Project Number: CE-LDA-0904

Environmentally Sustainable Design for a Residential Building

A Major Qualifying Project Report

Submitted to the Faculty

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by

Timothy Glover

Tracy Golinveaux

Meghan Woods

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Approved:

Prof. L. D. Albano, Major Advisor

keywords

1. green design
2. residential design
3. sustainable

Abstract

The goal of the project is to develop life-cycle data and cost analysis to investigate the feasibility of a sustainable residential structure compared to a traditional residential structure. The first structure incorporates traditional design methods and the second includes sustainable design, as specified by LEED. A fire protection system was designed and integrated into both structures.

Authorship

All Chapters of this project were worked on equally by all members of this project group with the exception of the following:

Chapter 3: Methodology
    Written by Timothy Glover
Chapter 4: Design Plans
    Written by Tracy Golinveaux
Chapter 5: Traditional Design
    Tracy Golinveaux and Meghan Woods
Chapter 6: Green Design
    Timothy Glover and Meghan Woods

The signatures below indicate acceptance of the above.

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Tracy Golinveaux

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Meghan Woods

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Timothy Glover

Capstone Design Statement

This Major Qualifying Project, in conjunction with ABET general capstone requirements, integrates eight important constraints to the project that exist in the real world. Economic, environmental, sustainability, constructability, health and safety, social, and political limitations are explored. The project was a culmination of the group members' previous coursework knowledge and research of civil engineering topics including structural design, environmental engineering, geotechnical engineering, and cost estimation.

Economic

The economic inquiry of the project was investigated through a cost analysis of a traditionally designed one story house and a green design of a house. A 20 year payback cycle was reviewed. This enhanced the group members' understanding of construction and project economics.

Environmental

Environmental limitations are very prevalent in today's world. The group members explored environmentally conscious aspects of the project such as alternative energies, environmentally safe materials, and environmentally conscious design. The green design was to LEED certification.

Sustainability

Sustainability encompasses social, environmental, and economical aspects of life. The project design is focused on bringing those aspects together. The project also focuses on the reusability of certain things such as rain water, graywater, etc. These concepts benefit the building and the environment. Because reuse and flexibility is so important, the aspect of sustainability played a key role in the design.

Constructability

The design of the house was developed to be constructible. The house is designed using New England climate, energy and cost data. The data is not limited to one particular state or town in order to provide a wide range of locations for the house to be built. The use of common, accessible construction materials and a repetitive design make the house simple and easy to manufacture.

Health and Safety

Healthy and safety restrictions were met throughout the project with various building code provisions. In addition to structural integrity, a fire protection system was an important safety aspect to the design. The International Residential Codes were used for building design requirements and NFPA 13 was used for the fire protection system design.

Political

An understanding of the political constraints was also accomplished during project research. Today, green designs are becoming more popular due to the environmental concerns. Because the government is supporting green designs, the topic is in the political spotlight. This has occurred in Boston through the Solar Boston Project. Boston's Mayor Menino announced the city's plan to have 25 megawatts of solar capacity by 2015. ((Boston), 2008) The Mayor's interest in solar technology sparks new interest for Boston residents and businesses. At the time of Mayor's announcement in 2008, the City's capacity was only 0. 5 MW and today it is already at 1. 0 MW, proving that political interest can stimulate interest in green technology.

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1 Introduction

Green buildings are becoming increasingly common for both residential and commercial structures. The high demand for green design spurs from a greater than ever world consciousness for the environment and sustainability. In many cases as well, green structures may provide a lower lifetime cost alternative to conventional building methods. Although green technology is more expensive than traditional technologies, it has the potential to have a shorter payback period due to significantly reduced utility bills. With the current economic condition, cost-effective designs will certainly drive the market forward.

The idea of green design is still a new concept. Therefore, the definition of what is, and what is not green has sometimes been confusing. However, there are many emerging ways to define a green design. Since 1998 a rating system for green design called LEED has existed. LEED (Leadership in Energy and Environmental Design) was developed by the U. S. Green Building Council and provides a checklist to achieve sustainable building design. Features in the checklist include a range of construction aspects from site selection, to energy sources, to materials of construction. Energy-efficient appliances, alternative heating/cooling sources, solar energy and water conservation all contribute to what is widely considered to be green. (U.S. Green Building Council, 2008)

The aim of this project is to design two similar houses and compare them. One design will involve traditional construction methods that are still widely used today; the other design will incorporate particular environmentally sustainable methods as defined by the LEED standard. The house is an assumed one-story home with seven rooms, two full bathrooms, and a two-car garage. The traditional home will be built to meet the provisions of the International Residential Code (IRC) and will use standard wood-frame construction. The green home will employ new technology and practices to meet the minimum certification by LEED standards for green design while also meeting the criteria set by the

IRC. The cost benefits and payback over a twenty-year period will be considered in the comparison of the two homes.

A fire protection system will also be developed and implemented within both designs. In 2007, there were 399,000 house structure fires in the United States. The fires caused 2,865 deaths and $7.4 billion in property damage. Because of the rising statistics for fire losses, the International Code Council (ICC) members voted in support of residential fire sprinkler requirements for all new homes (National Fire Protection Association, 2008). Therefore, in addition to designing a safer home by providing sprinklers, the project will be in conformance with the new fire protection standards in the 2009 edition of the IRC. An objective for the fire protection system is to incorporate it into the green design aspects to prove its sustainability in not only homes but in any type of building.

The project will include two building designs complete with design drawings, calculations, and cost analyses. The traditional building will be designed with bearing wall construction while the green building will make use of structurally insulated panels. The green building will incorporate Energy Star appliances and finishes (recognized by LEED), a geothermal heating system, a solar hot water system, and photovoltaic electricity to add to its sustainability and to meet LEED certification standards. The heating and water systems designs will include drawings and demand calculations.

The last objective of the project is to create a comparison between the traditional and green structures. The comparison will include an initial cost analysis, a life cycle cost analysis, and a 20-year payback analysis.

2 Background

With the emphasis on becoming a greener world, many aspects of the design and construction have changed over the years to satisfy the sustainability movement. From building materials to floor plan layouts, the emerging green methods are different than traditional techniques. Green methods strive to be more sustainable by taking into account other things than the actual material. For example, waste produced during production and installation, environmental impacts from materials and construction, lifetime of products, and other characteristics are all taken into account with a green design.

Many aspects were considered in the design of both the traditional and green homes. Figure 1 summarizes the focus areas for both the traditional and green designs. The framing, layout, systems, and costs were determined to be the major focus areas. These elements are not only the outline of the design, but they provide a framework for design comparison. Once determined, other factors were considered.

Architects, contractors, and suppliers use the MasterFormat specifications standard created by the Construction Specifications Institute to organize data and construction requirements for many commercial building design and construction projects. The MasterFormat specifications create a standard organization that is easily followed and managed by the various trades working on construction projects. This format allows for the construction process to be easily broken down into key elements. The MasterFormat provided the backbone of the focus areas for this project.

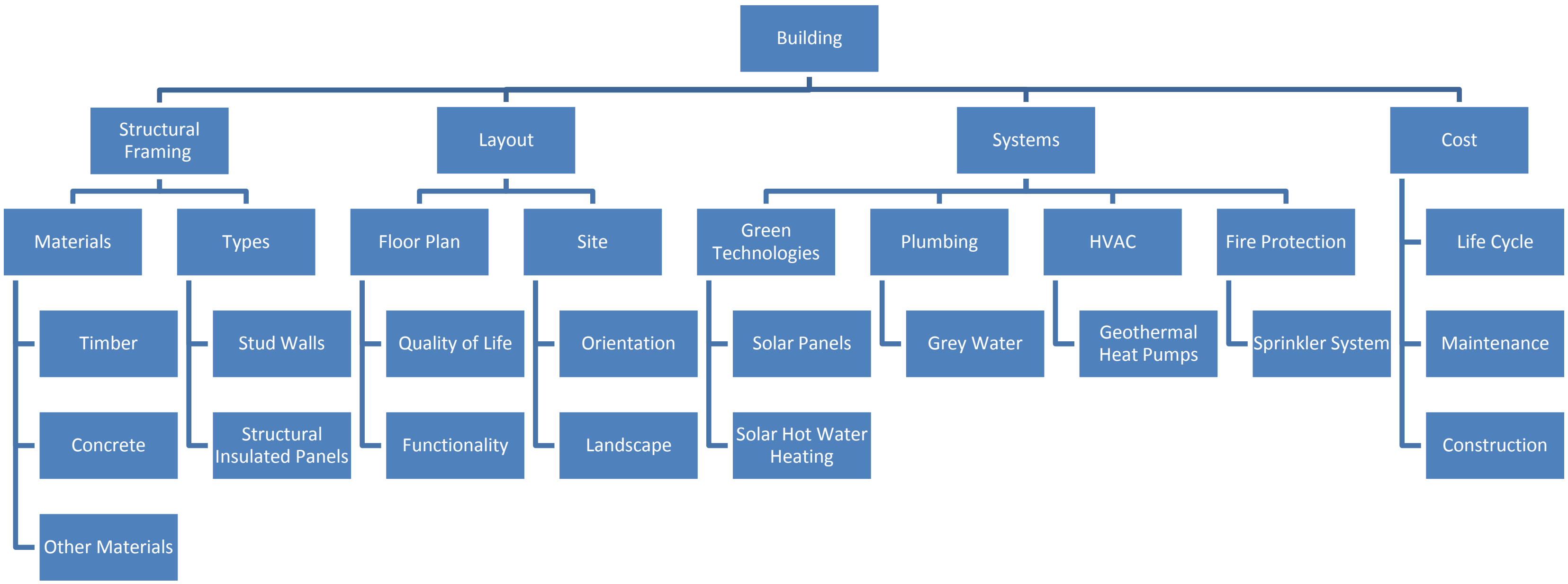

Figure 1: Focus Areas

2.1 Building Materials

Sheets of plywood, 2X4 wood studs, glass windows, ceramic tiles, and polyvinyl chloride (PVC) pipe are a few of the materials that can be found scattered across a typical residential construction site. The materials used in residential construction can be natural or manmade. These materials work together to provide an environment suitable for living.

2.1.1 Timber

Wood is a traditional building material because of its strength, availability, and low cost. (Council) It is readily available and inexpensive because it is a natural, renewable material. Compared to other building products such as steel, wood is easily manipulated and assembled on-site which saves time and money.

Traditional wood frame homes make use of many types of wood products such as studs, girders joists, plywood, and trusses. Figure 2 illustrates the wide variety of wood elements used in residential construction. The use of wood in many of the building's structural aspects allows the builder to save money without sacrificing strength or durability. Wood also gives flexibility to the builder to accommodate unique features and custom designs.

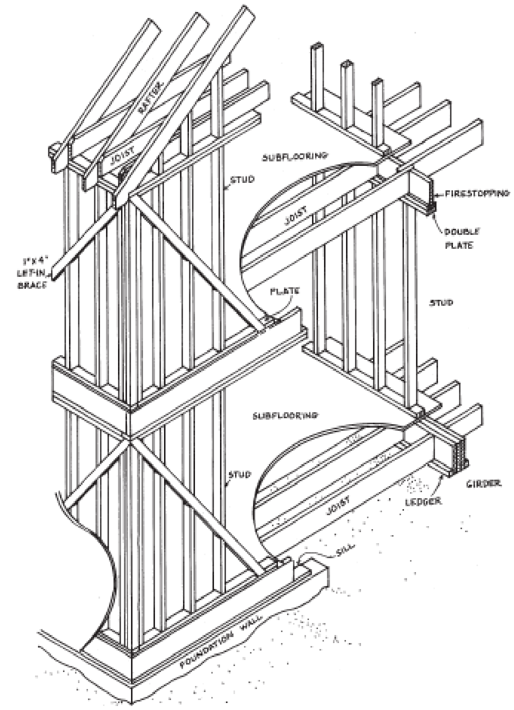

Figure 2: Timber Construction (Association)

Wood can also be made into structural insulated panels (SIP). SIP's are a building material made of two wooden structural boards sandwiching an insulating material. Structural insulated panels have been used since the 1930's. Recently, SIP's have been becoming more and more popular. One reason is that they are a green alternative to the conventional use of studs and joists. SIP's are also very versatile as they can be used in residential (house, garage, work shop, duplex, etc.), commercial (school, restaurant, church, computer lab, etc.), and industrial (storage container, hazmat chamber, electrical housing, etc.) applications (SipFAQs, 2007). Another reason for their popularity is that less skilled labor and a lesser amount of time are needed to construct a building with SIP's than traditional lumber frame.

Structural insulated panels help improve the building envelope by providing greater thermal insulation. A building envelope, which includes the roof, walls, foundation, doors and windows, is the outer shield that protects a home from the environment. To provide a comfortable living environment, it is important to control the inside conditions from the outside conditions. To be reasonable, this has to be done in an efficient and cost effective way. SIPs help promote a tight envelope because they limit the amount of holes or entries for air to the inside or outside of the home. They also have a high insulating value with minimum thermal bridging which makes them ideal for extreme climate conditions. This results in a comfortable living environment. (Canam)

Structural insulated panels are used for walls, roofs, and floors. The structural faces are made of two oriented-strand boards (OSB) and the inner insulation is made of polystyrene, polyurethane or polyisocyanurate foam board. The panels are normally 4' wide x 6', 9', or 12' long, and range from 4.5" to 6.5" in thickness for standard polyurethane SIP's. Interior walls are normally stick construction because the SIP technology is unnecessary for the nonbearing walls. This allows those walls to be utilized for HVAC and other systems purposes.

Structural insulated paneling is considered a "green" type of construction, especially compared to conventional wood lumber frames. Since OSB is made from wood chips, 95% of a tree can be used versus 63% when lumber is sawn (BuildCentral, Inc., 2009). Also, wood lumber contains many defects such as knots, warping, or mold spores which can result in uneven walls or ceilings, nail and/or screw "pops" in drywall, and the growth of toxic mold. These defects are not transferred to the wood chips that make up the OSB. Since the SIP's are prepared in a factory, there is less waste produced at the construction site and more waste recycled at the factory. The use of SIP's help reduce energy consumption. Because SIP's improve a tight envelope, HVAC costs are 35%-50% less than that for a conventionally designed house. Also, found through research studies, SIP's are more fire resistant than studs and joists. (A Brief History of SIPs)

In addition to providing a leak proof building envelope, SIPs are very versatile. The green home can very easily be expanded to accommodate a larger family. SIP walls can be lengthened to reach a second floor in a balloon style framing design. In this case, the balloon style would be preferable because it ensures that the building envelope will remain intact. Typically, interior floors are not designed with SIPs. As a result, stacking floors would leave an opening between the SIPs at each floor level. Instead, a SIP wall can hold a hanging floor.

Structural Insulated Panels are tested in a number of ways to ensure safety and compliance with building codes. They are designed with respect to fire resistance, structural loadings, building, and other performance criteria. Fire tests include ASTM E-84 15-minute, UL 1256 15-minute, among others (Porter Corporation, 2001). All SIPs and some of their components must bear the UL classification mark (Porter Corporation, 2001). SIPs having a foam insulating material must be covered with a material having a fire rating of at least 15 minutes. An example of suitable covering is gypsum wall board.

Standards produced by ASTM International (originally known as American Society for Testing and Materials) and National Design Specification for Wood Construction are used for testing different aspects of SIPs. Standards used for testing include ASTM D 2915, ASTM D 4933, ASTM D 5266, AFPA 2, and more(NTA, Inc., 2007). The standards test the strength of the SIPs, adhesives used, and thermal capabilities. Each type of panel has respective axial and transverse allowable loadings. The allowable limits are determined through different types of tests and provided for different sizes, types, and lengths of SIPs. Each SIP manufacture publishes independent allowable limits. An example from the Porter Corporation is provided in Figure 3 and Figure 4 (NTA, Inc., 2007). The transverse load would be analyzed for each design based on expected dead and live loads. The allowable loads in Figure 3 and Figure 4 would be the maximum loads for the selected panel size. If the expected calculated loads for exceed those in the tables then an alternative panel size or design must be chosen.

