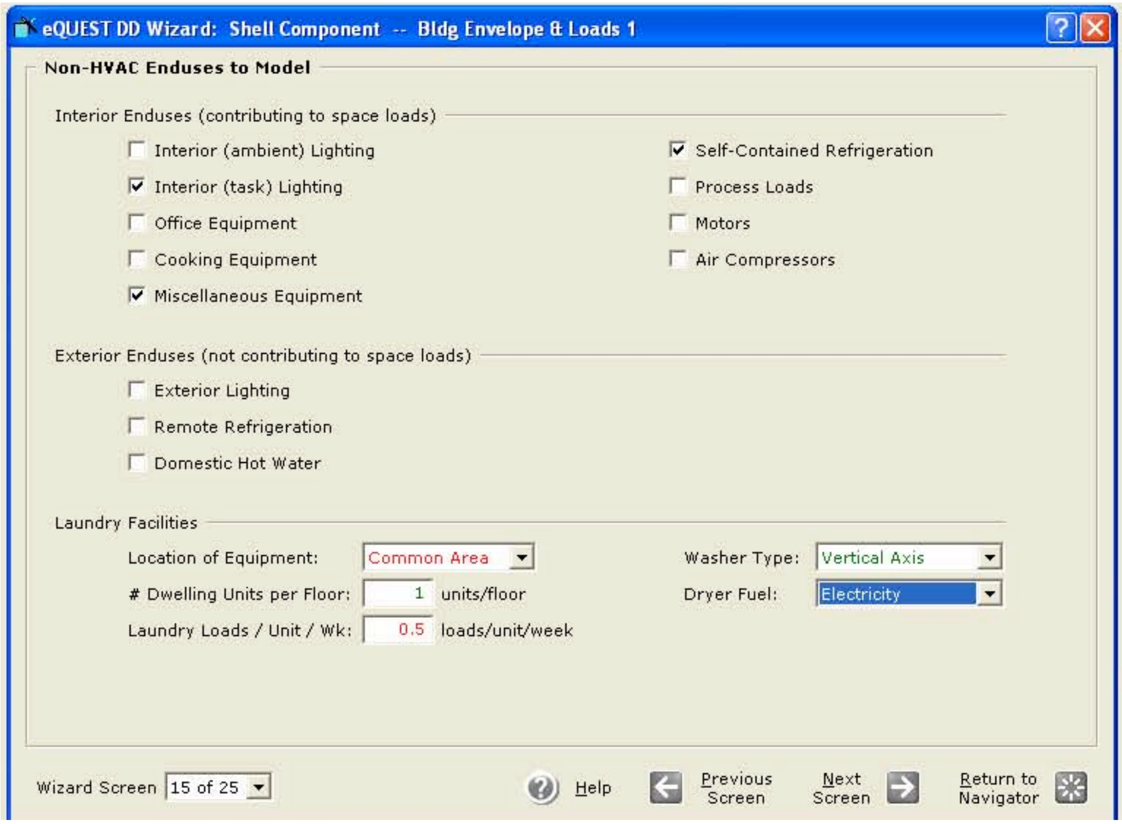
Zone group definitions [none]

Figure C-20: Zone group definitions.



Non-HVAC end-uses to model

Figure C-21: Non-HVAC end-uses to model.



Interior lighting loads and profiles

Figure C-22: Interior lighting loads and profiles.

Self-contained refrigerator loads and profiles

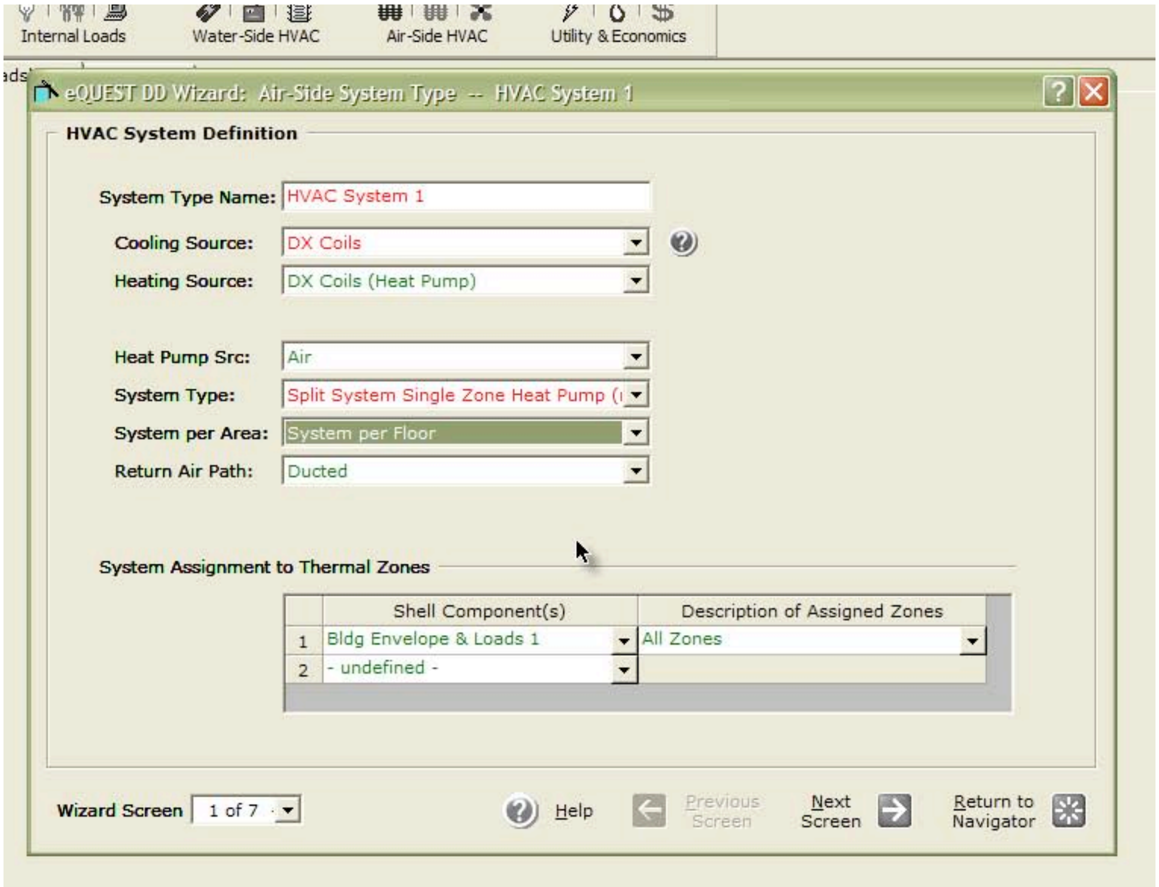
Figure C-23: Self-contained refrigeration loads and profiles.

Miscellaneous loads and profiles

Figure C-24: Miscellaneous loads and profiles.

Selected air-side system- HVAC system definition

Figure C-26: HVAC system definition.