		SANDWICH PANEL DIMENSIONS				
Skin Thickness Core Thickness Panel Depth		7/16" 3 5/8" 4 1/2"	7/16" 5 5/8" 6 1/2"	7/16" 7 3/8" 8 1/4"	7/16" 9 3/8" 10 1/4"	7/16" 11 3/8" 12 1/4"
Panel span between supports	DEFL. LIMIT	ALLOWABLE TRANSVERSE LOAD FOR SIMPLE SUPPORTED WALL PANELS (DEAD + LIVE) psf				
7.5 ft	L/180	22 s	32 s	41 s	52 s	63 s
	L/240	22 s	32 s	41 s	52 s	63 s
	L/360	22 d	32 s	41 s	52 s	63 s
9.5 ft	L/180	17 s	25 s	33 s	41 s	49 s
	L/240	17 s	25 s	33 s	41 s	49 s
	L/360	17 s	25 s	33 s	41 s	49 s
11.5 ft	L/180	14 s	21 s	27 s	34 s	40 m
	L/240	14 s	21 s	27 s	34 s	40 m
	L/360	14 s	21 s	27 s	34 s	40 m
13.5 ft	L/180	12 s	18 s	23 s	29 s	29 m
	L/240	12 s	18 s	23 s	29 s	29 m
	L/360	11 d	18 s	23 s	29 s	29 m
15.5 ft	L/180	10 s	16 s	20 s	25 s	22 m
	L/240	10 s	16 s	20 s	25 s	22 m
	L/360	8 d	15 d	20 s	25 s	22 m
17.5 ft	L/180	9 s	14 s	18 s	22 s	17 m
	L/240	9 s	14 s	18 s	22 s	17 m
	L/360	6 d	12 d	17 d	22 s	17 m
19.5 ft	L/180	8 s	12 s	16 s	20 s	14 m
	L/240	7 d	12 s	16 s	20 s	14 m
	L/360	5 d	10 d	14 d	20 d	14 m
21.5 ft	L/180	8 s	11 s	14 s	17 m	11 m
	L/240	6 d	11 s	14 s	17 m	11 m
	L/360	4 d	8 d	11 s	16 d	11 m
23.5 ft	L/180	6 d	10 s	13 s	14 m	10 m
	L/240	5 d	9 d	13 s	14 m	10 m
	L/360	3 d	6 d	9 d	14 d	10 m

Notes:
1. Values shown in tables are the allowable wind load.
2. Controlling conditions: "s" shear, "m" moment, "d" deflection.
3. Minimum bearing required is 3 inches.
4. Deflection criteria is L/180 for wall loads.
5. All loads are normal duration loads. No duration factors are allowed.
6. Loadings shown above are mainly limited by the connection details of the panels to the floor.
7. For comparison purposes the following are wind speed conversions:

70 mph = 12.6 psf   80 mph = 16.4 psf   90 mph = 20.8 psf   100 mph = 25.6 psf

Table TW-1   Transverse Loads on Wall Sandwich Panels   Updated 4/29/02

Figure 3: Allowable Transverse Loads (Porter Corporation, 2001)

	SANDWICH PANEL DIMENSIONS				
Skin Thickness Core Thickness Panel Depth	7/16" 3 5/8" 4 1/2"	7/16" 5 5/8" 6 1/2"	7/16" 7 3/8" 8 1/4"	7/16" 9 3/8" 10 1/4"	7/16" 11 3/8" 12 1/4"
Transverse wind load (psf)	0	0	0	0	0
Panel clear span	ALLOWABLE AXIAL LOAD (DEAD + LIVE) plf				
10	2585	2680	2763	2858	2954
12	2355	2485	2598	2727	2856
14	2126	2289	2432	2595	2758
16	1897	2094	2266	2463	2660
18	1667	1898	2101	2332	2563
20	1438	1703	1935	2200	2465
22	1208	1508	1769	2068	2367
24	979	1312	1604	1937	2270

Notes:
1. Allowable loads are based on axial loads being applied over entire panel thickness.
2. The deflection criteria for the wall panels is L / 240.
3. All values are normal duration loads. No increases for other load durations allowed.
4. Some allowable loads and spans are not totally based on deflection, therefore no multipliers for other deflection criteria shall be allowed.
5. All listed values are for single span panels with supports at the top and bottom.
6. All axial loads can be applied with a maximum eccentricity equal to one-sixth of the panel thickness.

Table A-1 Axial Loads on Sandwich Panels Updated 11/19/99

Figure 4: Allowable Axial Loads (Porter Corporation, 2001)

The R-Value is a measure of the thermal resistance in a building, its ability to resist heat flow. A large R-value means that the building has effective insulation while a small R-value reflects inefficient insulation. The R-value is affected by the building envelope, and is given as an ideal number. However, R-values are reduced due to holes from nails, seams, splines, etc. Figure 5 compares the R-values of SIPs with those of stud walls (Structural Insulated Panel Association, 2007). It is apparent that stud walls loose more of their R-value after construction.

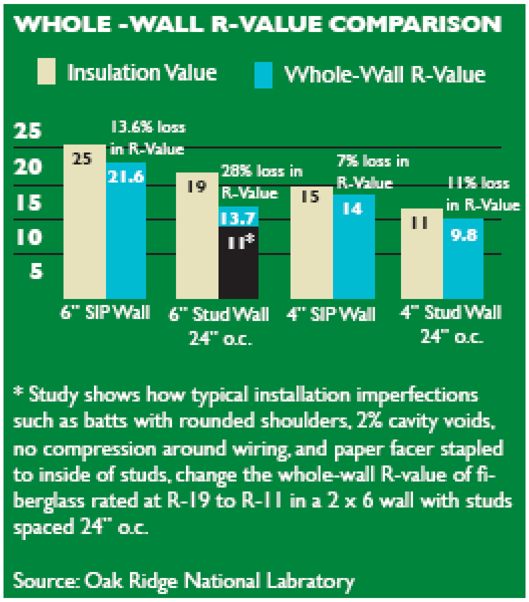

Figure 5: R-Value Comparison (Structural Insulated Panel Association, 2007)

Some builders are reluctant to use SIPs in their construction practices due to problems they may encounter. It is difficult for the HVAC equipment to be incorporated into existing SIP because space between the interior and exterior boards is limited. However, some SIP manufacturers produce the panels with HVAC systems in mind. For example, the Murus Company, Inc. installs horizontal chases at specified heights into their SIPs for electricians to use (Murus Company, Inc., 2008). In other cases, a vertical or horizontal chase can be built along the panel and concealed to protect the system. Also, when necessary, ductwork can be routed through interior stick construction to accommodate. Figure 6 illustrates an example of a horizontal and vertical chase for the HVAC industry to utilize, provided by Porter Corp., (Porter Corporation, 2001).

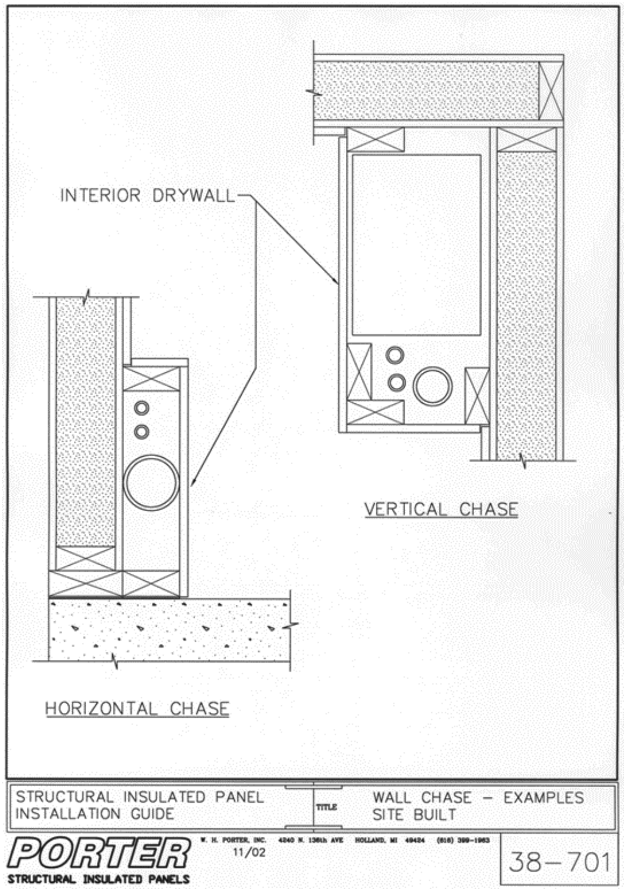

Figure 6: HVAC Chases for SIPs (Porter Corporation, 2001)

2.1.2 Enclosure

Providing protection from the elements is the primary purpose of a residential structure. In addition to the structural framing, the windows, doors, insulation, and roofing all provide levels of protection. Windows and doors provide access in and out of the enclosure.

Glass is used as a building material to allow occupants to make use of natural light while providing protection from the elements. Operable glass windows and doors allow light to filter in, air to flow throughout the home, and ultimately increase the contentment of one's surroundings. Since human beings are drawn to and thrive in natural light, it is essential to integrate it into the design. The ever so environmentally conscious world has steered the design and installation of windows as a sustainable aspect of a home. Characteristics affecting a green window include the frame, the insulating glass material, glass spacers, installation, size, and solar orientation.

Double paned windows are the most energy efficient. They involve two panes of glass with an air separator between them. The air acts as a buffer so heat is transferred slower, keeping the home warmer in the winter and cooler in the summer. Using argon or krypton gases to fill the air space is becoming popular due to their low thermal conductivity.

Protection from the elements can also be provided with installation between the exterior and interior walls. Typical homes might use fiberglass insulation, made up of glass fibers, for this purpose (Energy). Environmentally friendly methods for thermal and moisture protection can be implemented at similar costs to traditional methods. Composite siding uses recycled materials like newspaper, and waste woods such as sawdust. Loose-fill insulation in the walls can also be made from recycled materials while providing an R-Value comparable to standard insulation.

Proper roofing techniques can increase a structure's thermal and moisture protection as well. There are also several options for eco-friendly roofing. Metal shingles can be made from recycled metals and can also be easily recycled in the future. Although mineral-fiber cement shingles make good use of basic and common building supplies, often the supplies come from far away which increases the carbon footprint made from the production of such shingles. Lastly, for the consumer looking to put his house to work, there are Photovoltaic cells that can be integrated into the shingles of the house that provide carbon-free energy.

2.1.3 Concrete

Concrete is another common building material used to create foundations, columns, and paved surfaces. Concrete consists of three key ingredients, Portland cement, aggregate, and water. Portland cement requires large amounts of energy to produce and is necessary as the main bonding ingredient in concrete. Coal fly ash is commonly used as a substitute for Portland cement. Coal fly ash is a byproduct of the burning of pulverized coal in a coal-fired boiler furnace. The fine particles are carried off in flue gas. 60% of the recycled fly ash is used in cement production and concrete products. The 40% leftover is used in other construction applications. Characteristics of the fly ash are monitored closely because they can adversely affect the Portland cement. Such properties include fineness, loss on ignitions, and chemical content. (Turner-Fairbank Highway Research Center, 1996) Up to 60% of the cement can be substituted by this otherwise disposed of material. Using coal fly ash as an admixture to concrete is a green alternative while still keeping the strength of the material. Not only does the concrete have improved workability, but reusing the fly ash prevents it from sitting in landfills, therefore giving it an environmental advantage. (Building Green) Various other industrial waste products can be used in the same manner. (CSI Division 03: Concrete, 2008).

2.2 MEP Systems

Compared to other facilities, a residence may seem simple to run. However, there are many systems that contribute to the functionality of a home. Lighting, heating, and running water are a few of the many attributes that contribute to a habitable home.

2.2.1 Electrical Systems and Technologies

The appliances in a home typically rely on electricity for their power. Electricity is produced in a variety of ways. Burning coal or natural gas is one of the most common methods of providing electricity. There are also green alternatives including nuclear power, hydroelectric power, and solar power which are all carbon free. It is important to realize the importance of these alternative energy sources as fossil fuel prices increase and the amount of available fossil fuel diminish (Administration, 2008). It is also important to maximize efforts to conserve our natural resources by minimizing the use of electricity.

Solar technology is becoming increasingly popular with the rise in fossil fuel prices. Photovoltaic (PV) cells, also known as solar panels, produce direct current (DC) from the sun’s energy. An inverter converts the DC into alternating current (AC) which can be used to provide electricity to household appliances. Inverters are a vital part of the solar energy system because they require maintenance and repair more often than the panels themselves. Although solar power is a great way to reduce the use of energy produced by fossil fuels, it is difficult to rely solely on solar power. Batteries used to store excess solar power are extremely expensive. Without batteries, any unused power generated during the day is lost. One option for solar panel investors is to connect to the local power grid. During the day, excess solar power produced by the panels can be sold back to the grid effectively reducing the electricity bill. The grid connection will also provide power when the sun is down and if there are any problems with the solar panels. An example of a PV grid connected system is illustrated in Figure 7.

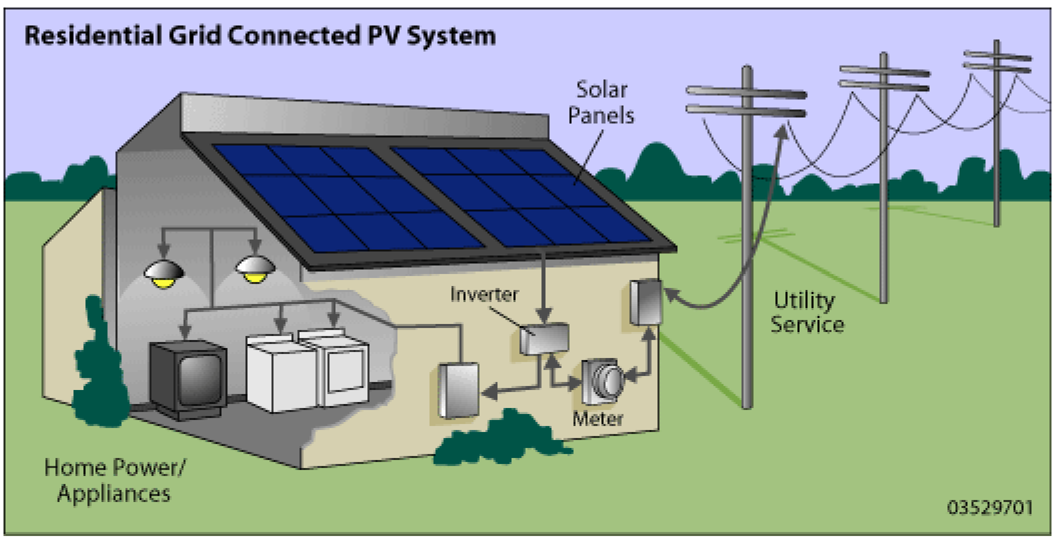

Figure 7: Residential Solar Power (EERE, How Small Solar Electric Systems Work)

In addition to producing green energy, it is important to conserve the amount of energy used. In 1992 the U. S. Department of Energy and the U. S. Environmental Protection Agency (EPA) joined together to create a program to help decrease the usage of electricity. Energy Star was produced to protect the environment and save money by using energy efficient manufacturing products and promoting conservation practices. Energy Star was first used as a voluntary labeling program by manufacturers to identify energy efficient products. Computers and monitors were the first to be labeled. As years passed, the list of labeled products grew larger including major appliances, office equipment, lighting, home electronics, and now new homes, commercial, and industrial buildings. There are over 50 product categories and thousands of models. Products are examined using Energy Star criteria to determine if they are eligible to be labeled (Energy Star). Products include refrigerators, freezers, dishwashers, clothes washers, room AC, geothermal heat pumps, ceiling fans, central AC, boilers, windows, doors, televisions, cordless phones, DVD/VCRs, computer/laptops, printer/scanners, light bulbs and fixtures, and others. Clothes dryers are not included because there is not a significant amount of savings between models. Using Energy Star labeled equipment will provide the "green" home with the most efficient and environmentally conscious products. It is estimated that Energy Star has helped save approximately $16 billion in 2007 alone. If followed, energy costs and green house gas emissions can be reduced by about 1/3 for a household. (Energy Star)

2.2.2 Fire Protection System

Fire suppression is the act of controlling and extinguishing a fire after it has been detected. Residential fire suppression can occur within the home from residents using tools such as a fire extinguisher or from outside the home by the fire department. Another way fire suppression can occur is with an automatic fire sprinkler system. Fire suppression is extremely important in residential structures. According to the National Fire Protection Association, a residential fire occurred every 79 seconds in 2007 (NFPA, 2007).

Residential automatic fire sprinkler systems are made up of many components. The first is the sprinkler head itself (See example in Figure 8). The sprinkler's deflector allows the water to spray in many directions to cover as much area as possible. The water spray pattern is important for preventing fire spread. The sprinkler's glass bulb is filled with a temperature sensitive liquid that expands at a certain temperature. Once this critical temperature is reached, the liquid expands and breaks the glass blub. Once the bulb breaks, the water can flow freely through the sprinkler head. Above the sprinkler head are a series of pipes and connections that convey water flow from the water source to the sprinkler heads. The water source typically comes from city mains.