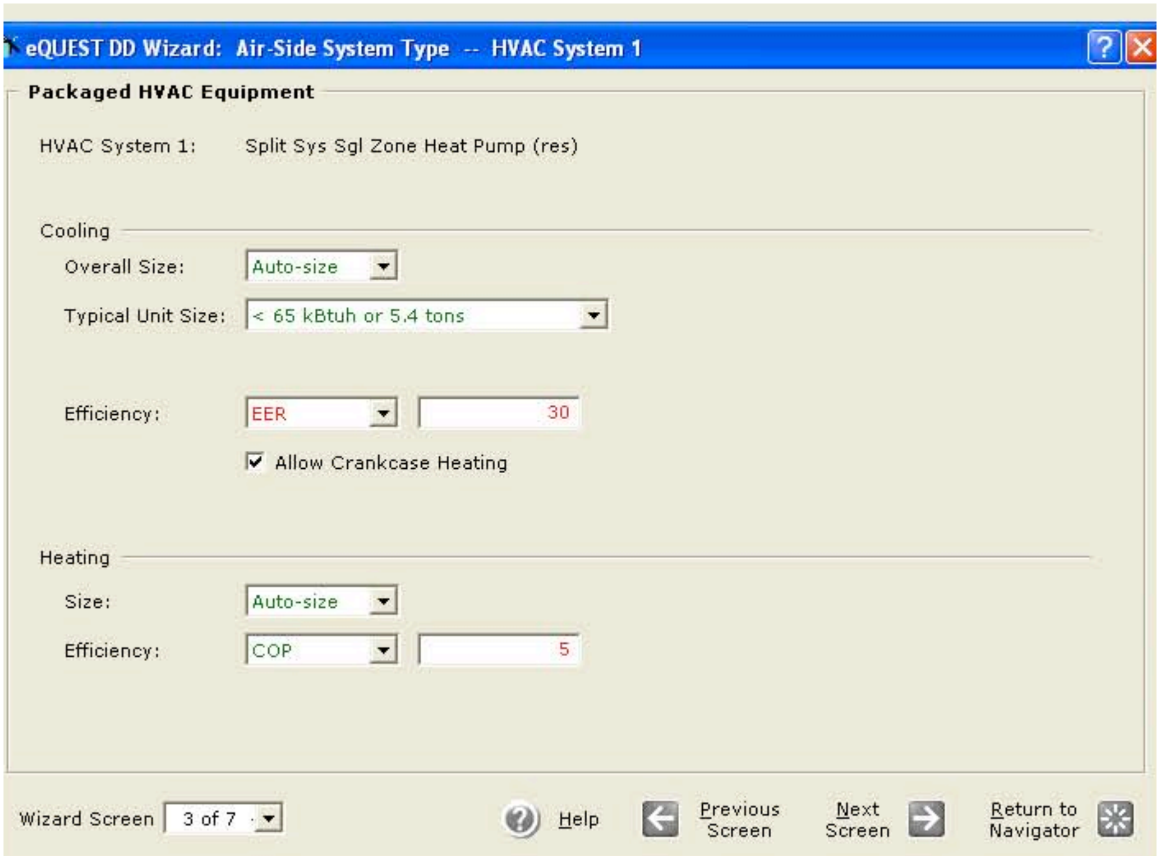


HVAC zones- temperatures and airflows

Figure C-27: HVAC zones: temperature and air-flows.

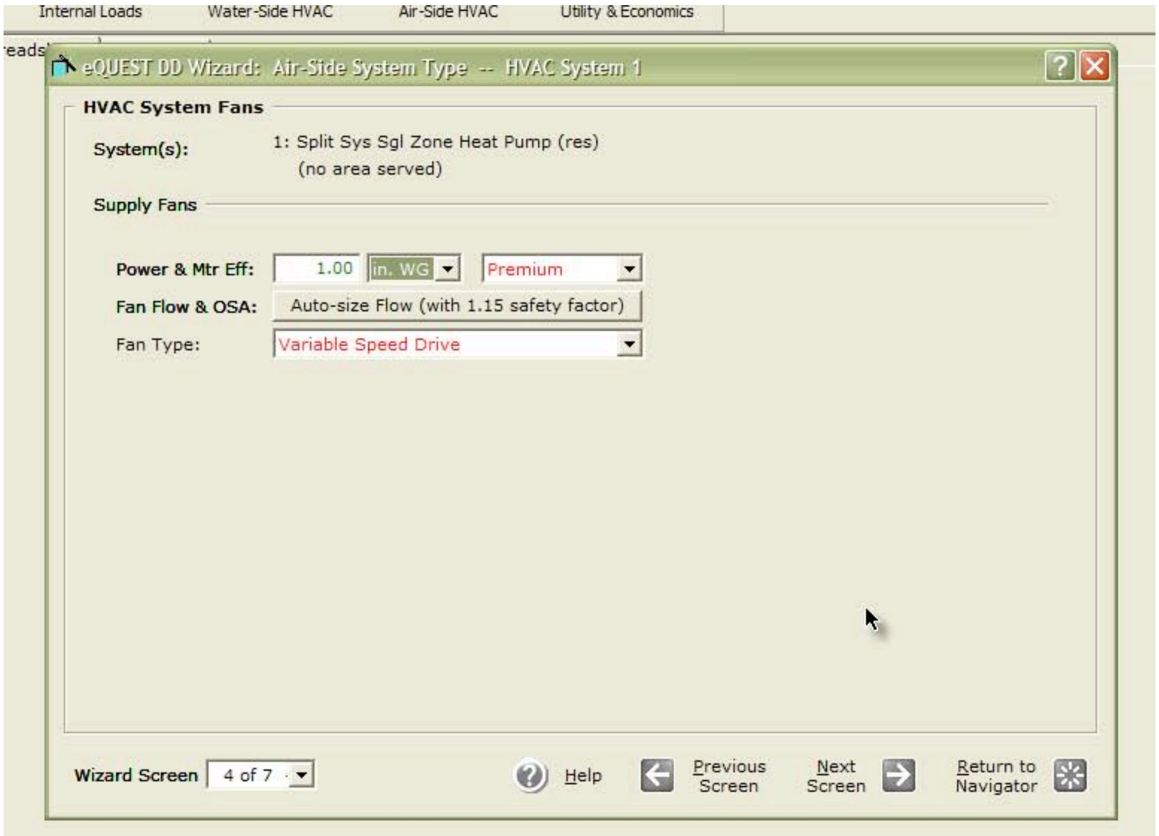
Packaged HVAC equipment

Figure C-28: Package HVAC equipment data.



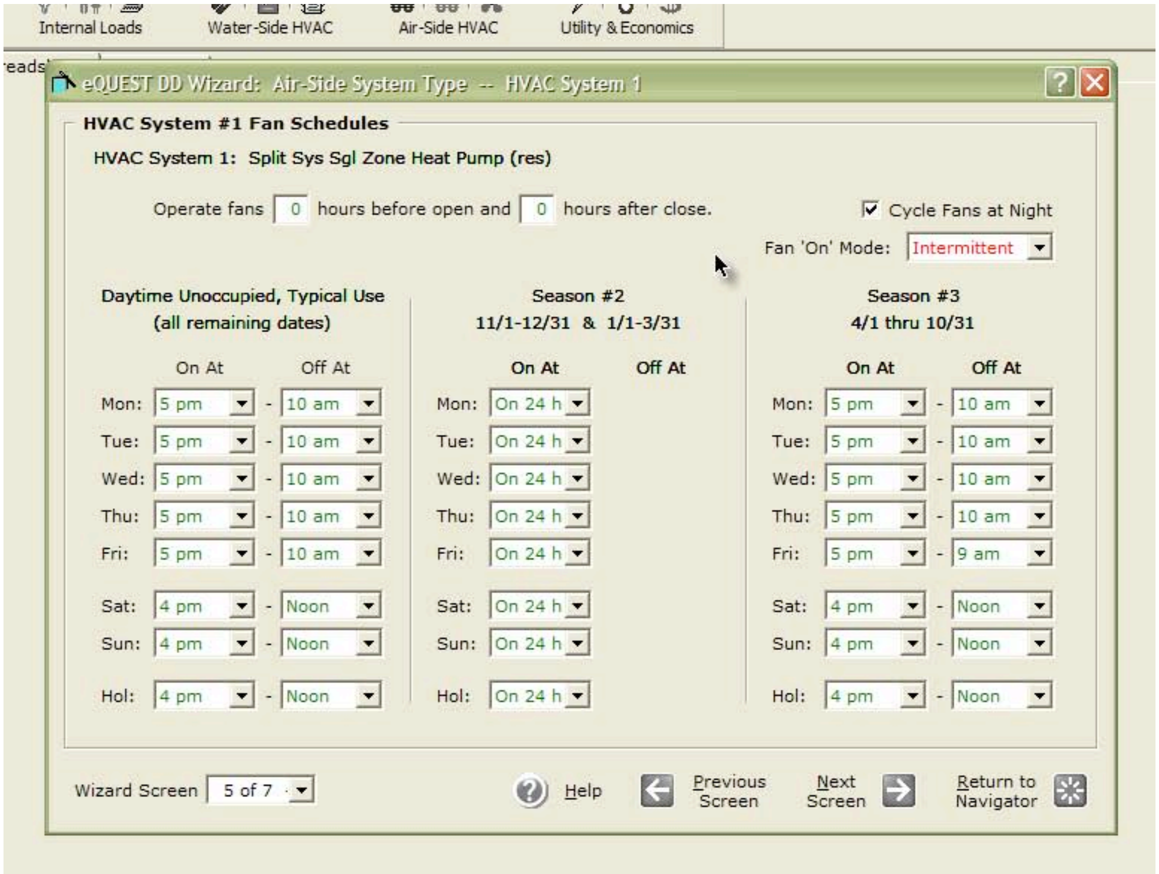
HVAC system fans

Figure C-29: HVAC system fans information.



HVAC fan schedules

Figure C-30: HVAC system fan schedules.



HVAC zone heating, vent, economizers

Figure C-31: HVAC zone heating, vent and economizers.

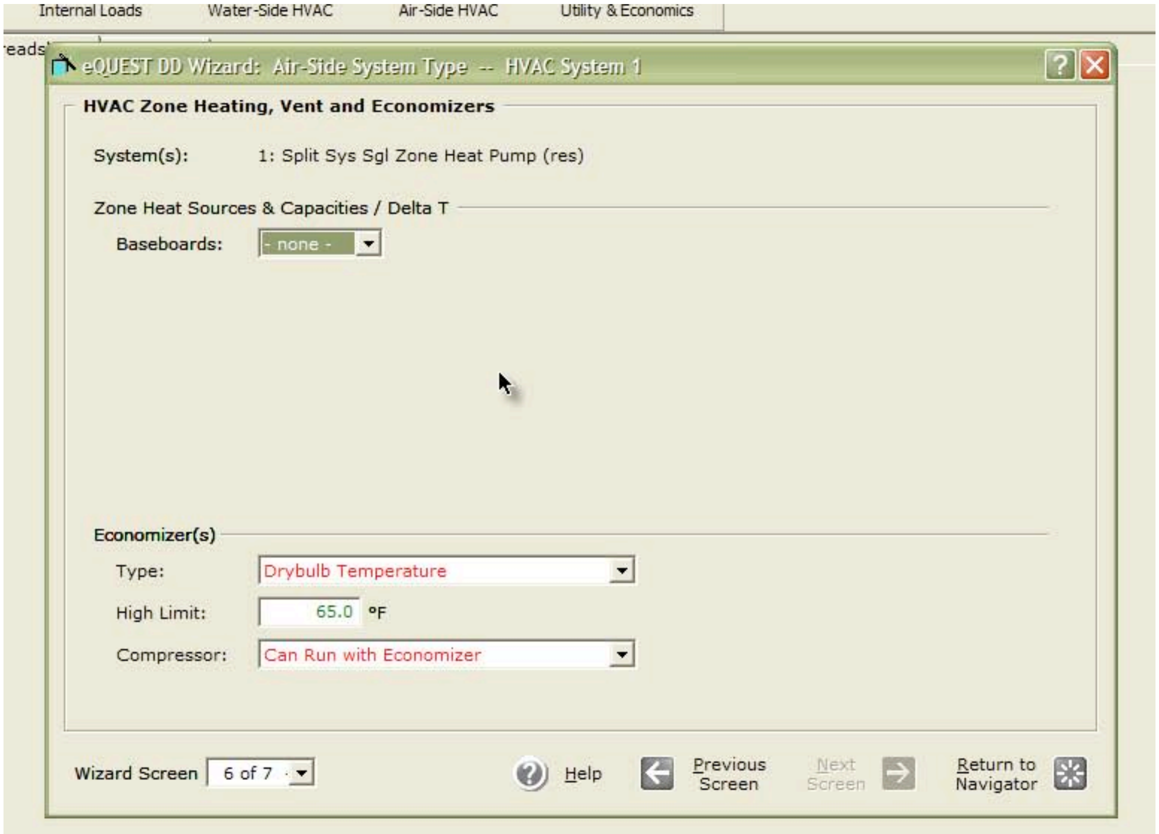


Figure C-32: Spring occupancy graph.

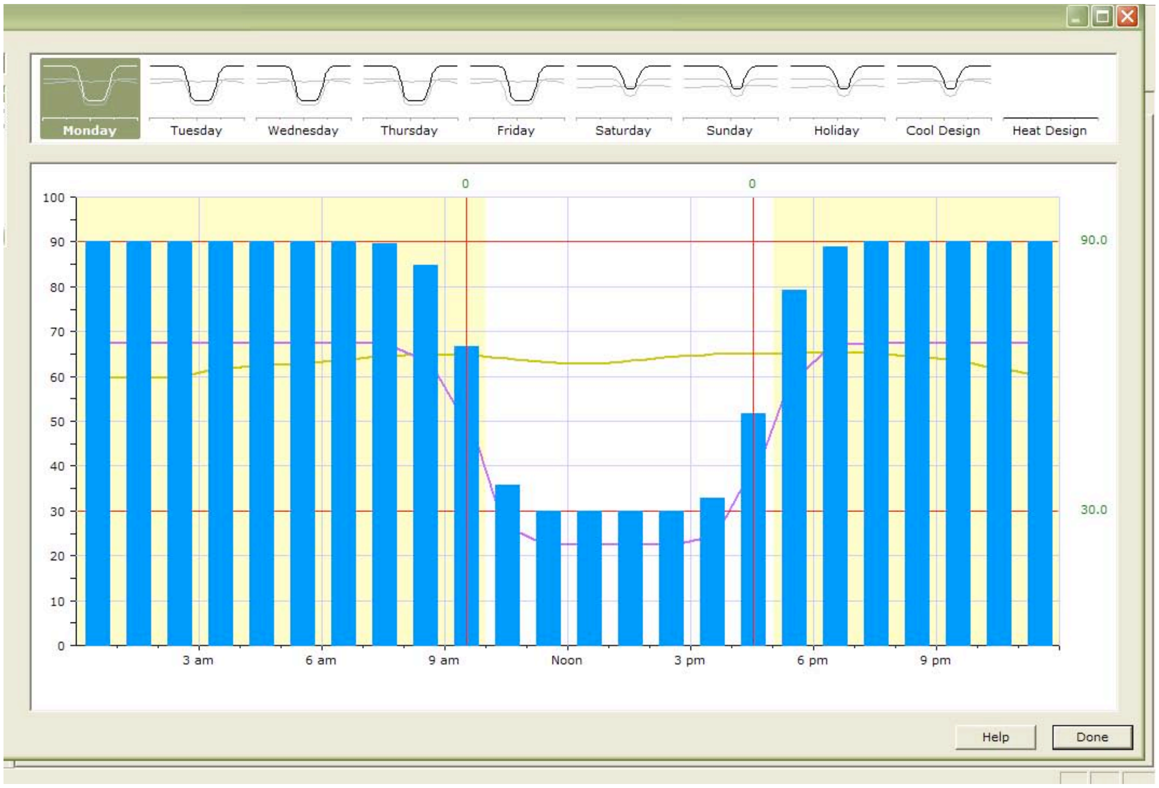


Figure C-33: Winter occupancy graph.