Recently it has been proposed that fire sprinkler systems are green alternatives to fire protection. Since fire sprinklers control the fire at an early stage they reduce the amount of toxic gasses that are released into the air from burning wood, paints, household cleaners, and other items in the home.

Fire sprinkler systems also use less water to control a fire than the fire department would use. While fire sprinklers quickly detect the fire and start to suppress it automatically, the fire department needs to be notified, travel to the structure, begin setting up, and finally start their firefighting efforts. The elapsed time it takes before the fire fighters are ready to extinguish the fire allows the fire to grow rapidly and engulf more areas of the structure. Sprinkler heads typically flow 12 to 20 gallons of water per minute while fire department hoses flow 150 to 250 gallons per minute. The amount of water used to extinguish the fire is reduced if automatic sprinklers are installed. Therefore the amount of waste water is also reduced. Fire department hoses can produce large amounts of runoff water that is filled with toxins from the burning home, polluting the surrounding vegetation or the city sewers.

With quick suppression of the fire, fire sprinklers reduce the area of the structure that is affected by the fire. Therefore it reduces the amount of building materials that need to be replaced by new materials. This reduces the amount of waste and the amount of natural resources used to make new materials.

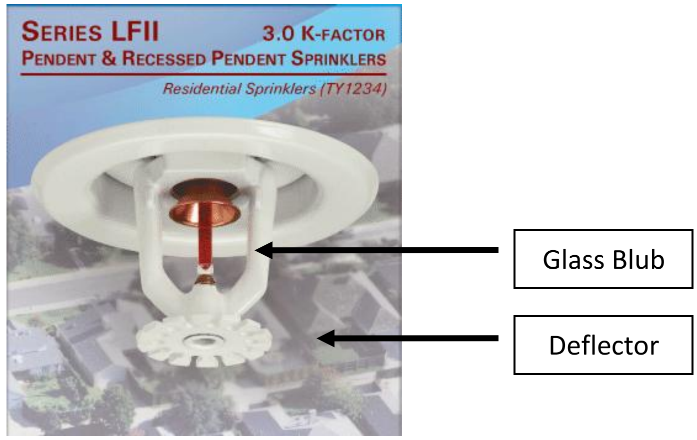

Figure 8: Residential Sprinkler (Tyco)

2.2.3 Plumbing Systems

Many alternative plumbing designs are available that help save both water and money. While Energy Star appliances can help reduce the amount of water used in washing machines and dishwashers, there is still a large amount of waste water produced in the daily use of these appliances. The American Water Works Association estimates that the average household uses 127,400 gallons annually (AWWA). A graywater system can be installed to help utilize the wastewater that is produced in the household. Graywater systems recycle water from sinks, washing machines, showers, and dishwashers and use the water to flush toilets or, in some states, to irrigate the landscape. This process helps preserve water and saves money. Toilets use up to 40% of the daily residential water use. Using graywater would reduce the amount of clean fresh water that is used to flush toilets. Dual flush toilets also save the amount of water that is used during flushing. These toilets have two flushing options, one for low-volume flushes such as liquid or paper and one for solids (Building Green).

There are also alternative piping materials available that reduce the amount of toxins that clean water is exposed to within the house. XLPE and polypropylene (PP) pipe is considered a clean halocarbon and does not emit toxins into the water (Building Green).

Another way to reduce costs associated with heating water is to invest in solar hot water heaters. These use the sun's energy to naturally heat water. They are relatively inexpensive and require little maintenance (EERE, Solar Water Heaters, 2008). A solar hot water heater will drop water heating bills by approximately 50%-80% (EERE, Economics of a Solar Water Heater), saving money and energy. An example of a solar hot water heater configuration is shown in Figure 9.

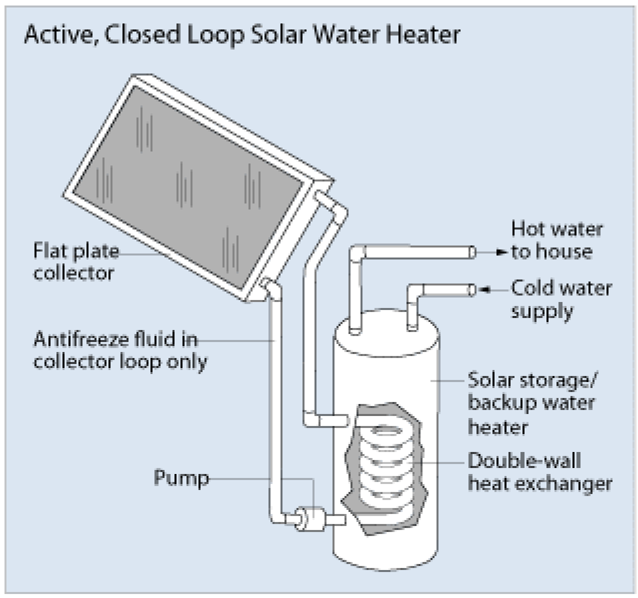

Figure 9: Closed Loop Solar Water Heater (EERE, Solar Water Heaters, 2008)

2.2.4 Heating, Ventilating, and Air-Conditioning

Heating, ventilation, and air conditioning (also known as HVAC) systems allow the occupants to remain at a comfortable temperature during the warmer and colder days of the year. Ventilation is another important factor since it distributes clean air throughout a space. If the house is too hot, cold, or stuffy, then the quality of life is compromised. There are new alternative methods to heating, cooling, and ventilating a house versus the accepted conventional methods.

Traditional methods of heating a home require the use of fossil fuels, either directly through natural gas or oil burning furnaces, or indirectly by electric heating. A typical traditional system is a split system. A split system includes a central air unit and a gas or oil furnace along with a ventilator and an air cleaner to pump fresh clean air into the home. A control/thermostat is used to regulate the temperature to one's liking. The central air unit is located outside while all other components reside inside the house. When it is cold out, the furnace kicks on to heat the cooler air to the temperature desired. When it is hot out, the air is cooled by the central air unit using refrigerant coils. The central air unit, a pump, can also be used to heat the home. Due to the rising costs of fossil fuels such as oil and natural gas, alternate methods of heating and cooling a home are necessary. (Bryant)

Geothermal heating and cooling is a way to maintain a comfortable temperature in one's home during the warm and cold months of the year. While the outside temperature changes from day to day and season to season, the ground temperature four to six ft below the surface stays relatively the same, about 55° F (Residential Environmental Design, 2008). The geothermal system utilizes this constant by circulating pipes beneath the ground. The pipes are filled with a water solution. During the heating cycle the pipes obtain heat from the ground since the water solution inside is colder due to the cooler indoor temperatures. The heat from the ground is compressed by the unit resulting in a high temperature. This hot air is then distributed throughout the home via a duct or similar system. Figure 10 illustrates the heating cycle. During the cooling cycle, hot indoor air heats the water solution in the pipes. The pipes then circulate through the cool earth ground and return cool air to the duct or similar system. Figure 11 illustrates the cooling cycle. (GeoComfort, 2008)

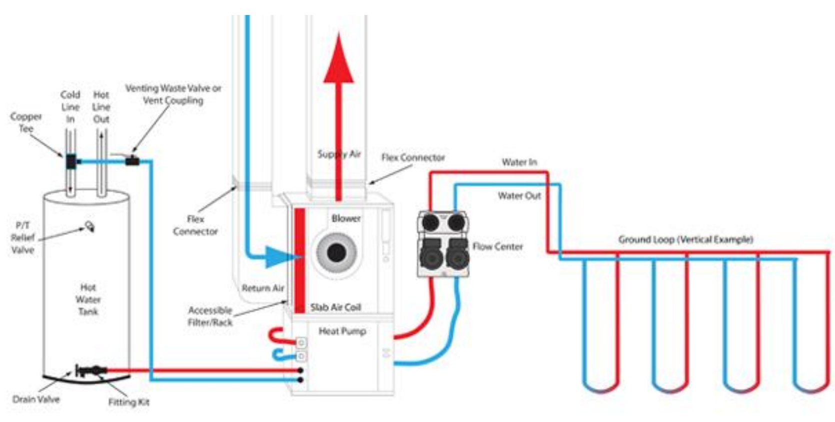

Figure 10: Geothermal Heating Cycle (GeoComfort, 2008)

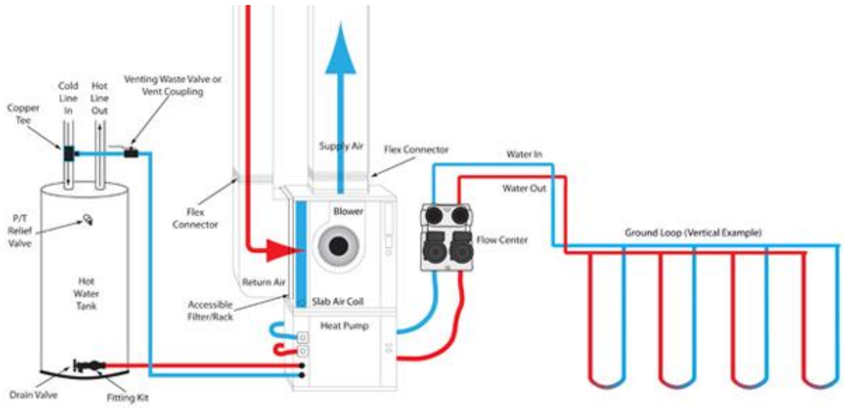

Figure 11: Geothermal Cooling Cycle (GeoComfort, 2008)

Different types of the loop system exist. All are buried in the yard of the owner's property. The four systems are a vertical loop, horizontal loop, pond loop, and open loop. These are illustrated in Figure 12 through Figure 15. The horizontal loop is the most common type of system. It requires more land but excavation is only six to eight feet deep. The vertical loop requires excavation of 150 to 200 feet deep but less property area. The pond and open loops require a reliable source of water; therefore, they can only be used when one exists. Coils are anchored in a pond and use the water temperature like the loops use the ground temperature in a pond loop. In an open loop a discharge of approximately four to eight gallons of water per minute is necessary along with a proper discharge area. Therefore, the design for this particular project will be the horizontal loop system assuming the land space is available. (GeoComfort, 2008)

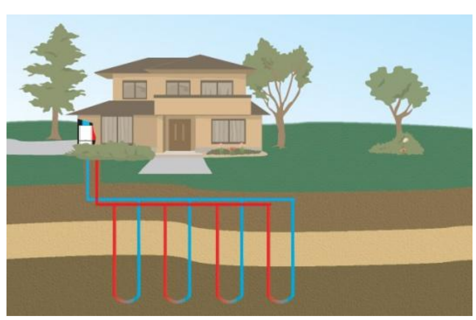

Figure 12: Geothermal Vertical Loop (GeoComfort, 2008)

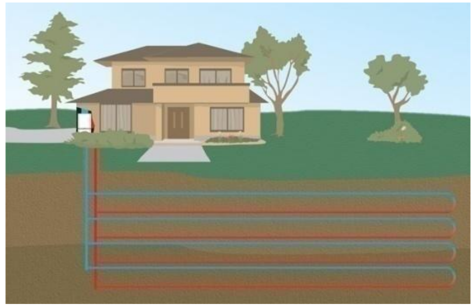

Figure 13: Geothermal Horizontal Loop (GeoComfort, 2008)

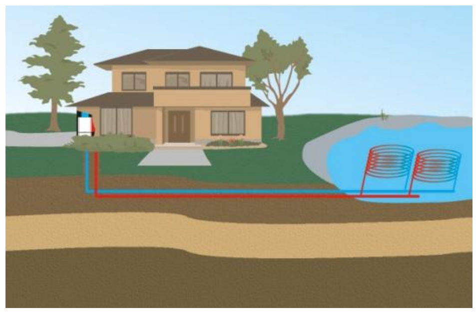

Figure 14: Geothermal Pond Loop (GeoComfort, 2008)

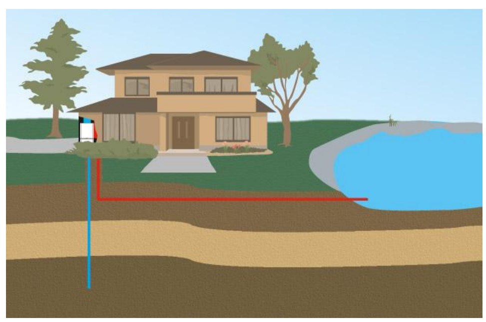

Figure 15: Geothermal Open Loop (GeoComfort, 2008)

Geothermal systems have many advantages. The mechanical system is located within the house; therefore it is protected from inclement weather, vandalism, or theft. Because of the protection it has a longer life cycle. Also, since there are no combustibles, the risk of fire is reduced and there is no chance of a carbon monoxide leak. Geothermal systems are also environmentally friendly. The design simply uses the earth's temperature. After the initial installation cost, heating and cooling bills will decrease, therefore it is more economical. The geothermal system is a green option for the project's house design. (Residential Environmental Design, 2008)

As discussed earlier, ventilation is a key factor in a comfortable living space. Because the SIPs create such an efficient building envelope, air must be brought into the house by mechanical means. The ventilation helps remove pollutants produced inside the house such as fumes from combustion appliances, radon, formaldehyde, excess humidity, tobacco smoke, etc. The ventilation also helps minimize the humidity inside the house to prevent mildew growth. There are various types of ventilation. Air to air heat exchangers draw heat from higher humidity areas in the house (i. e. kitchen) and send it through ducts to transfer the heat but remove the moisture from the house. The fresh air entering is then heated by the air going out. Exhaust only systems take stale air out and rely on natural permeation from outside to replace it. Ventilating windows are manually operated windows that contain a small grille to exhaust and replace air in the house depending on the setting. Air cleaners come in all different sizes ranging from small units for one room to a whole house system. They remove particulate pollutants. They do not remove gaseous pollutants and therefore are not recommended for humidity or radon control. (Structural Insulated Panel Association, 2007)

Geothermal systems and ventilation systems are environmentally friendly when compared with traditional HVAC systems. However, the pumps used in both technologies use electricity for power. The increase in electricity use can be offset by using electricity generated from solar panels or other renewable energy sources.

Another, inexpensive solution to maintaining comfortable temperatures at home is to build a trellis along the home's southern facing wall. In the summer, when thermal radiation from the sun is high, vines on the trellis will grow leaves and provide shade. When the leaves fall in the winter, the sun will be able to enter the windows and provide heat.

2.3 Layout

Both traditional and green structures are designed to be built anywhere in New England. This allows for greater flexibility in the constructability of the structure. New England is subject to harsh winters with temperatures on average of about 30 degrees (Channel). These factors were taken into consideration when preparing both designs.

2.3.1 Orientation

In the northern hemisphere, the sun moves across the southern sky. To maximize the home's exposure to the sun, the largest wall, with the most windows, will be orientated on the site to face south. Naturally, this orientation will provide extra light and reduce the amount of energy needed to power artificial lighting. It will also allow maximum thermal gain through the windows during the winter months.

2.3.2 Spatial Planning

Residential structures are designed to provide a safe and comfortable living area. In the past houses were smaller, had fewer bedrooms, and rarely had a garage. Today average homes are larger and have many additional rooms including laundries and multiple bathrooms (Christie, 2007). A standard one family one story home includes a few bedrooms, living room, kitchen, and a bathroom. These homes are designed for small families with one or two children and are relatively inexpensive. Designer homes can have multiple stories, bedrooms, and bathrooms. They can feature multiple living areas such as a dining room, living room, and family room. With all the luxurious upgrades comes a very expensive price. Creating a balance between these two extremes is important to minimize cost without sacrificing functionality and value to the owner.

The first impression of a home's design is felt upon entering. Therefore, it is important to correctly establish the floor plan. Upon entering the home should feel welcoming and open with plenty of light and air. This can be accomplished by utilizing an open floor plan, which minimizes the number of walls separating areas such as the foyer or entry, living room, and kitchen. The living room is an important area for families to get together and enjoy each other's company. This room should be large enough to comfortably provide seating for the entire family, guests and additional furniture such as a television.

Another one of the most important areas of the design is the kitchen. The kitchen may be one of the most popular places in the home because it is where meals are prepared and shared and where families gather to talk. There are a few main factors that influence a kitchen design. The first is the work triangle, which describes the area of space between the kitchen sink, refrigerator, and stove.

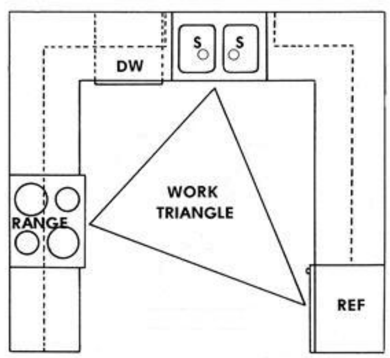

Figure 16: Kitchen Work Triangle (Psychological Enviornments)

The triangle should be no more than 26' and no less than 12' in perimeter (Buster, 2005). The size of the work triangle affects the efficiency of preparing a meal. The larger the work triangle, the more distance one has to walk between the major focus areas of the kitchen. Another factor that is essential to the kitchen design is the cabinets which provide an organized space to store pots, pans, dishes, and cutlery. Organization is a key factor for a functional kitchen area. Cabinets come in a large variety of styles ranging from white laminate to dark cherry hardwood, which are considerably more expensive but are very popular and stylish.

The number of bedrooms and bathrooms also contribute to the home's functionality. Bedrooms are required by building codes to have a window and be a minimum of 7' wide by 7' long (IRC, 2006). Building codes also require at least one bathroom, which includes a toilet and a shower or bathtub in every residential dwelling. Large homes with multiple bedrooms can reduce the amount of traffic in one bathroom by adding additional full or half baths.

Basements are a common feature in many New England homes. They can provide additional living space, storage space, or even a workshop area. Typical basements house utilities such as electric panels, water heaters, washers, and dryers.

Although hallways and stairwells may not be the most important visual aspect of the home, there are many regulations that specify these areas. The IRC requires hallways to be at least 3' wide and for stairwells to be at least 36" wide. Stairs should be uniform and have a riser height of 7 ¾" and a tread depth of 10" (IRC, 2006).

Following these basic building code requirements and providing a spacious open layout can help create a floor plan that is both comfortable and functional.

2.3.3 Exterior Improvements

The landscape design of a house is an important area to consider when striving for environmentally friendly living. Storm water runoff is a major environmental concern with the constant increase in impermeable surfaces. In warmer climates, driveways made of recycled aggregate are effective water absorbing solutions. In colder climates however, snow removal becomes very difficult with aggregate driveways and another solution must be found. In these situations driveways can be created with porous concrete or contain drainage systems within to deal with storm water or snow melt.

Properties with large amounts of grass are not ideal for green sustainable living. Lawn maintenance such as gas powered mowing is a large contributor to air pollution and greenhouse gases.

Large grass areas can be replaced with indigenous trees, shrubs and other perennials that require little maintenance and watering. More specifically, particular plants can be drought resistant which will reduce irrigation costs. Those same plants are also often resistant to disease and insect damage as well. In most cases, native plants will be the best plants to satisfy both conditions and to maintain a healthy interaction with the existing environment. (Harris, Sustaibable Plants)

2.4 Cost Estimation

A life cycle cost analysis is an economic estimation that uses financial data gathered throughout years along with an interest rate determined by the economy to simulate a realistic estimate over a period of time. The analysis takes into account initial construction costs, energy costs, and maintenance and operational costs. Some life cycle costs take into account the disposal of the building. Since homes normally last longer than 20 years, demolition will not be examined in this project. Also, many rebates are offered for the use of green appliances and systems, those costs will be taken into account as well. The life cycle cost analysis can be performed on any building whether it's a large skyscraper or a small shed, therefore making it appropriate for these house designs. The analysis will provide a comparison between the traditional and green house designs. The study will help show whether the environmentally friendly design is economically friendly as well. (Kirk & Dell'Isola, 1995)

2.5 Summary

As discussed earlier, there are many alternatives to the traditional methods and materials of a home's design. These alternatives have environmental, cost, and consumption impacts on the home. Many of the systems, methods, and materials are incorporated into the designs. Such components can be grouped into major categories of structural framing, layout, systems, and cost. Table 1 outlines which design and construction elements will be used for both the traditional and the green designs.

Table 1: Traditional and Green Design Elements

Traditional	**Green**
Structural Framing	
Stick Construction (roof, wall, floors)	SIPs (roof, wall, floors)
Layout	
Traditional Landscaping	Sustainable Landscaping
Traditional Driveway	Permeable Interlocking Concrete Pavement Driveway
	Trellis
Systems	
Traditional Appliances	Energy Star Appliances
Electrical Cooling (AC Unit)	Energy Star Light Fixtures
Gas Heating	Geothermal Heating and Cooling
Traditional Flow Faucets/Showers	PV Solar Shingles
Fire Sprinkler System	Solar Hot Water Heating
Balanced Ventilator	Low Flow Faucets/Showers
	Dual Flush Toilets
	Fire Sprinkler System
	Air to Air Heat Recovery Ventilator

3 Methodology

The goal of the project was to investigate the feasibility of building a cost-effective sustainable home. By creating two home designs, one with standard traditional building practices and materials, and the other with sustainable features, an accurate comparison was made. A cost analysis of all the components of both homes was performed with life cycle considerations to determine if purchasing a sustainable home is a better investment than purchasing a traditional home.

3.1 Background Research

In the design of the house, it was important to understand the many concepts and pre-existing knowledge that encompass the design of a home. The research was broken down into three major areas: materials, systems, and layout.

The materials researched ranged from common building materials including timber, glass windows, and concrete to green building materials such as structural insulated panels (SIPs) and double pane windows. The information found during the background research was used to determine the feasibility of incorporating certain materials into the designs.

The systems research included mechanical, plumbing, fire protection, and ventilation systems. Traditional and green alternatives were researched and compared to determine which types of systems would be used.

Typical floor plan layouts were researched to determine the proper sizing and location of spaces within the home. The International Residential Code was referenced to determine the standards for minimum room, hallway, and bathroom sizes as well as stairway requirements. The importance of the orientation of the home was also researched. The layout research also included an examination of exterior improvements such as landscaping and driveways.

3.2 Design Plans

It was decided that both the traditional home design and the sustainable home design would have the exact same floor plan to ensure a fair comparison of the costs and benefits. The floor plan was designed to accommodate an average American family; the layout includes three bedrooms, two full baths, a large open space that includes the kitchen, dining room and a living space. A two-car garage is attached to the front of the house as well.

The floor plan was originally drawn up on Auto CAD, but was soon converted to Revit Architecture for ease of use. Since the traditional design required less research, it was chosen to be designed first, while the research for the sustainable design was done simultaneously. The floor was designed by referencing the research completed in the background section to determine the proper spacing and sizing of all spaces. The floor plan layout was designed using a trial and error approach.

This project also incorporates a sprinkler system design into both traditional and green structures. The sprinkler design was created using NFPA and IRC standards.

3.3 Structural Design

The house was designed with a top-down approach, following the load path. It started with the roof and ended with the foundation. The roof had special design considerations to account for; the load from the roof had to be transferred entirely to the exterior walls. To do this, roof trusses were used to distribute the loads to the walls. Since the garage roof extends outward from the front of the house, the roof system had to be modified in the area where the two roofs meet. A ridge beam extends from the main roof truss system to the garage roof truss system to support the loads. Next, the walls were designed to support the roof. The exterior walls in the home support the entire weight of the roof with no interior wall support. The floor system and foundation were designed last. The floor is supported by foundation walls around the perimeter of the floor plan with six interior support columns spaced evenly throughout the basement.

The dead loads for the roof include the weight of all of its components. The material component dead loads were found in Chapter 3 of Minimum Design Loads for Buildings and other Structures ASCE 7-05(ASCE, 2006). Both the weight of all the wood members in the truss system, and the load values for all other considerations were found including: plywood, insulation, asphalt shingles, and ceiling. The snow load was calculated using the average snowfall amounts for New England, found in Chapter 7 of Minimum Design Loads for Buildings and other Structures ASCE 7-05(ASCE, 2006).

The walls were designed with spruce pine-fur, 2X6 studs. Spruce pine-fur studs are the typical grade used in most home construction in New England according to National Lumber. Wind loads for New England were found in Chapter 6 of Minimum Design Loads for Buildings and other Structures ASCE 7-05(ASCE, 2006) and checked against the strength of the walls.

Both the floors and the foundations were designed according to IRC building codes. The foundation was designed with the standard eight inch -thick concrete walls found in the IRC; it is a continuous footing that spans the entire perimeter of the house. The floor slab of the basement, as well as the slab on grade under the garage, was designed to the residential building code specifications for their respective applications. The code specifies a four inch-thick concrete slab in the basement and a six inch-thick concrete slab under the garage each with a vapor barrier and a layer of gravel underneath. The columns supporting the floor are made up of round steel pipes of minimum three inch nominal width according to the IRC. A typical soil type for the central New England area was used to determine the soil capacity. The typical soil falls into the category: sand, silty sand, clayey sand, silty gravel and clayey gravel soil. According to the IRC, the bearing pressure of this type is 2000 PSF (IRC, 2006). This bearing pressure was used to calculate the size of the footing.

3.4 Cost Estimates and Life-Cycle Cost Analyses

A cost estimate was developed for both homes. The results were used to compare the two home designs. The cost analysis was broken down into three major areas: construction, life cycle, and maintenance. The construction costs were calculated using RS Means. Initially, the unit cost values per square foot of area were determined for a 1200ft^2, one-story house. A two-car garage was added, and various adjustments were made for the floors, walls and roof. For example, the RS Means value for a house gives a standard 2X4 stud wall frame. The traditional home calls for 2X6 studs, while the green home calls for structural insulated panels. Unit costs were considered individually, for example the cost of each sprinkler head in the fire suppression system.

In addition to the decreased energy cost of the green house, the installation of renewable energy systems comes with monetary benefits from both the local energy providers and from the government. Special rebates greatly reduced the cost of these seemingly overwhelming price tags.

The life cycle cost analysis used data from local energy suppliers, product manufactures, and finical intuitions to determine energy, maintenance, and replacement costs of both designs. Using various economic equations, the amount of money presently needed (present worth) to invest in either design was calculated. An analysis was also done on the investment opportunities for the initial cost savings of the traditional design.

3.5 Conclusions and Recommendations

The conclusions and recommendations were produced by analyzing and comparing the cost data. The initial costs and present value amounts were compared. The energy usage and costs were also compared to determine which design was most energy efficient. Because the project closely examined each part of the residential structures, it was easy to find and identify any changes that could be made to create a more cost effective design.

4 Design Plans

The design plans include a floor plan and propose a layout design for the sprinkler system based on the proposed floor plan. The room layout of the house was decided with quality of living in mind. With a large open space including the living room, dining room and kitchen, the house will seem larger than it is. The proposed sprinkler system will provide adequate fire suppression; the design was based off room sizes.

4.1 Proposed Floor Plans

The traditional and green structures are designed using the same floor plan (Figure 18) in order to provide an accurate cost evaluation and comparison. The residential structure is designed to comfortably accommodate a four-person family. It has three bedrooms including a master bedroom. The master bedroom is 145 sq ft with two separate closets. The master bedroom is attached to a private bathroom. The second and third bedrooms have their own closets and share the common bathroom.

In addition to the bedroom closets, there are many other storage areas in the house. There are three linen closets, and a large storage area with stairs leading to the basement. These spaces can be used for a variety of functions. The basement houses the water heater, circuit breaker, and the laundry area.

The kitchen's work triangle, illustrated in Figure 17 is sized to be spacious yet not large enough to require an excess amount of walking during cooking. The perimeter is 17.4' which is within the limits of a comfortably sized kitchen area (Buster, 2005). The kitchen is open to the dining area to allow for easy flow from kitchen to the serving area.

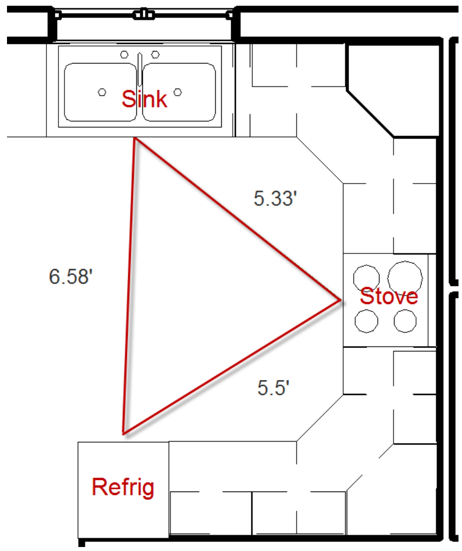

Figure 17: Kitchen Work Triangle

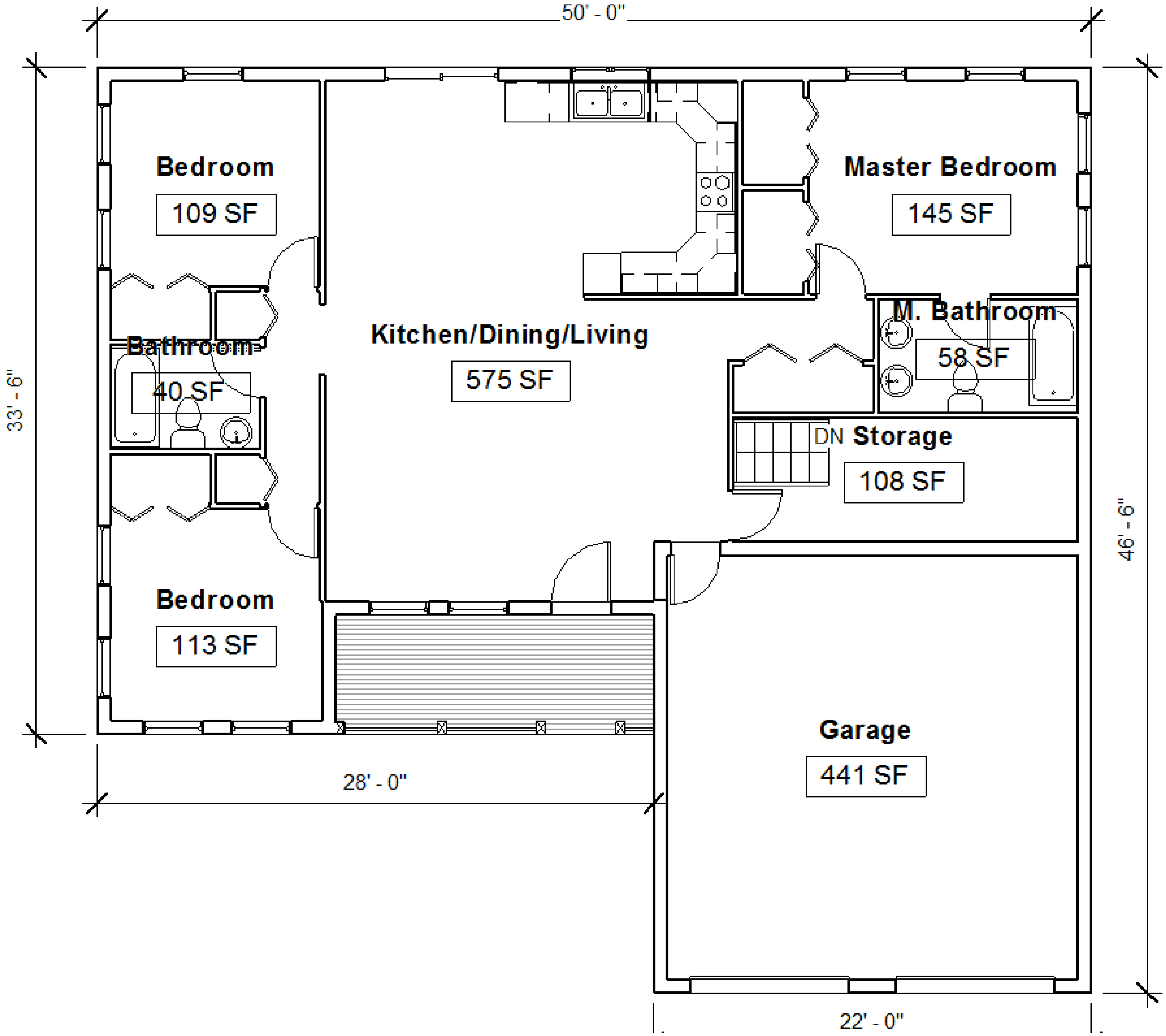

Figure 18: Floor Plan

An open layout is also used in the living room. The absence of interior walls in the living areas allows the residents to enter the front door and see directly through the house into the backyard.

The 22'x22' garage is large enough to be used as a two car garage or as a one car garage with additional storage space. Entry into the garage is located between the storage room and the main entry way. To add curb appeal to the house a front porch was added. Depending on the lot the house is located on, a deck can easily be added to the back of the house.