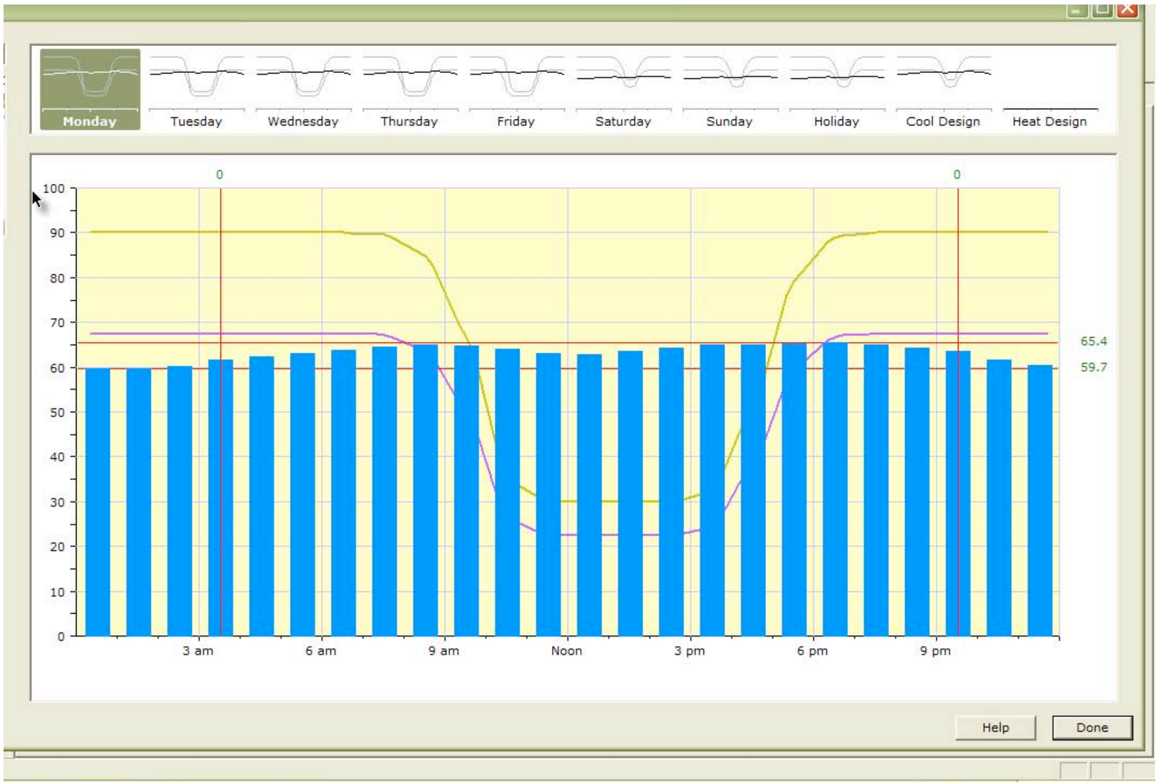


Figure C-34: Summer occupancy graph.

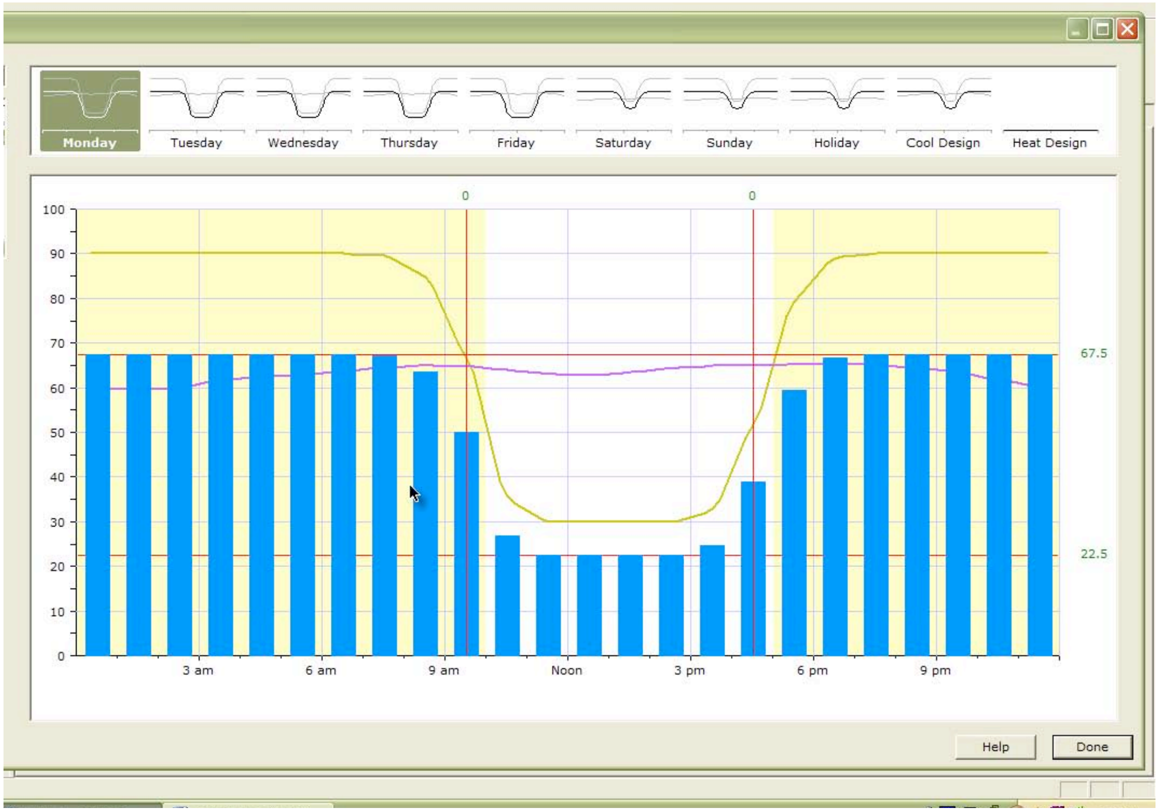


Figure C-35: Spring ambient lighting profiles.