Table 2 summarizes the various spaces and areas within the home.

Table 2: Floor Areas

FLOOR AREA				
Heated Space (sq ft)			Unheated Space (sq ft)	
Bathroom 2	39		Basement	1228
Bedroom 2	122		Garage	441
Bedroom 3	125		TOTAL	1669
Closet Space	27			
Kitchen/Dining/Living	575			
Master Bath	58			
Master Bed	168			
Utility	108			
TOTAL	1222			

4.2 Fire Sprinkler System Design

The sprinkler system was designed using Tyco Series LFII Pendent Sprinklers (Figure 19). These residential sprinklers have a K factor of 3. 0 and are rated for 155-175 degrees Fahrenheit. Manufacturer data is supplied in Appendix E: Sprinkler Head Specifications. The water pressure in the area is assumed to be between 40-70 psi, which is typical for residential areas (Free Drinking Water). With water flow reductions due to risers, and home water usage, a sprinkler with an 11 psi water flow minimum was selected. These sprinklers could be spaced 14' apart in any direction (Tyco Fire and Building Products). The sprinkler attributes are compliant to the provisions set forth by Chapters 5 through 6 in NFPA 13D, Standard for the Installation of Sprinkler Systems in One- and Two-Family

Dwellings and Manufactured Homes (NFPA, 2007). There are similar sprinkler heads available through Tyco which are flush mounted and usually considered more visually attractive. However, these sprinklers are more expensive and therefore were not selected for the design.

The sprinkler piping used in the design is Schedule 40 Chlorinated Poly (Vinyl) Chloride (CPVC) Pipe supplied by BlazeMaster. Specific pipe specifications are included in Appendix D: Sprinkler System Pipe Specifications. Compared to metallic pipes, CPVC is inexpensive, easy to install, and corrosion resistant (Charolotte Pipe and Foundry).

The sprinkler play layout was designed by first calculating the areas of each room. The areas were then compared to the sprinkler's maximum spacing requirements to determine how many sprinklers are needed for each room. Using branch lines to connect each sprinkler, a piping layout was created which used the minimum amount of piping to save money. Alternative layouts were investigated. For example, one layout featured branch lines spanning the short distance of the house. This layout used much more piping material than the selected layout and therefore was not used. The sprinkler system design is illustrated in Figure 21. There are a total of 15 sprinklers throughout the house. According to NFPA 13D, sprinklers are not required in closets if the area does not exceed 24 ft^2 (NFPA, 2007) Sprinklers are also not required in garages or open porches (NFPA, 2007).

Apart from savings lives and belongings, a sprinkler system has many other benefits. Although they may be theoretical, the National Institute of Standards and Technology recognizes the cost savings sprinkler systems provide such as fatalities averted and injuries averted. Sprinkler systems also reduce home insurance costs. (Butry, 2007)

Figure 19: Tyco Series LFF Pendent Sprinkler (Tyco Fire and Building Prodcuts)

Maximum Coverage Area [a] Ft. x Ft. (m x m)	Maximum Spacing Ft. (m)	Minimum Flow [b] and Residual Pressure For Horizontal Ceiling (Max. 2 Inch Rise for 12 Inch Run) 155°F/68°C or 175°F/79°C
12 x 12 (3,7 x 3,7)	12 (3,7)	8 GPM (30,3 LPM) 7.1 psi (0,49 bar)
14 x 14 (4,3 x 4,3)	14 (4,3)	11 GPM (41,6 LPM) 13.4 psi (0,92 bar)
16 x 16 (4,9 x 4,9)	16 (4,9)	13 GPM (49,2 LPM) 18.8 psi (1,29 bar)

(a) For coverage area dimensions less than or between those indicated, it is necessary to use the minimum required flow for the next highest coverage area for which hydraulic design criteria are stated.

(b) Requirement is based on minimum flow in GPM (LPM) from each sprinkler. The associated residual pressures are calculated using the nominal K-factor. Refer to Hydraulic Design Criteria Section for details.

TABLE A
NFPA 13D AND NFPA 13R WET PIPE HYDRAULIC DESIGN CRITERIA FOR THE SERIES LFII (TY1234) RESIDENTIAL PENDENT AND RECESSED PENDENT SPRINKLERS

Figure 20: Design Criteria for Series LFII (Tyco Fire and Building Prodcuts)

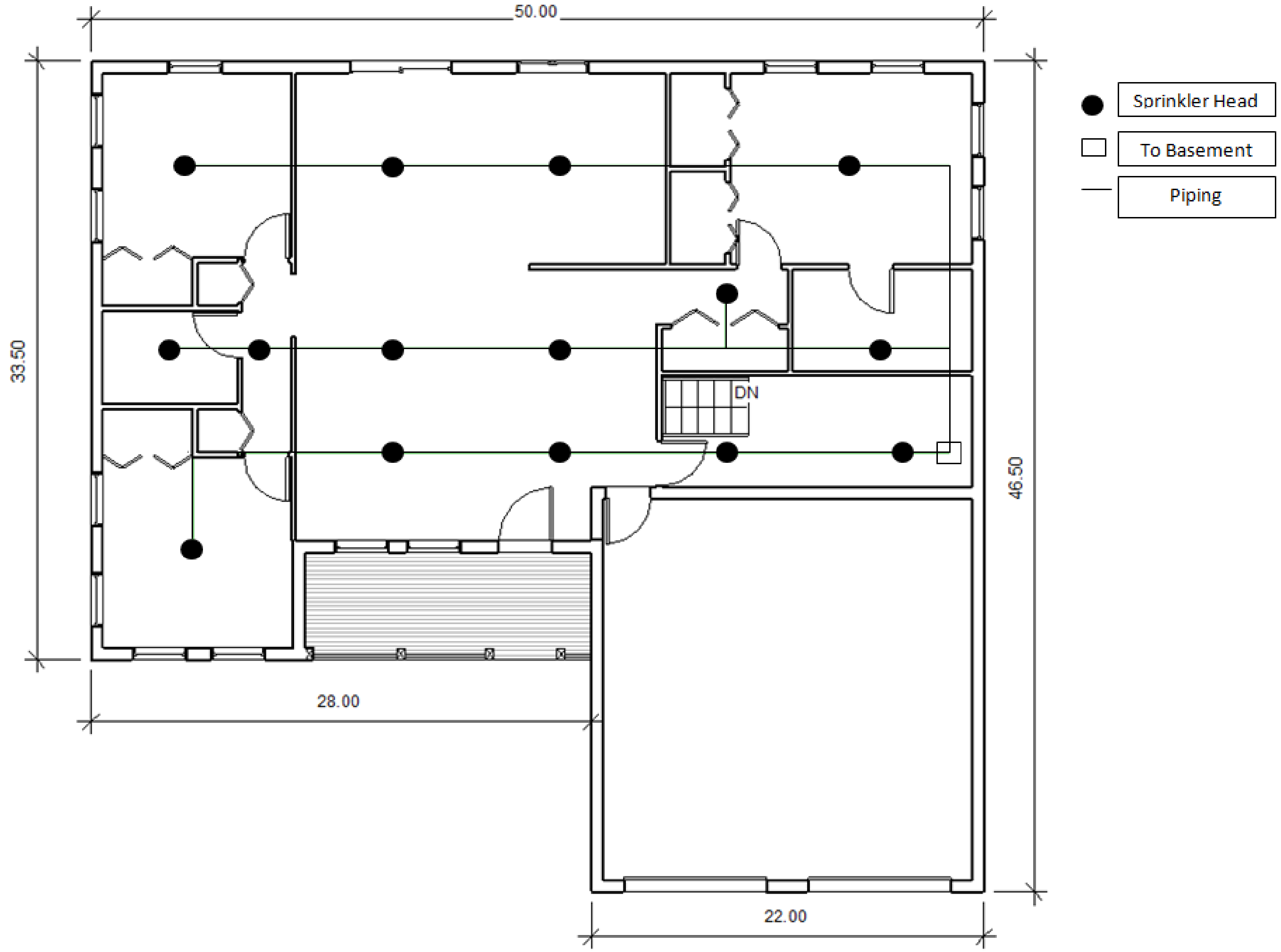

Figure 21: Sprinkler System Layout

5 Traditional Design

The traditional design includes a floor plan, roof design, flooring design, wall design, and a foundation design. All of the loads from the roof design are transferred directly to the foundation walls through the exterior walls. There are no bearing walls inside of the residential structure. Therefore, the only forces acting on the columns in the basement are from floor dead loads and live loads. The regional factors such as snow and wind loads were selected to represent typical situations in the New England area. After consulting with local building companies, the wood species Spruce-Pine-Fir was selected for the traditional design because it is commonly used throughout the area. The cement used for the construction of the concrete foundation in the traditional design is Type 1. This is a general use cement that is made with Portland Cement. Portland Cement is a type of cement that is manufactured on a wide scale by most manufacturing facilities. It was chosen for the traditional design because it is the common choice for home foundations.

5.1 Roof Design

Figure 22 illustrates the roof and it's framing design. All of the roof components were designed using ASD methods and National Standard Design (NDS) tables (AF&PA, 2005). The first step in the roof design is to determine the loads acting on the roof. From the ASCE Code, the dead loads were calculated. (ASCE, 2006)

The traditional roof is covered with plywood sheathing and asphalt shingles which are typical for traditional residential roofs. Roof insulation is provided by loose insulation installed between roof trusses. There is no attic storage space because of the roof truss webbing. The trusses are designed not to overhang beyond the walls of the house. The roof shingles and gutter systems will provide the necessary rain protection. These elements are factored into the dead load calculations.

Table 3: Traditional Roof Dead Loads (ASCE, 2006)

Dead Load	psf
Roofing (3 ply)	1. 5
Plywood (1/2")	1. 5
Insulation (loose)	0. 5
Shingles (Asphalt ¼")	2. 0
Framing (2x6)	1. 9
Ceiling (Gypsum Wallboard)	2. 5
	Total Dead Load = 10 psf

The snow load was calculated to be 35 psf in New England areas. All of the roof systems were designed using the dead load and the snow load as the maximum loading scenario. Example calculations are supplied in Appendix B.

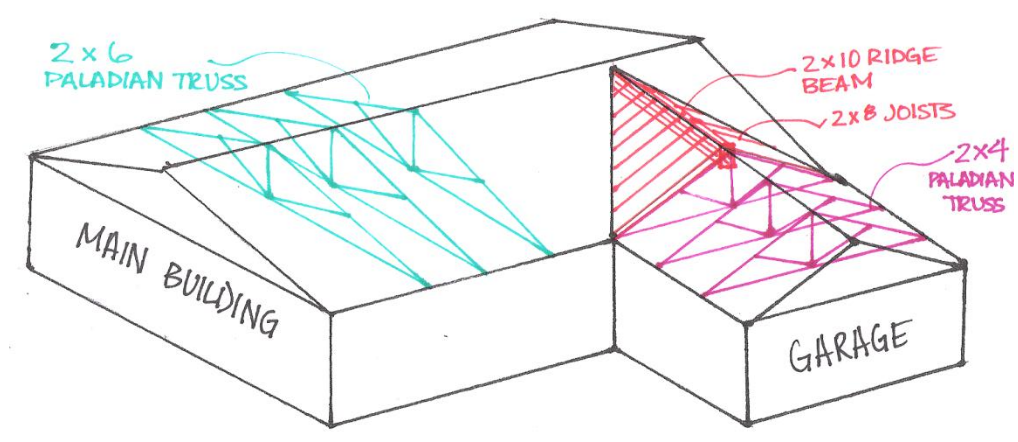

Figure 22: Traditional Roof Layout

The garage roof was designed first since some of its weight will be transferred to the roof of the main building. The garage roof is made up of a paladian truss system and a small rafter system. The truss system was designed to support the combined dead and snow loads. Member sizes were selected by calculating the bending stresses and axial forces. The members were chosen using a trial and error approach. The final garage truss design uses 2x4 No. 1 grade Spruce Pine Fir (SPF) trusses spaced 24" on center.

The garage roof and the main building roof connect at the peaks to create a valley. Trusses would not fit in the small triangular area created by the meeting peaks so a rafter system was designed. The rafters and ridge beam were designed to support the same loads as the trusses. By checking compression and tension stresses a ridge beam was selected. Using 2x8 SPF rafters, a 2x8 SPF ridge beam would be adequate. To allow for nailing space and proper connections, a 2x10 ridge beam will be used.

Because of the large width of the main portion of the building, a typical rafter roof is not feasible. The rafter roof would need to have spans of over 19 feet and would need to support 45 psf. With these requirements, the rafters would need to be very large and expensive. Therefore a truss system is used in the main building. A portion of the main building also supports the loads from the garage rafter roof system. Therefore one side of the truss needed to be designed to support more load. To make the design easier to construct, the entire roof system was designed using the largest reaction forces from the additional loading. The trusses were designed using ASD methods and checked for bending and required area. The members were chosen using a trial and error approach. The final main building truss design uses 2x6 No. 1 SPF trusses 24" on center.

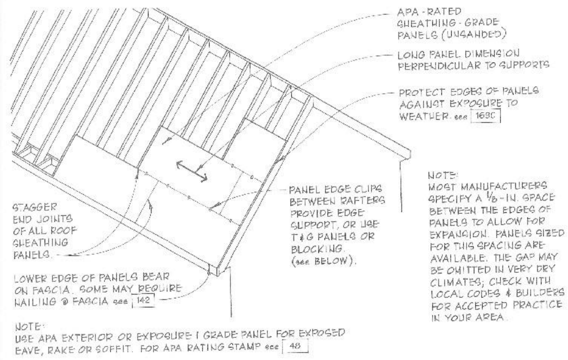

Figure 23: Roof Sheathing (Thallen, 2000)

5.2 Wall Design

Exterior walls were designed using ASD methods. The exterior walls are designed as bearing walls to support the vertical loads from the roof and the lateral loads from wind. The first step in selecting wall stud sizes is to determine how much force is acting on each stud. The main building's roof transfers the largest amount of load, so the typical studs will be designed for the main structure. Each of the trusses on the main building are spaced 16" on center. Therefore if the 2x6 studs are spaced at 16" on center also, there would be 38 studs along the 50' side of the structure. After dividing the forces from each truss into the amount of studs, it was determined that each stud supports 1. 5 kips of vertical force from the roof.

By using trial and error, members were checked for capacity. The 2001 NDS supplement Appendix A: Clause A: 11. 3 states that studs attached to sheathing or drywall can be designed using the depth of the stud as the weakest side (AF&PA, 2005). After checking capacity, it was determined that 2x6 stud grade SPF studs 16" on center would be adequate to support the given loads. Example design calculations are supplied in Appendix B: Design Calculations.

The wind load design determined the wall board type, wall board thickness, and the fastener schedule along with bending effects on the exterior studs. The design utilized the provisions of the 2006 International Residential Code for wind load calculations. Exposure C was chosen since an open terrain with scattered obstructions was assumed for a likely building area. This exposure sets limitations based on the area for wind loads. Three second wind gusts were determined by geographical location, choosing the central Massachusetts area. Using this information, pressures were calculated for all zones of the house and are summarized in Table 4: Traditional Wind Pressures for Main Building and Table 5

Table 4: Traditional Wind Pressures for Main Building

Zone	$P_{s,30}$	P_s (psf)
A	16. 1	19. 481
B	2. 6	3. 146
C	11. 7	14. 157
D	2. 7	3. 267
E	-7. 2	-8. 712
F	-9. 8	-11. 858
G	-5. 2	-6. 292
H	-7. 8	-9. 438

Table 5: Traditional Wind Pressures for Garage

Zone	$P_{s,30}$	P_s (psf)
A	16. 1	19. 481
B	2. 6	3. 146
C	11. 7	14. 157
D	2. 7	3. 267
E	-7. 2	-8. 712
F	-9. 8	-11. 858
G	-5. 2	-6. 292
H	-7. 8	-9. 438

Reaction forces were then determined to find the shear force. Using Table R.603.3.2(1), a minimum of 15/32 inch plywood exterior sheathing was chosen with a fastener schedule of no more than No. 8 screws spaced 6” on center on edges and 12” on center at intermediate supports. The maximum spacing for the nails is 4”. These requirements ensure the wall is fastened well enough for the possible maximum wind loads on the house.

The design for the openings in the stud walls is described in Figure 24. Figure 25 illustrates a framing detail for corner construction.

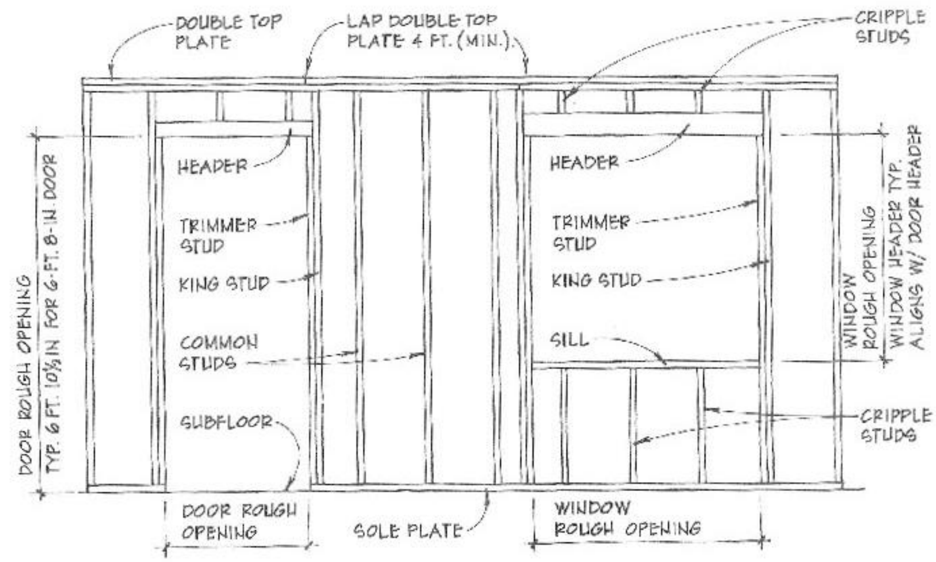

Figure 24: Stud Wall Opening (Thallen, 2000)

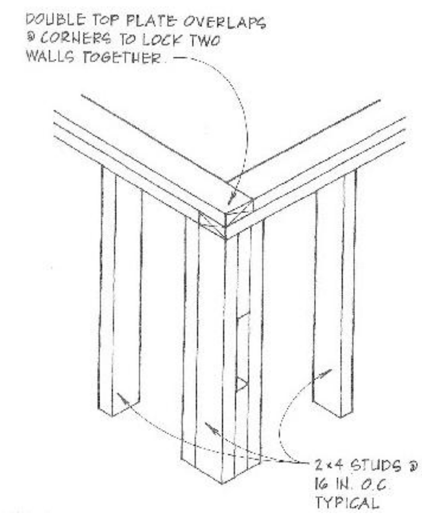

Figure 25: Corner Design (Thallen, 2000)

5.3 Floor Design

After examining the floor layout, a column plan was designed. The basement houses two rows of three columns. Before girders or columns could be designed, the floor loads were calculated.

Table 6: Traditional Floor Dead Loads (ASCE, 2006)

Dead Loads	psf
Ceramic Tile (3/4”)	10.0
Wood Floor Joists (2x8 16” O. C)	1.9
Subflooring (3/4”)	3. 0
Insulation (loose)	0. 5
Total Floor Dead Load = 15.4 psf	

Although only the bathrooms and kitchen are covered in ceramic tile, the entire floor area is assumed so. Since ceramic tile creates a larger dead load, the approach is conservative. The typical live load for residential structures is 40 psf (ASCE, 2006).

The total load, from combining these loads results in a maximum load scenario of 56.7 psf. Each girder’s tributary area was calculated and multiplied by 56.7 psf to determine the design force acting along each girder. The dead load of the interior wall structure was calculated separately for each girder; the girder supporting the largest load was used as a conservative base to design the entire floor system. The wall area per girder was multiplied by the dead load of a typical interior wall (5. 9 psf) and then added to the total floor dead load. The largest calculated load, 9.35 k, was used to design all of the girders in the structures.

Calculated dead loads were applied to a trial sized joist to determine if the selected size was sufficient. Trial sized joists were chosen as 2 x 8’s, 16” o.c. Adjustment factors were used based upon the type of wood selected. They are listed in Table 7. The loads from the joists are then transferred to the girders and then to the columns and foundation.

The girder size was chosen using trial and error while checking bending, shear and deflection. The deflection limit of L/240 was difficult to meet since the length of each girder is 12.5 ft due to column spacing. Using select structural SPF 8x14 girders, the ASD limits were satisfied. Figure 26 illustrates the joist and girder arrangement. Examples of the design calculations are supplied in Appendix B: Design Calculations.

Table 7: Traditional Floor Adjustment Factors (AF&PA, 2005)

Adjustment Factors	
Load Duration Factor	C_D = 1. 0
Repetitive Member Factor	C_r = 1. 15
Wet Service Factor	C_M = 1. 0
Temperature Factor	C_t = 1. 0
Beam Stability Factor	C_L = 1. 0
Size Factor	C_F = 1. 1
Incising Factor	C_i = 1. 0
Flat Use Factor	C_{fu} = 1. 0

Shear and moment diagrams were developed. A maximum shear force of 259.7 lb and a maximum moment of 8726.8 in-lb were calculated. As previously mentioned, the trial size of floor joists was selected as 2 x 8's SPF 16" on center. The characteristics of the selected trial joist are:

Table 8: Traditional Joist Characteristics (AF&PA, 2005)

Trial Joist
F_b = 875 psi
F_v = 135 psi
$F_{c, perp}$ = 425 psi
E = 1,400,000 psi
A = 10. 88 in^2
S = 13. 14 in^3
I = 47. 63 in^4

Bending, shear, deflection, and bearing were analyzed in order to ensure the 2 x 8 joists were appropriate for the design. All equations were in accordance with ASD standards and sample calculations can be found in Appendix B: Design Calculations. Figure 26 below shows the girder layout and floor joist system along with the column locations. Figure 27 below shows the connection between the floor joists and the girders. Figure 27 and Figure 28 show both the girder and joist placement on the foundation.

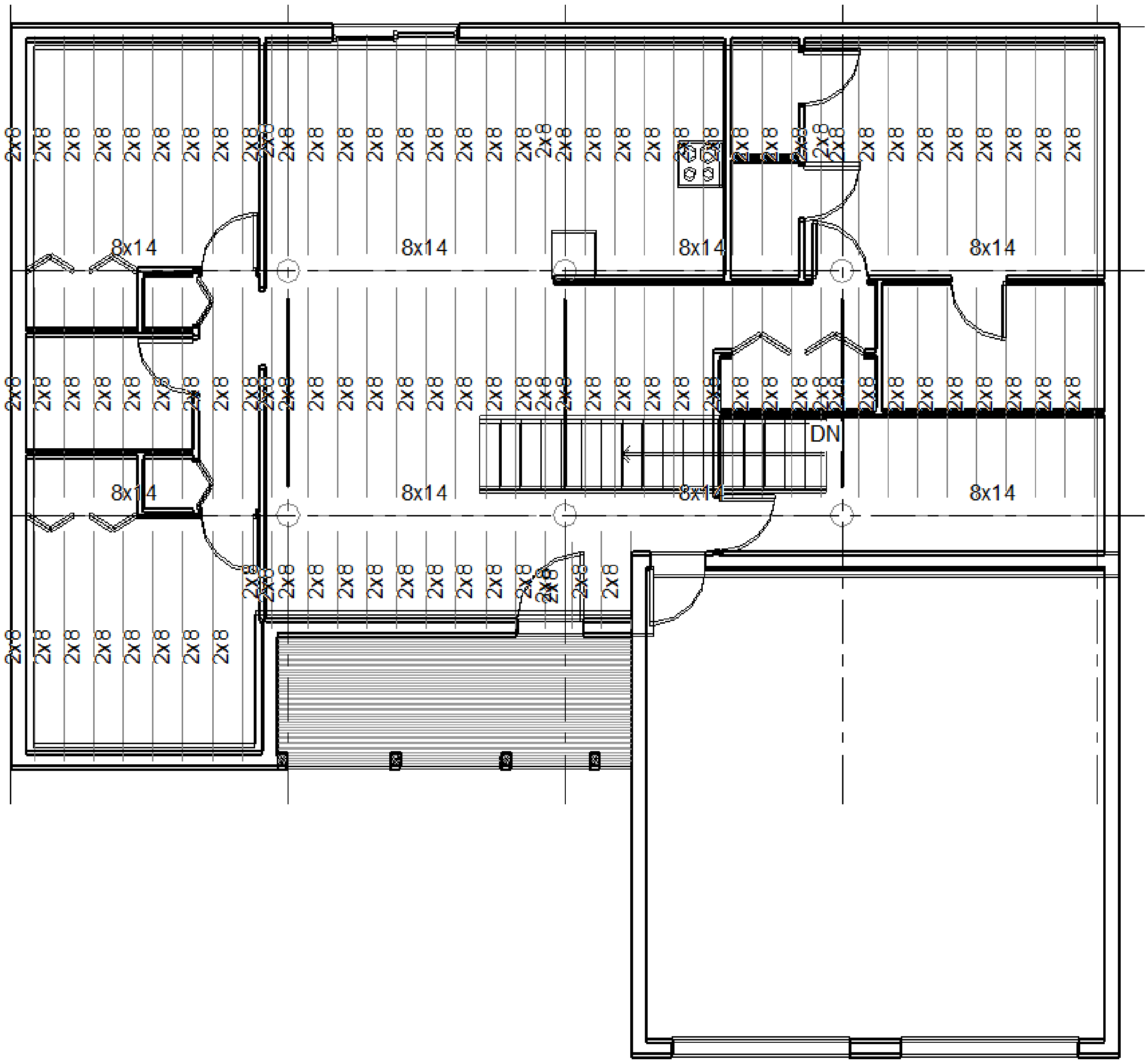

Figure 26: Floor Members

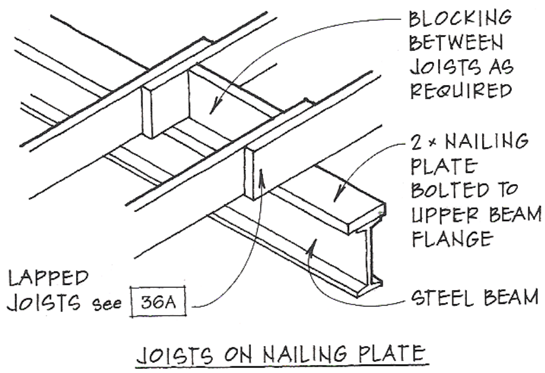

Figure 27: Joist to Girder Connection (Thallen, 2000)

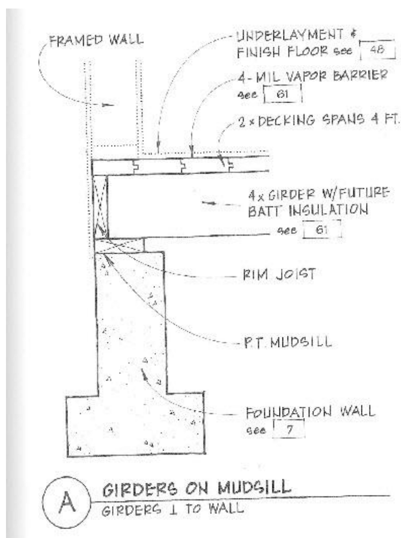

Figure 28: Girder Placement on Foundation (Thallen, 2000)

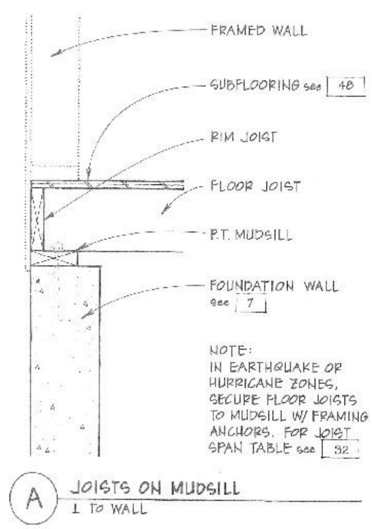

Figure 29: Joist Placement on Foundation (Thallen, 2000)

5.4 Foundation and Column Design

The largest loaded girder was also used to determine the force acting on each column. Using free body diagrams, the largest loaded column needed to support at least 9.35 k. The foundation was designed with six evenly spaced interior columns to support the floor. A steel pipe with nominal diameter size of 3” was used. The pipe was painted inside and out to protect against moisture. Based on the analysis, each column can hold approximately 13 k.

The foundation was designed according to the IRC building code. The foundation walls are 8 in thick, and 8 ft high. The strip footings supporting the foundation walls are rather wide to accommodate the large loads caused by the direct transfer of the roof loading down through the walls and into the foundation. The concrete footings are 36 inches wide, 6 inches thick. A 4-in thick concrete slab is used for the floor of the foundation; it is supported by the wall footings on the edges. The rest of the basement floor is considered a slab on grade. Under the garage, there is no basement, and the floor is a 6-in thick concrete slab on grade. Concrete footings below the foundation slab for the columns are necessary to support the column loads. The footings are 2.5 ft by 2.5 ft and 6 in thick. Examples of the design calculations are supplied in Appendix B: Design Calculations. Figure 30: Concrete Foundation shows the foundation wall and footing design.

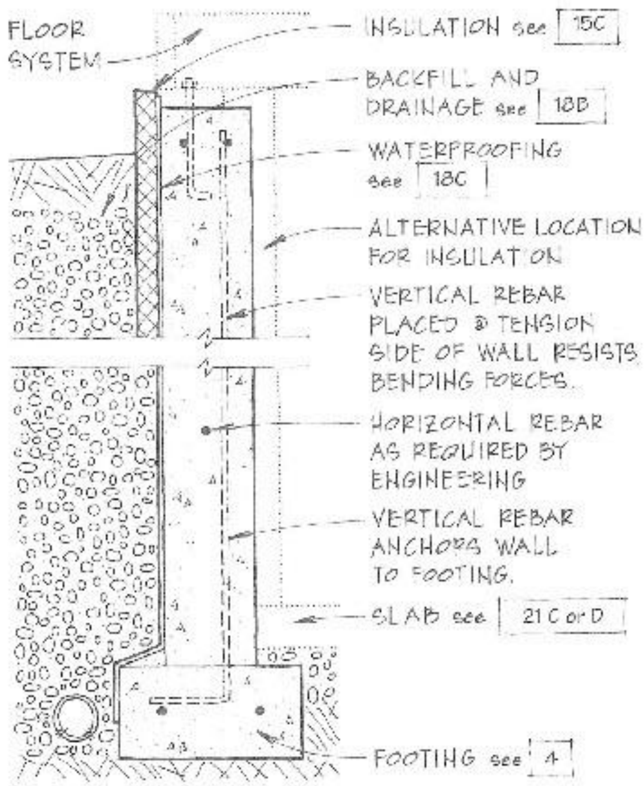

Figure 30: Concrete Foundation (Thallen, 2000)

5.5 Additional Considerations

The traditional design also includes appliances and HVAC equipment that is discussed in detail in the Cost Estimation chapter. The selected appliances and equipment are typical for residential construction and are sized according to the size of the residential structure.

6 Green Design

The green design includes the same floor plan arrangement as the traditional design. It features alternative building systems for the roof, walls, floors and foundation. The green design integrates sustainable materials rather than those that may typically be found in a traditional design and construction. The design also includes green technologies which improve the home's energy efficiency. The initial cost, life cycle cost, and energy savings of these technologies is discussed in the cost estimation section of this report.

6.1 Roof Design

The roof of the green structure was designed using Structural Insulated Panels (SIP's) because of their high thermal resistance which prevents heat from escaping or entering the structure through the roof. Typically, SIP roof systems are supported by a ridge beam. In this project however, a ridge beam is not feasible because of the 50' distance between the exterior bearing walls. Therefore, a truss system was designed. The trusses use the same paladian configuration as used in the traditional design; however, they are now spaced 4 ft on center. The SIPs span the entire 18 ft length from the walls up to the peak. They are 4 feet wide and 12.25" thick. The SIPs are supported in the short direction by the trusses. The panels will not be used on the garage roof due to construction constraints discussed later in the SIP wall section. Figure 31 shows the modified truss support. Refer to Figure 33 for the wall-to-roof connection. Figure 32 illustrates the roofing layout.