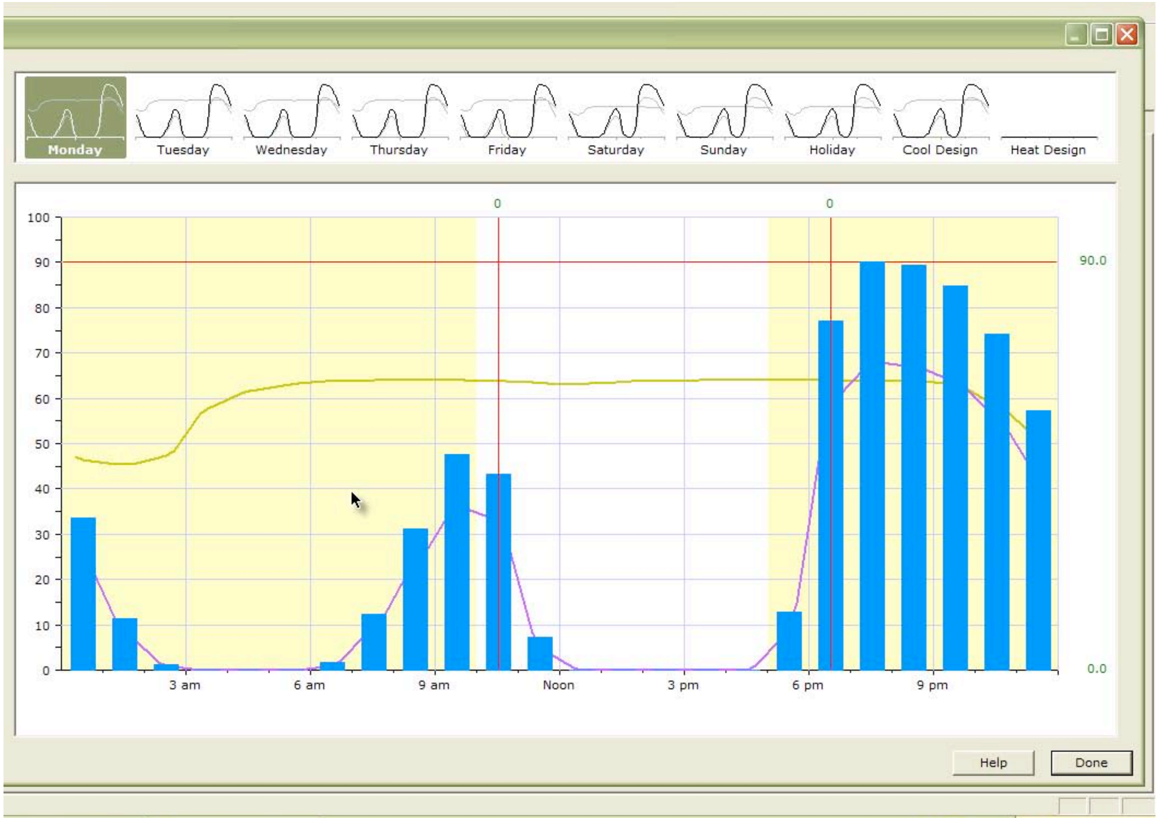


Figure C-36: Winter ambient lighting profiles.

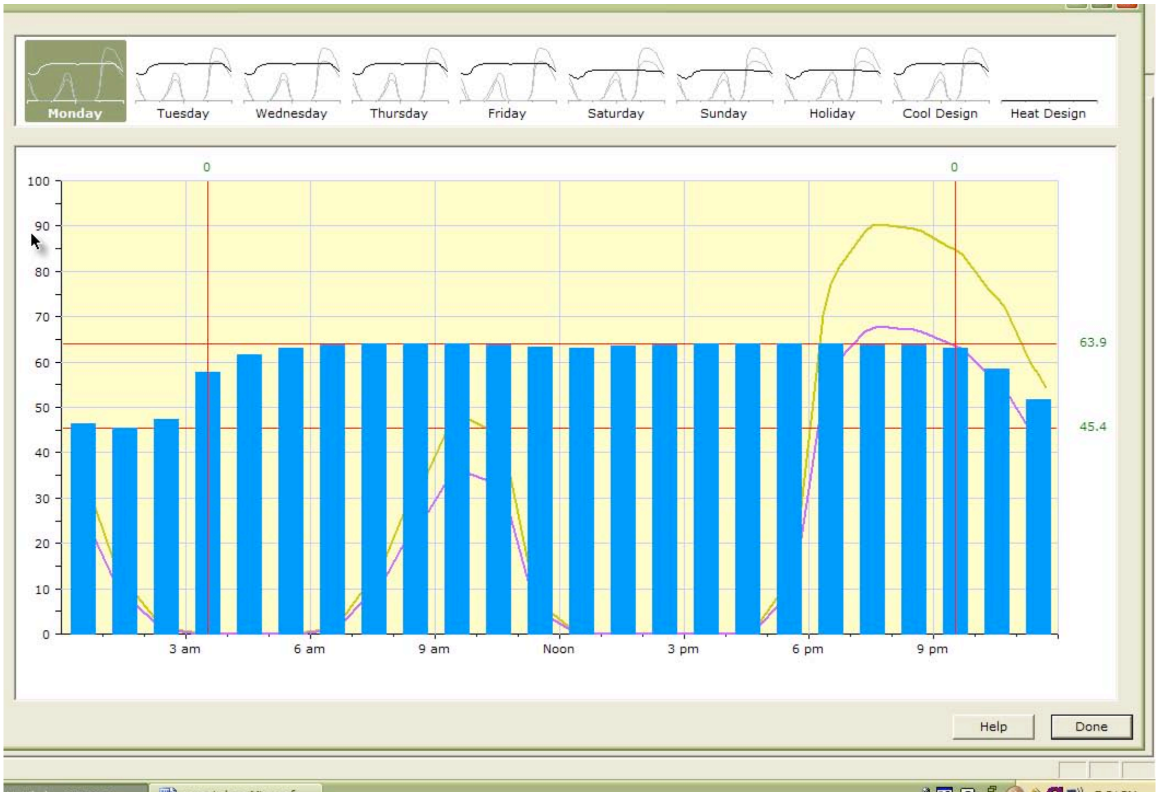


Figure C-37: Summer ambient lighting profiles.