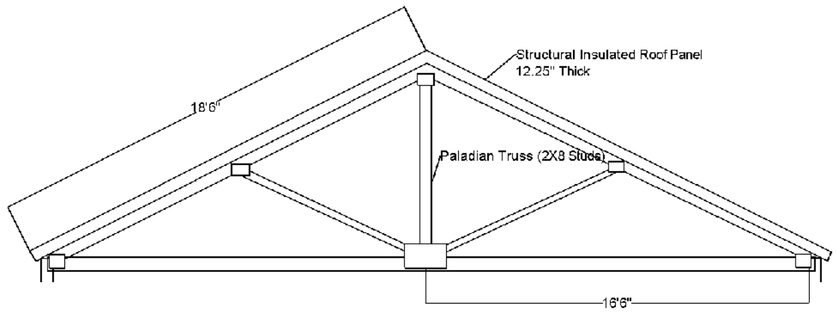

Figure 31: SIP Truss Design

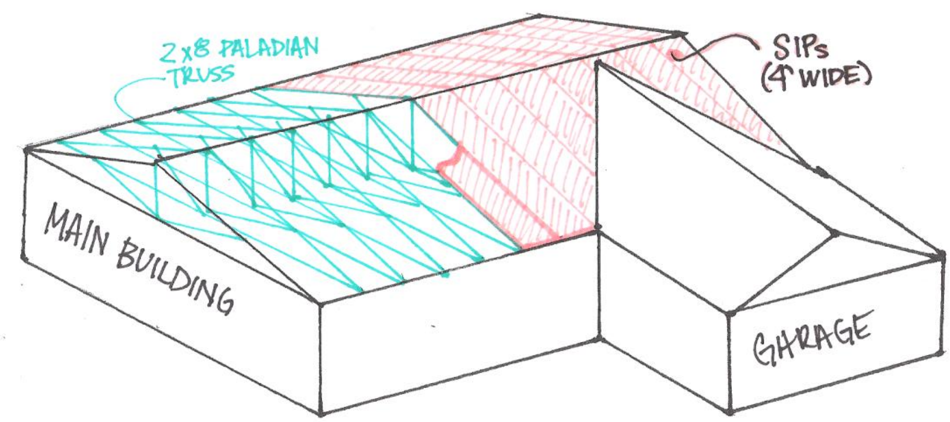

Figure 32: Green Roof Layout

6.2 Wall Design

The SIP walls were designed using a method developed by The Structural Insulated Panel Association (SIPA). The method, called the "Prescriptive Method for SIP Wall Systems in Residential

Construction", provides certain specifications for SIP wall systems (Structural Insulated Panel Association, 2007). It is also in compliance with the International Residential Codes (Structural Insulated Panel Association, 2007). The Prescriptive Method was used as a reference for the project design.

Table 1.1: Applicability Limits (Appendix F: SIP Design Specifications) from the Prescriptive Method outlines certain limitations for the design. The building is limited to a maximum width of 40' and length of 60'. In order to adhere to this limitation, the garage is not part of the SIP wall design; it only includes the main building. The garage is built using traditional stick construction as explained in the traditional design section. Therefore, the dimensions of the SIP design are 50' x 33. 5'. The remaining size limitations for the SIP sizes used in this project are described in Table 9.

Table 9: SIP Size Limitations

Type	Length of SIP	Thickness	Max Load (PSF)
Roof	18'	12.25	24
Wall	10'	4.5	43
Floor	12'	10.25	70

The SIP wall components include two facings with adhesive on both sides which attach to a core insulating material. The facing is a minimum of 7/16" of oriented strand board (OSB). The core material is composed of molded expanded polystyrene in accordance with ASTM C 578 [5], type I, with a density of 0.90 lb/ft^3 or greater. The adhesive is in compliance with ASTM D2559 [7].

To establish the design wind load, the project team assumed Exposure C and a 3 second wind speed of 90 mph, the same as in the traditional design. As mentioned earlier, the assumptions are based on geographic location. A snow load of 50 psf was chosen. A 50 psf snow load differs from the 35 psf snow load used in the traditional design because the Prescriptive Method limits the SIP design to the following snow loads: 20, 30, 50, and 70 psf. Table 3 is an excerpt from table 4.2 of the prescriptive method showing the minimum wall thickness required. The assumed characteristics are a representation of those found in the New England area. An example of the SIP wall system is shown in Figure 33.

Table 10: Required Panel Thickness

Table 4.2
Nominal Thickness (Inches) for SIP Walls Supporting SIP or Light-Frame Roofs Only[1]

Wind Speed (3-sec gust)			Building Width (ft)														
			24			28			32			36			40		
		Snow Load (psf)	Wall Height (ft)			Wall Height (ft)			Wall Height (ft)			Wall Height (ft)			Wall Height (ft)		
Exp. A/B	Exp. C		8	9	10	8	9	10	8	9	10	8	9	10	8	9	10
85		20	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		30	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		50	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		70	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
100	85	20	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		30	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		50	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		70	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
110	100	20	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		30	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		50	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		70	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5

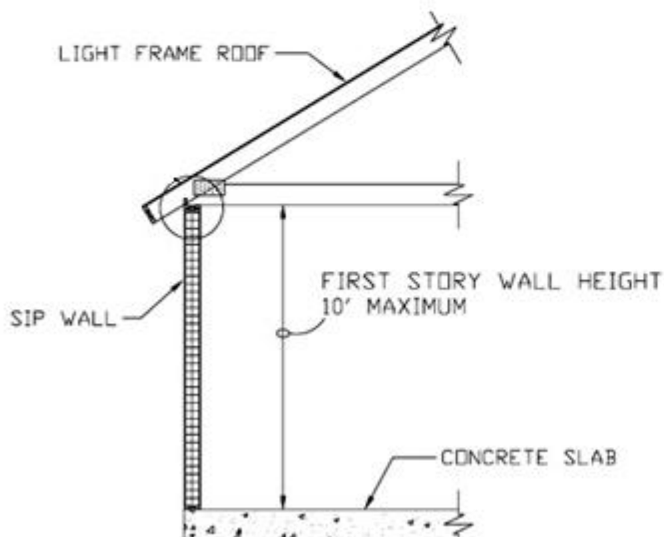

Figure 33: SIP Wall System (Structural Insulated Panel Association, 2007)

Connections of the SIP walls are in accordance with The Prescriptive Method and illustrated in Figure 34 through Figure 38. Figure 34 shows the SIP connected to the roof. Figure 35 is an example of how SIPs can be used in balloon framing applications. Figure 36 illustrates the SIP connection to the concrete foundation. Figure 37 demonstrates how two SIPs are connected to one another to form one continuous wall. Figure 38 exemplifies how two SIPs meet to form a corner.

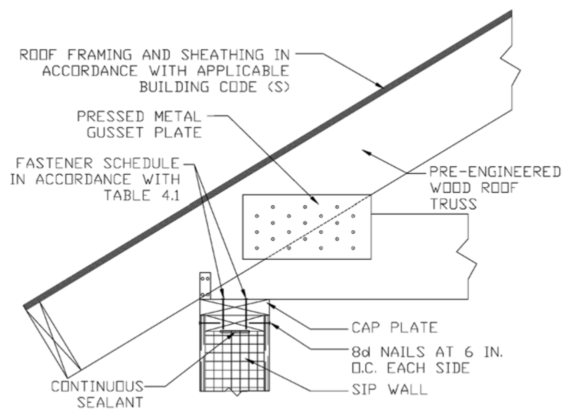

Figure 34: SIP Wall to Roof Connection (Structural Insulated Panel Association, 2007)

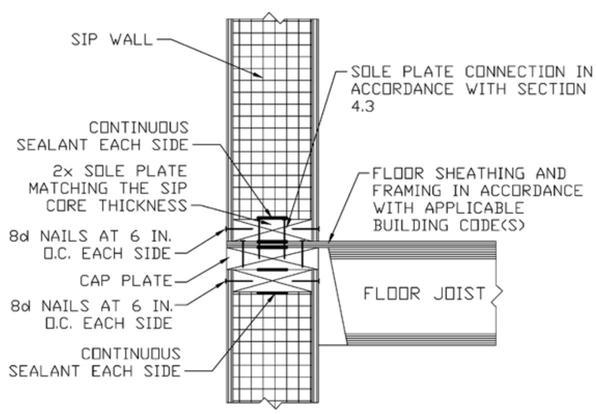

Figure 35: SIP Wall to Wall Balloon Frame Connection (Structural Insulated Panel Association, 2007)

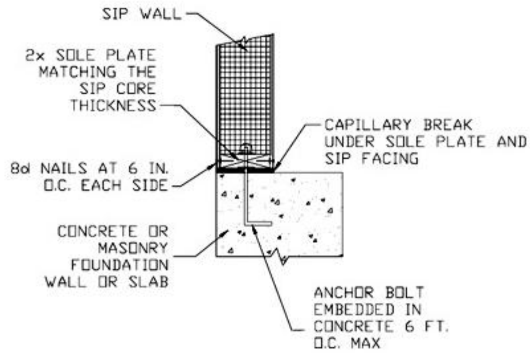

Figure 36: SIP Wall to Concrete Slab or Foundation Wall Attachment (Structural Insulated Panel Association, 2007)

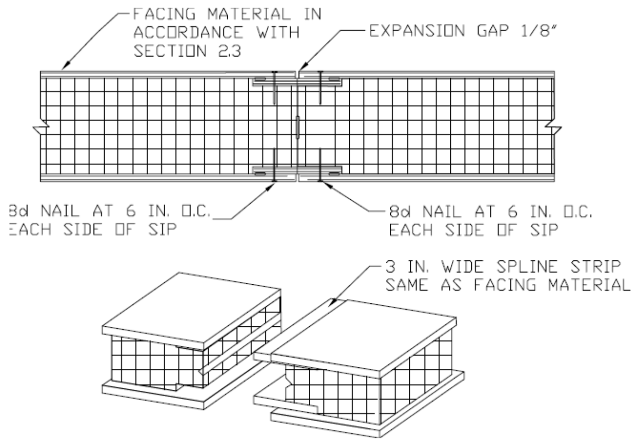

Figure 37: Surface Spline (Structural Insulated Panel Association, 2007)

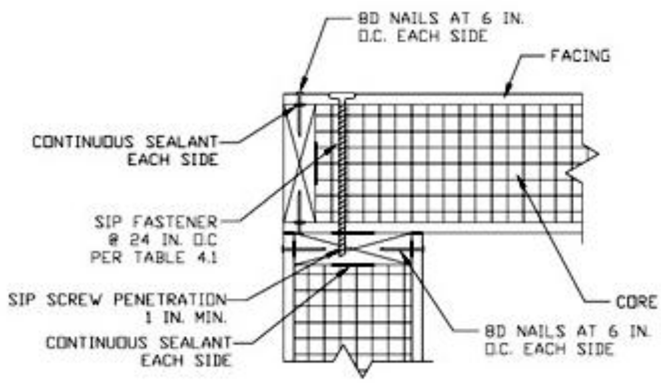

Figure 38: SIP Corner Framing (Structural Insulated Panel Association, 2007)

6.3 Floor Design

SIPs were examined to be used as floor panels in place of joists. According to a report done by Precision Panel Structures, Inc., using SIPs in substitution of a joist system is feasible and common practice (ICC Evaluation Service, Inc., 2008). SIP floors are required to be upwards of 8" (ICC Evaluation Service, Inc., 2008)thick to support service loads, this, in addition to the necessary support girders, makes the whole floor system just under two feet deep. For this house, the foundation walls are 8 ft tall. To implement a SIP floor system would decrease the clearance height in the basement where the girders are located, but that may be a worthy sacrifice to completing an air-tight building envelope.

The team was able to utilize the same column and girder layout for the design of the floor SIP's. The panels span the floor the same way the joists do in Figure 26 for the traditional design. The panels are 4 ft wide and 10' ¼" thick. They are connected using long screws per the manufacturer's specifications.

6.4 Foundation and Columns Design

The foundation was designed to support the same loads as the traditionally designed foundation. However, the mix design for the concrete was changed to reflect the environmentally friendly nature of the green design. In substitution of Portland cement, coal fly ash can be used; up to 60% of the Portland cement can be substituted. Coal fly ash is a waste product of coal-fueled power plants; when combined with lime, it forms a cement-like compound stronger than Portland cement. Production of Portland cement requires large amounts of energy and contributes to green house gas emissions. Since coal fly ash is typically disposed of in landfills, by using it in substitution of Portland cement, the amount of waste to landfills is reduced. (Headwaters Resources)

6.5 Green MEP Systems

The side of the roof opposite of the garage will face south and will integrate a 100 sq ft photovoltaic (PV) shingles array. The PV shingles are similar to solar panels; they convert sunlight into electricity. The difference between the two is that PV shingles can easily be incorporated into a conventional asphalt shingle system. They are installed the same way as asphalt shingles with exception that wires run out the tops of the shingles and join together in a control box. The control box in our design is located in the basement. The shingles would only be placed on the south most facing side of the roof for maximum exposure.

The PV shingles selected for this design are called SUNSLATES and are manufactured by Atlantis Energy Systems Inc. An example of a SUNSLATES installation is pictured in Figure 39. They are expected to deliver 20 or more Watts per module (Atlantis Energy Systems). SUNSLATES are approved by UL 1703, the Standard for Safety Flat-Plate Photovoltaic Modules and Panels. The inverter for the shingles, also supplied by Atlantis Energy Systems is stored in the basement of the home near the main electrical house panel. Batteries can be installed in the system to hold excess charges, which can be sold back to the electric company. (Atlantis Energy Systems)

Figure 39: PV Shingles (Atlantis Energy Systems)

Atlantis Energy System teamed up with a solar thermal systems company called Dawn Solar (Dawn Solar). Together they found a way to integrate solar shingles and solar hot water heaters. The coils that are part of the solar hot water heater system are placed underneath the solar shingles before they are installed as illustrated in Figure 40. When the solar shingles collect energy from the sun, they also collect heat. The water inside the coils behind the shingles is heated by conduction and convection. This process cools the solar shingles which allows them to have a higher energy output (Capra, 2009). Both solar systems can be placed on the same southern facing roof area that is exposed to the maximum amount of sun. The integration of these two technologies allows both systems to operate more efficiently.

Figure 40: Dawn Solar Hot Water Heater Coils (Dawn Solar)

A geothermal heating and cooling system will be installed in the home. The heat pumps will circulate water through vertical, closed loops underground. Closed loops were chosen because there is no assumed body of water nearby for discharge which is necessary for open loops. Vertical loops were chosen because of the small lot size. The warmed or cooled air will be distributed throughout the house through air ducts maintaining a comfortable interior temperature.

6.6 Exterior Improvements

The landscape design of a house is an important area to consider when striving for environmentally friendly living. Storm water runoff is a major environmental concern with the constant increase in impermeable surfaces. Typical asphalt or concrete driveways are not considered sustainable according to LEED specifications. A driveway that meets LEED requirements needs to be able to reduce water runoff and reduce the heat island effect. Impervious asphalt driveways cause storm water to run off into surrounding areas creating flooding and often spreading polluted water. Asphalt also absorbs large amounts of heat energy from the sun, creating heat islands which contribute to a general temperature increase of urban areas. (Home Design Professionals , 2007)

In warmer climates, driveways made of recycled aggregate are effective water absorbing solutions. In colder climates however, snow removal becomes very difficult with aggregate driveways and another solution must be found.   Driveways can be created with porous concrete or contain drainage systems within to deal with storm water.

For the green home, the group decided to use Permeable Interlocking Concrete Pavement (PICP) for the driveway. PICP is a series of interlocking concrete blocks with open joints to allow water to penetrate. An example of a PICP arrangement is illustrated in Figure 41. Beneath the concrete blocks are a layer of crushed stone that stores water and facilitates the filtration of pollutants and the infiltration of the clean water back into the surrounding soil sub-grade. In addition to the 100% permeability of the surface, the concrete is also significantly more reflective of the sun's energy than asphalt. This reduces the heat island effect. (Home Design Professionals , 2007)

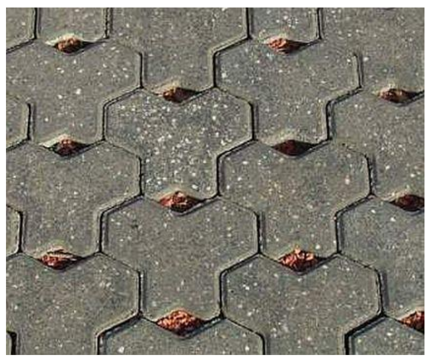

Figure 41: Concrete Pavers

Properties with large amounts of grass are not ideal for green sustainable living.   The maintenance involved with large lawn areas is time consuming, costly, and harmful to the environment. Gas powered mowing is a large contributor to air pollution and greenhouse gases in residential areas. Grass lawns require frequent watering which is costly and uses a large amount of potable water. Finally, lawns occasionally require chemical treatment as fertilizer or pest control which pollutes runoff water. Large grass areas can be replaced with sustainable trees, shrubs and other perennials that require little maintenance and watering. An example of this is pictured in Figure 42. More specifically, particular plants can be drought resistant which will reduce irrigation costs. Those same plants are also often resistant to disease and insect damage as well. Between plantings and trees, sustainable ground covering such as pachysandra can be planted to provide erosion resistance. In most cases, native plants will be best to satisfy both conditions and to maintain a healthy interaction with the existing environment. Native plants can be selected by consulting with local landscaping businesses or gardening suppliers. The site for this project is to be made up of 75% local drought-resistant vegetation.(Harris, Sustainable Plants, 2008)

Figure 42: Sustainable Landscaping (URI)

6.7 LEED Certification

LEED certification is a major goal of the project's alternative design. Incorporating sustainable elements helps achieve points. A minimum of 45 points is needed to attain basic certification. The design so far has received 40 points, based on the elements discussed in this chapter. The awarded points are summarized below in Table 11. There are a number of additional points that can be awarded to this project that cannot be considered until completion of the project. For example, the home can be tested for Energy Star performance, with a maximum of 34 possible points based on the Home Energy Rating System Index.