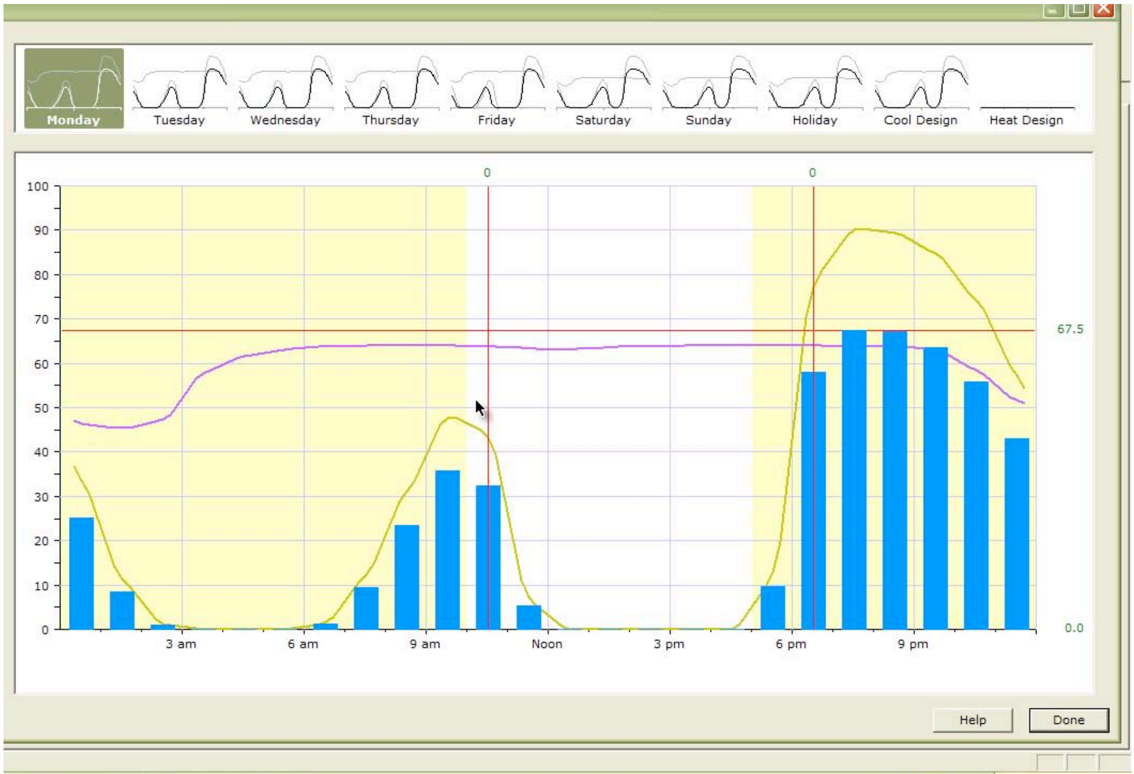


Figure C-38: Spring cooking equipment profiles.

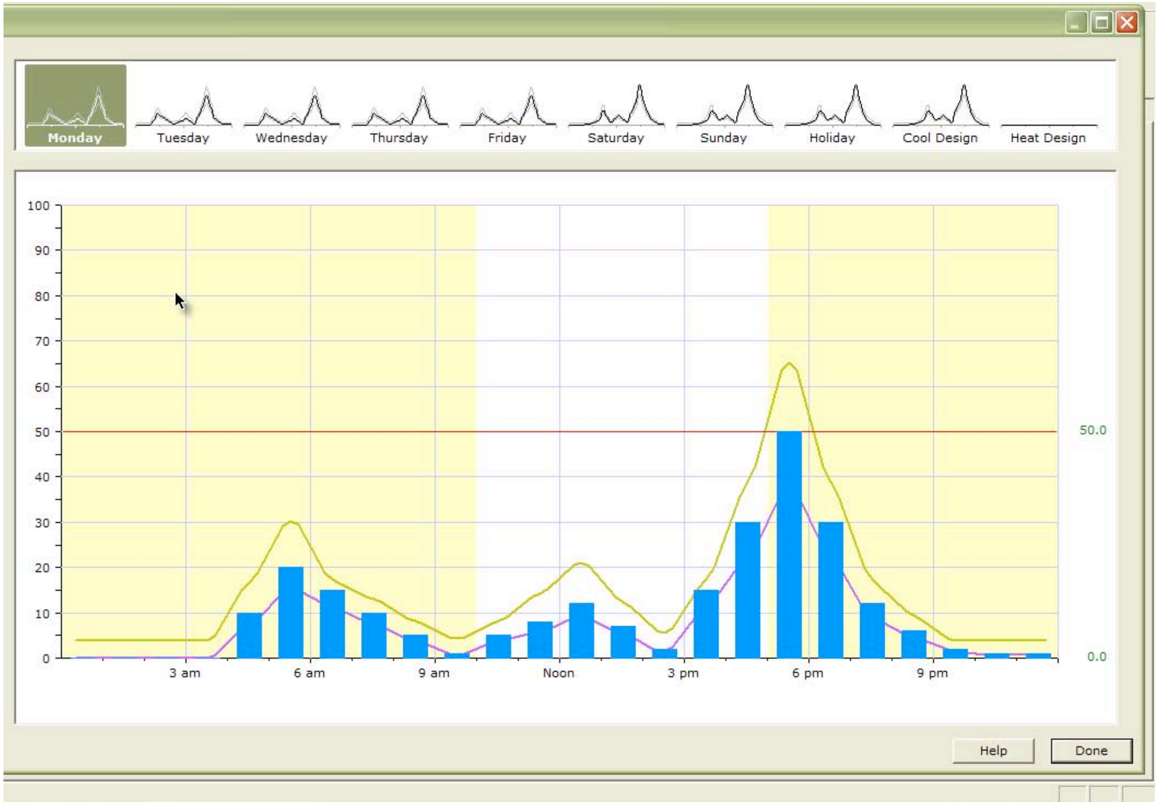


Figure C-39: Winter cooking equipment profiles.

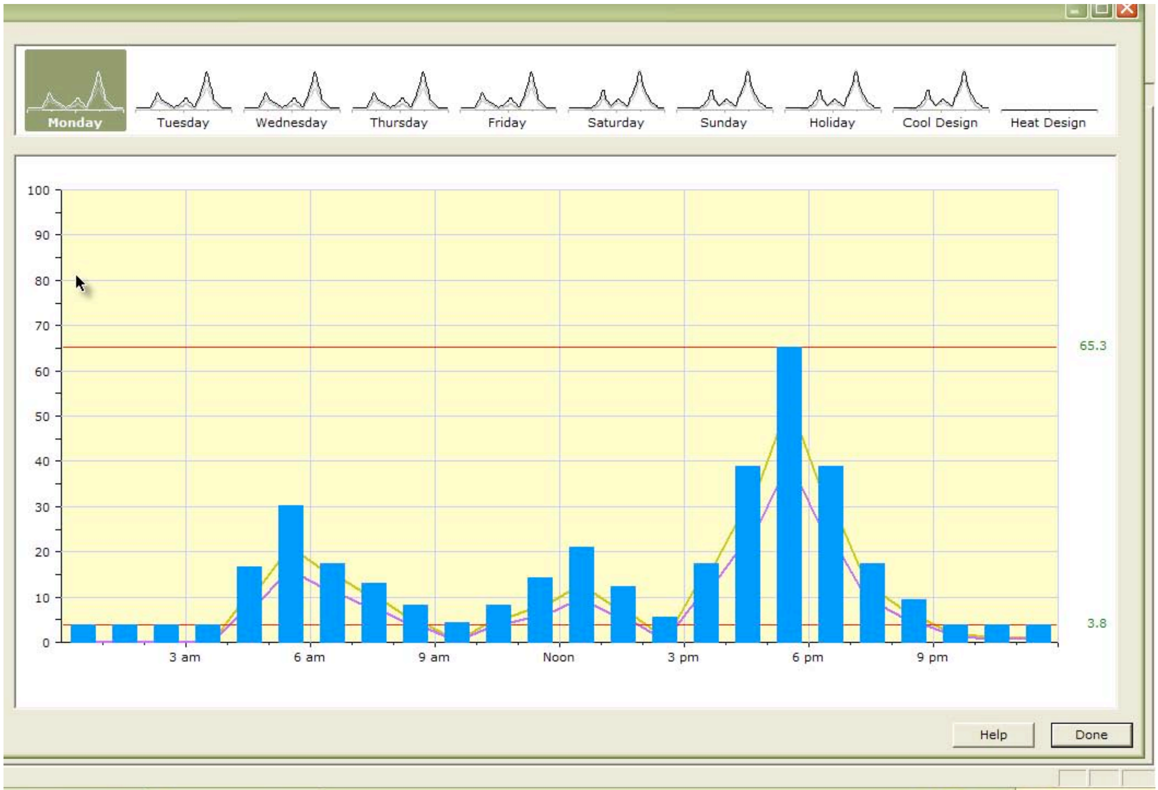


Figure C-40: Summer cooking equipment profiles.

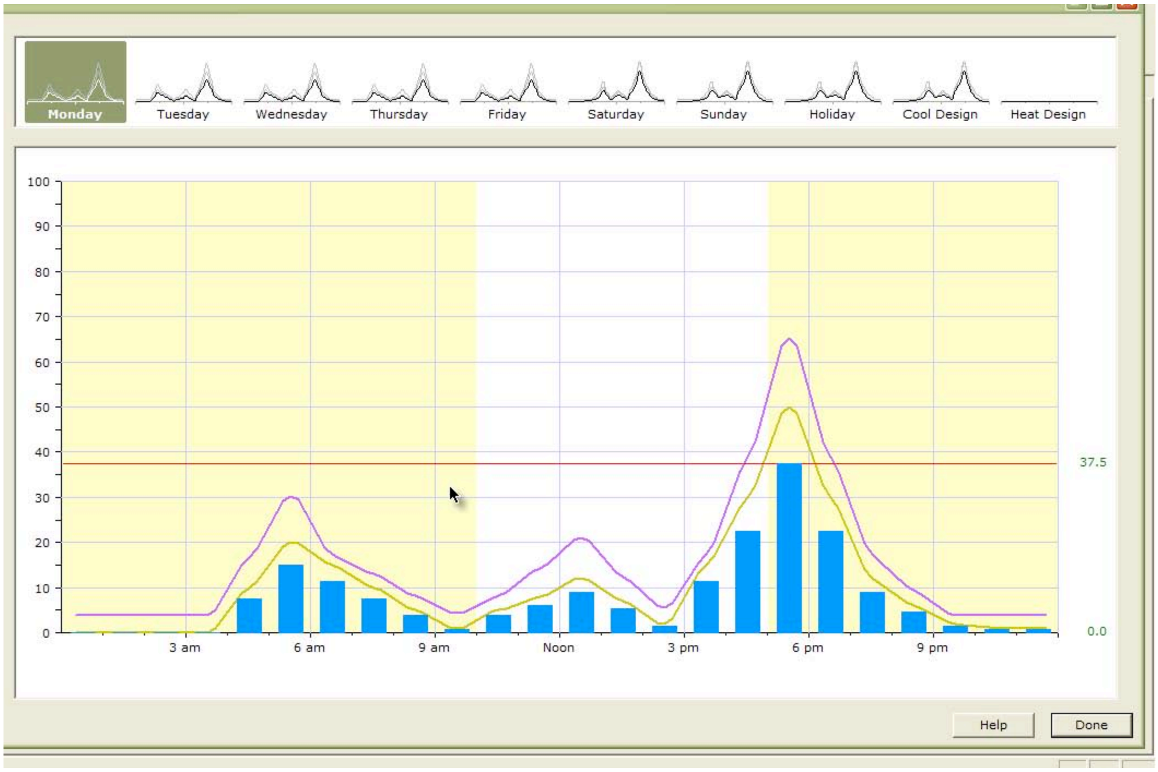


Figure C-41: Spring miscellaneous equipment profiles.

Figure C-42: Winter miscellaneous equipment profiles.

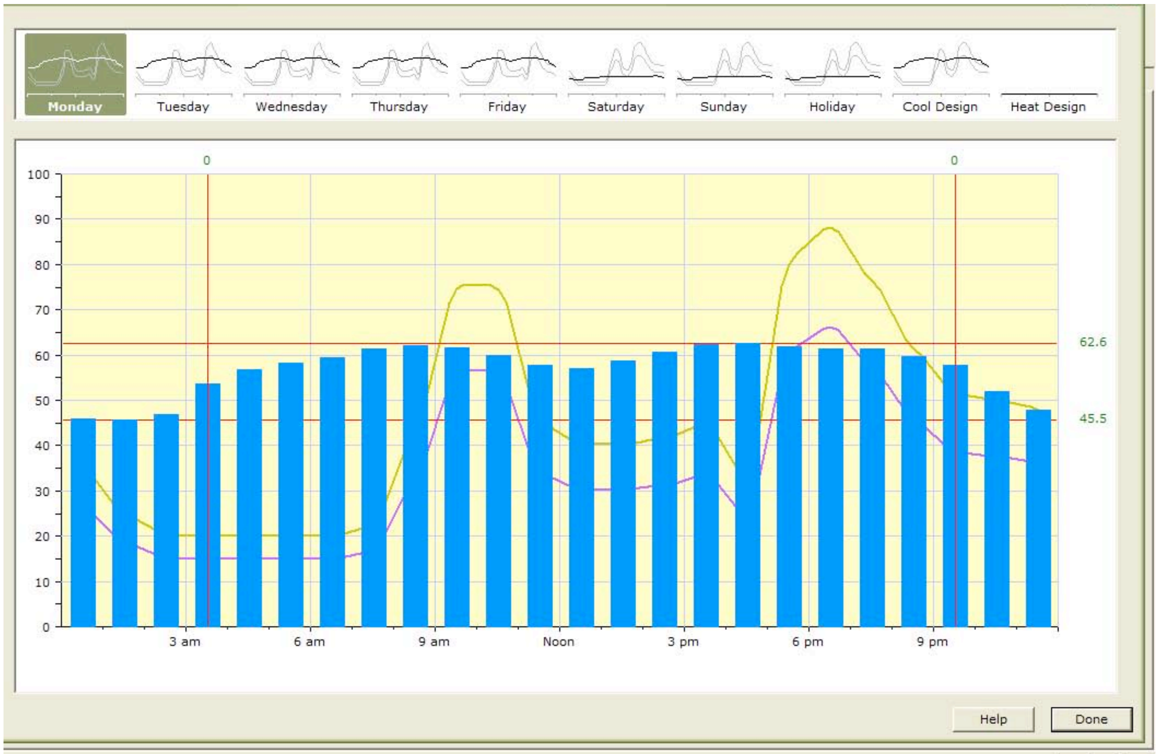


Figure C-43: Summer miscellaneous equipment profiles.

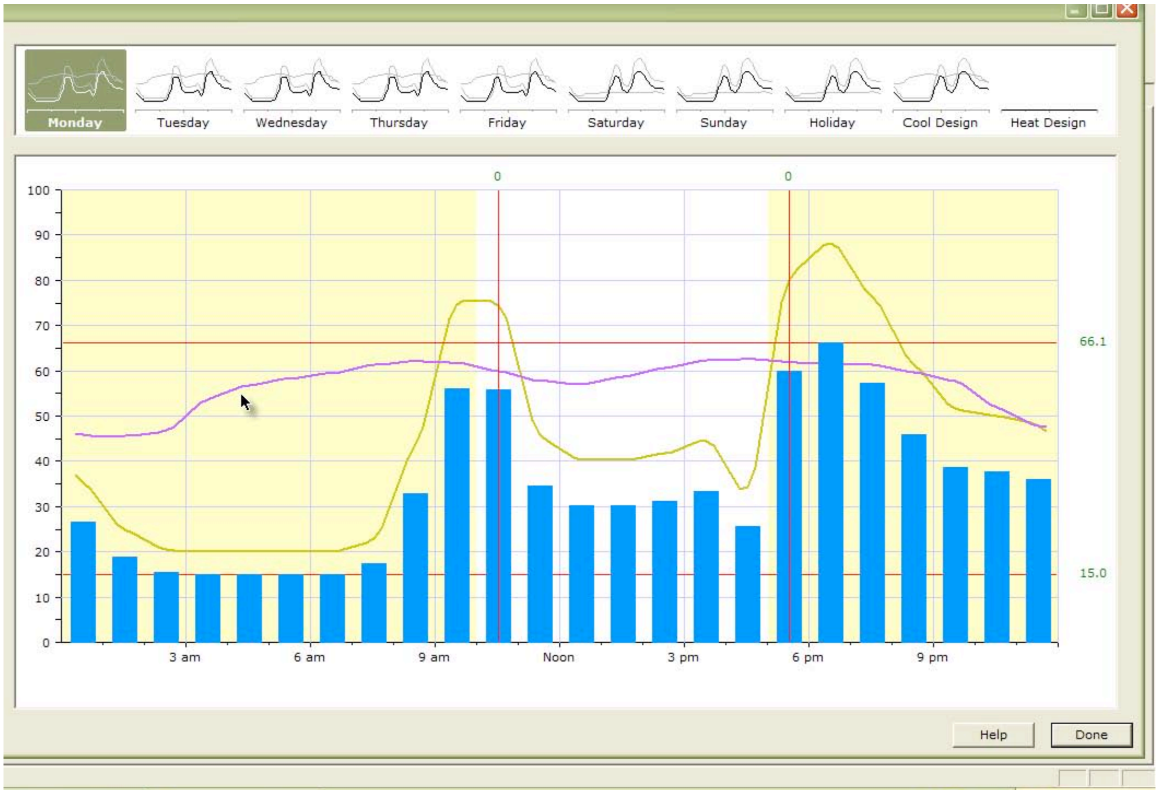


Figure C-44: Spring self-contained refrigeration profiles.

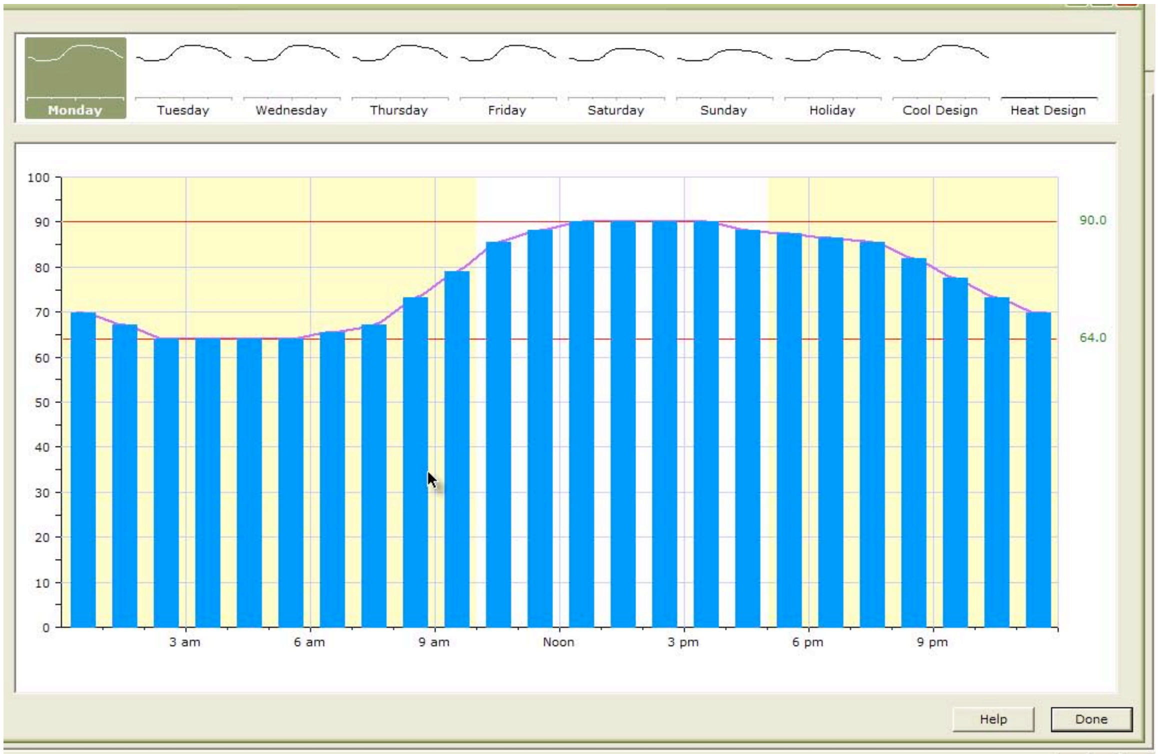


Figure C-45: Winter self-contained refrigeration profiles.

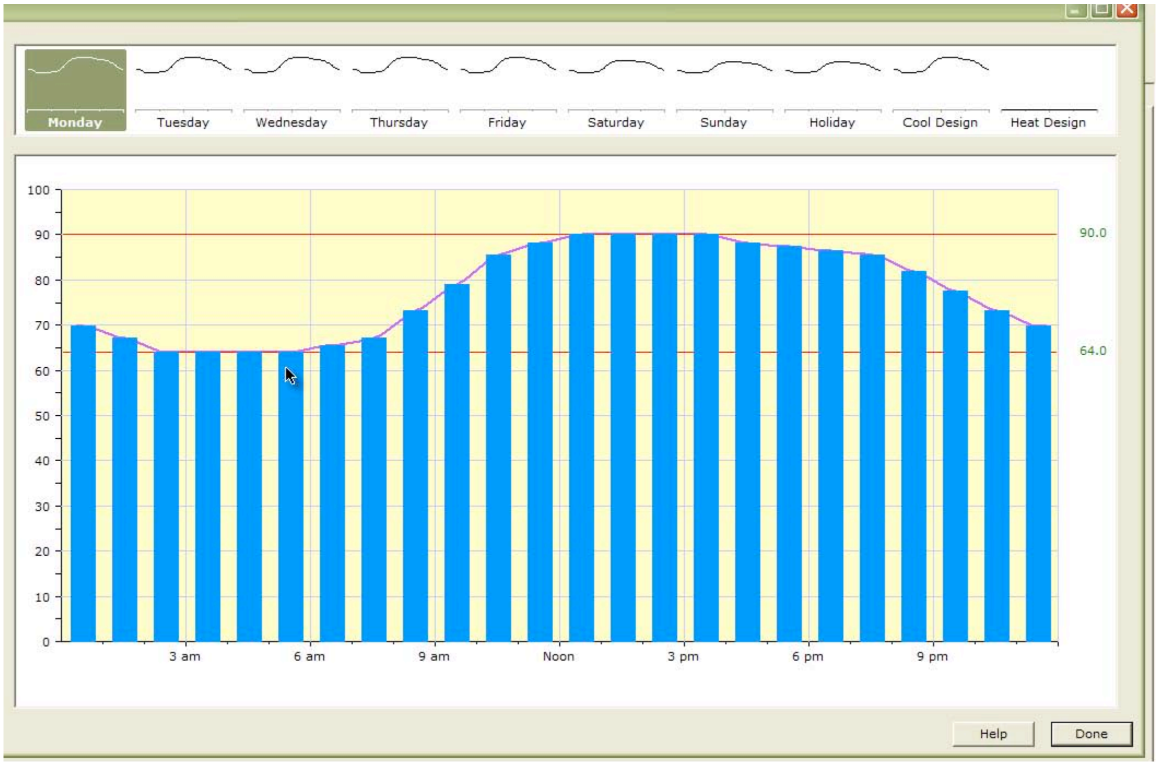


Figure C-46: Summer self-contained refrigeration profiles.