Table 11: Summary of LEED Points Awarded

Points Received	
Innovation and Design Process (ID)	**1**
Building Orientation for Solar Design	1
Sustainable Sites (SS)	**10**
Limit Conventional Turf to 15%	3
Drought-Tolerant Plants	1
Reduce Local Heat Island Effects	1
Permeable Lot	3
Permanent Erosion Controls	1
Management of Runoff from Roof	1
Water Efficiency (WE)	**3**
High-Efficiency Fixtures and Fittings	3
Energy & Atmosphere (EA)	**12**
Pipe Insulation	1
High Efficiency HVAC (Geothermal)	4
Solar Hot Water Heating	2
Energy Star Lighting fixtures	3
High-Efficiency Appliances	1
Water Efficient Clothes Washer	1
Materials & Resources (MR)	**7**
Detailed Framing Documents	1
Framing Efficiencies	3
Environmentally Preferable Products	3
Indoor Environmental Quality (EQ)	**7**
Air Filtering	2
Moisture Control	1
Enhanced Exhaust	3
Exhaust Fan in Garage	1
Awareness & Education (AE)	**0**
TOTAL	**40**

To achieve certain point requirements, particular restrictions needed to be placed on the project. For instance, by demanding that at least 85% of the property is composed of permeable surfaces and vegetation, the project was able to get 3 LEED credits. Other steps, such as requiring Energy Star certification for all lights and lighting fixtures grants the project 3 extra points. The LEED checklist includes an allowance for solar energy alternatives; however, the annual energy consumption for the home needs to be calculated in order to determine the acquired points. It is necessary to demonstrate that the solar systems will provide the amount of energy they are expected to. This project includes a solar energy system but it is not included in the LEED Checklist. Table 12 shows the amount of points that could be obtained after completion of the project, including the theoretical solar energy system points.

Table 12: Potential Points to be Gained After Completion

Possible Points	
Location and Linkages (LL)	**5**
Site Slection	2
Preferred Locations	2
Access to Open Space	1
Energy & Atmosphere (EA)	**44**
Exceptional Energy Performance	34
Renewable Energy System*	10
Awareness & Education (AE)	**2**
Education of the Homeowner	1
Public Education	1
TOTAL	**51**
*system already in place	

6.8 Additional Considerations

In addition to the technologies previously discussed, green appliances and HVAC equipment were also used in the design. These attributes are important for obtaining LEED certification. They are discussed in detail in the Cost Examination chapter of this report. Although the appliances and equipment are initially more expensive than traditional technologies, they reduce energy consumption and save money on energy use.

Green technologies and design techniques provide a sustainable living environment. They reduce and conserve energy consumption and fossil fuel use.

7 Cost Examination

A cost estimate was developed for both traditional and green residential designs. The cost estimate provides a simple comparison between both designs. Using values from RSMeans publications, construction cost data was compiled and compared. The life cycle portion of the cost analysis examined the maintenance and energy costs of various products used in both designs.

7.1 Construction Costs

The construction cost estimation determines the approximate cost of the structure itself including materials and labor. Using RSMeans publications, the square foot, assemblies, and interior costs were calculated. RSMeans Square Foot Costs (RSMeans, 2009) determines the approximate costs of structures by category and size. Both green and traditional designs fall under the category of Custom Residential. This category includes the following project elements: site work, foundation, framing, exterior walls, roofing, interiors, specialty upgrades, and the mechanical and electrical systems. RSMeans breaks each element down further to explain what materials will be included in the estimate. For example, the exterior walls consist of 2x6 members spaced 16”. The Custom Residential category was selected because it consisted of many of the same design elements as our project which resulted in a minimum amount of cost data changes.

Although the custom category closely resembled our design, there were a few alternative cost estimation approaches used. For example, the floor joist size included in the RSMeans estimate was larger than that of our design. Using the RSMeans Assemblies publication, the difference between the joist costs was calculated and deducted from the square foot costs. The same approach was used to update the costs of the sliding glass door and the cost of the foundation.

The traditional residential design cost estimate including calculations is summarized in Table 14. The total cost of the traditional construction design is $227,000.

A similar approach was used to determine the construction cost estimate for the green design. The same RSMeans base cost was used for the estimation. Many updates were required for the green design including a few of the updates featured in the traditional design. For example, the sliding glass door addition and the foundation size were both considered when calculating cost estimates for the green and traditional designs.

Additional updates for the green design include SIP wall, floor, and roof construction. The cost data for the SIP construction was provided by a sales representative of Foard Panels (Panels, 2009), a SIP manufacturer located in New Hampshire. They provided a rough estimate of $10/sq ft of SIP area. The estimate is considered approximate because depending on the size and thickness of the panels, the cost differs. A more accurate estimate was difficult to obtain because it requires a thorough analysis of the design plans which is costly. However, the $10/sq ft estimate is sufficient for the purposes of this project. Using the RSMeans Assemblies data (RSMeans, 2007), the cost of the materials displaced by the SIPs was calculated and subtracted from the base costs. These materials included rafters, floor joists, studs, and insulation.

The sprinkler system cost is outlined in Table 13, which uses data from Tyco, the sprinkler manufacturer (Tyco). The total cost of labor and materials is about $1,170.

Table 13: Sprinkler System Cost Analysis

Sprinkler System Component	Quantity	Units	Bare Material Cost per Unit	Total Cost
Fire Sprinklers				
Tyco LF II - Low Flow Pendent, Fast Response, K=3.0	15	each	$29.75	$446.25
Accessories				
1" CPVC Pipe	147	ft	$2.75	$404.25
1" T Connection	2	each	$17.20	$34.40
1" Elbow Connection	2	each	$14.20	$28.40
Hangers	1	each	$5.96	$5.96
			Total Bare Material Cost	$919.26
Labor Cost (5 hr @ $50.31/h)	5	hr	$50.31	$251.55
			Total Material and Labor Costs	$1,170.00

Table 15 summarizes the cost estimation process and calculations. With the updates included, the construction cost estimate for the green design is $237,000.

At this point in the cost investigation, the green design is more expensive than the traditional design. This is expected because green building technologies are less common and typically more expensive than traditional technologies. The savings from green construction are seen in the utility and energy costs as discussed in the next section.

Table 14: Traditional Construction Cost Estimate

Traditional Construction Cost Estimate					
Base Cost					Estimated Cost
	For 1200 sq ft 1 story		$137.85	per sq ft	$168,000
Additions/Updates		**Calculation**			
	Unfinished Basement		$19.05	per sq ft	$23,400
	Additional Shower/Tub		$840.00	Total	$840
	2 Car Attached Garage		$24,917.00	Total	$24,900
	Open Porch		$53.92	per sq ft	$5,170
	Sliding Glass Door Upgrade				
	•from door to sliding glass	$1675-(148-38.50)	$1,565.50	Total	$1,560
	Foundation Update				
	•from 8" deep x 18" wide to 12" deep x 32" wide	35.55/linear ft - 20.05/linear ft	$15.50	per linear ft	$2,280
	Floor Joist Update				
	•from 2x 10s to 2x8s (10ft span) 16" o.c.	$3.33-2.78=$0.55 sq ft	-$0.55	per sq ft	-$670
	Sprinkler System		$1,170.81	Total	$1,170
				TOTAL	$227,000

Table 15: Green Construction Cost Estimate

Green Construction Cost Estimate					
Base Cost					Estimated Cost
	For 1200 sq ft 1 story		$137.85	per sq ft	$168,000
Additions/Updates		**Calculation**			
	Unfinished Basement		$19.05	per sq ft	$23,400
	Additional Shower/Tub		$840.00	Total	$840
	2 Car Attached Garage		$24,917.00	Total	$24,900
	Open Porch		$53.92	per sq ft	$5,170
	Sliding Glass Door Upgrade				
	•from door to sliding glass	$1675-(148-38.50) = 1565.50	$1,565.50	Total	$1,560
	Foundation Update				
	• from 8" deep x 18" wide to 12" deep x 32" wide	$35.55/linear ft - 20.05/linear ft = 15.50/linear ft	$15.50	per linear ft	$2,280
	Flooring Update				
	•from 2x 10s with fiberglass insulation to SIPs	$10/sq ft - [3.55/sq ft(2x10s) + 2.84/sq ft(insul)] = $3.61	$3.61	per sq ft	$4,400
	Exterior Wall Update				
	• from 2x6 stud walls 1/4" gypsum, 16" o.c., 2" fiberglass to SIPs	$10/sq ft wall area - 9.44/sq ft wall area = 0.56/sq ft wall area	$0.56	per sq ft wall area	$823
	Roofing Update				
	•from 2x8 rafters 16" o.c. with insulation to SIP truss system	$10/sq ft-[2.73/sq ft(2x8s) + 2.84 (insul)]	$4.43	per sq ft of roof area	$4,650
	Sprinkler System		$1,170.81	Total	$1,170
				TOTAL	$237,000

7.2 Utility and Appliance Costs

Utility and appliance costs are considered in this project to provide an accurate comparison between the green and traditional home. Also, there is consideration to the utilities and appliances in the LEED design checklist. The selected appliances and utilities are outlined in Table 16: Utility and Appliance Costs.

There is a difference of $21,000 between the initial cost of traditional utilities and appliances and the green utilities and appliances. The higher cost is expected as green technologies have a higher initial cost. However, there are many rebates available for green technologies that make the initial investment more appealing.

NSTAR, a local gas provider offers rebates for solar hot water heaters and programmable thermostats (NStar). The National Grid, which distributes electricity, also offers rebates for energy efficient windows and thermostats (National Grid). Finally, the Commonwealth of Massachusetts offers rebates for solar hot water heater installations. The rebates are summarized in Table 19: Rebates. With the $6,160.00 listed rebates, the cost for the green appliances and utilities is reduced from $33,000 to $26,600.

A cost estimation was done for the projected annual utility usage within each of the houses. An average household consumes 127,000 gallons of water per year (American Water Works Association, 2008) and pays an average of $4.27 per hundred cubic feet (NYC Department of Environmental Protection, 2005). Typical natural gas usage averages around 800 therms per year while prices per therm, about $1.788, were based off of a gas bill from NSTAR in the New England region. The average electricity usage for a year for a household is 7,500 kwh and the current rate is $0.17425 per kwh, which was determined from an electricity bill from National Grid. The annual costs are summarized in Table 17 and Table 18.

Utility prices for the green design remained the same as those in the traditional design; however, usages differed. According to the American Water Works Association, the use of water saving features on faucets and shower heads would decrease the total water usage by 30%. This was taken into account in the calculations. The total electricity usage also differed between the two homes. Energy efficient appliances and lighting fixtures, accounting for most of the electricity use, decrease the total by usage 30% (Energy Star). Also, the PV shingles produce approximately 1000 kwh (Commonwealth Solar, 2009). Therefore, less electricity is being used from the electric company. Since a geothermal system will be providing the heating and cooling system for the home, natural gas will be only used for the oven and the stove and therefore only 60 therms per year were calculated. 60 therms were based on an NSTAR gas bill during the warmer months when gas was only used for cooking.

Table 16: Utility and Appliance Costs

Appliance/Utility	Traditional	Cost	Green	Cost
Washer	Kenmore 3.5 cu ft Top Load	$484.49	Energy Star Kenmore 3.5 cu ft IEC High Efficient	$594.99
Dryer	Kenmore 5.8 cu ft Super capacity	$509.99	Kenmore 5.8 cu ft Super capacity	$509.99
Refrigerator	Kenmore 20.6 cu ft Top Freezer	$1,062.49	Energy Star LG 20.0 cu ft French Door Bottom Freezer	$1,169.99
Dishwasher	Kenmore 24" Built In	$416.49	GE 24" Built In	$499.88
Ventilation	Balanced Ventilator	$400.00	Air to Air Heat Exchanger	$800.00
Toilets (2)	KOHLER Cimarron (2)	$430.00	Dual Flush Toilets (2)	$578.00
Air Heating/Cooling	Gas Fired Warm Heat/Air Conditioning	$4,250.00	Geothermal + Backup Tankless	$7,542.00
Electricity	100 Amp Service	$1,000.00	SUNSLATE Solar Shingles (1KW System) + 100 Amp Service Backup	$16,000.00
Water Heating	75 Gallon Electric Water Heater	$1,000.00	Dawn Thermal System	$2,000.00
Thermostat	Traditional	$14.98	Programmable	$38.85
Lighting	Incandescent Bulbs (20)	$20.00	Energy Star Rated Light Bulbs (20)	$44.80
Windows	Single Hung Window	$1,400.00	Energy Star ThermaStar Pella Window	$2,758.00
Fixtures	Traditional Fixtures	$150.00	Low Flow Fixtures	$250.00
	TOTAL	$11,138.44	**TOTAL**	$32,786.50
			REBATES	-$6,155.00
			TOTAL AFTER REBATES	$26,631.50

Table 17: Traditional Annual Costs

Utilities - Traditional						
Water	127000	gallons/year	$4.27000	per HCF	$724.94	per year
Electricity	7500	KWH/year	$0.17425	per KWH	$1,306.88	per year
Gas	800	therms/year	*	*	1205.92	per year
				Total	**$3237.73**	**per year**

*

Gas Cost Breakdown	Base Cost	T (Per Year)	G (Per Year)
Distribution for First 50 Therms	0.541	27.05	27.05
After 50 Therms	0.2466	184.95	36.99
Gas Cost	1.2424	993.92	248.48
	TOTAL	1205.92	312.52

Table 18: Green Annual Costs

Utilities – Green						
Water						
Average Use	127000	gallons/year				
(Reducing fixtures/appliances)	-38100	gallons/year				
TOTAL	88900	gallons/year	$4.27000	per HCF	$507.46	per year
Electricity						
Average Use	*7500*	*kwh/year*				
(PV Shingles)	*-1000*	*kwh/year*				
(efficient appliances/lighting)	*-2250*	*kwh/year*				
TOTAL	4250	kwh/year	$0.17425	per KWH	$740.56	per year
Gas						
TOTAL	200		*	*	$312.52	per year
				Total	**$1,560.54**	**per year**

Table 19: Rebates for Green Technologies

Rebates	Limit	Value	Description
Tax Credits	15%	$300.00	Total purchase price and installation cost of solar hot water heater (up to $1000)
	15%	$1,000.00	Total purchase price and installation cost of photovoltaics (up to $1000)
MA State Rebate	$4.40/W	$4,400.00	Photovoltaics
	$10/window	$160.00	Rebate for Energy Star Window
	$50	$50.00	Programmable Thermostat
NSTAR	$1/light	$20.00	Rebate for Energy Star Lighting
	$200	$200.00	Rebate for Energy Star AC
	$25	$25.00	Energy Star thermostat
Total		$6,155.00	

7.3 Maintenance and Replacement Costs

As with any product or system, a house requires some maintenance during its life time. From a fresh coat of paint to reroofing, there are certain jobs that need to be done to maintain the condition and the performance of the building's systems. Because the life cycle being analyzed is only 20 years, it is unlikely that a new roof would be needed. System inspections are necessary to ensure that everything is working effectively and efficiently. Also included in the maintenance costs are the costs associated with replacing worn items such as light bulbs and faucet washers. Maintenance costs can be estimated as 1% of the initial construction cost per year (Consumer Credit Counciling Service of South Texas).

All of the appliances are expected to have a lifetime of at least 20 years except for the solar inverter. This equipment is expected to be replaced after its 10 year lifespan. Because the inverter was included in the cost estimate for the entire solar array, the approximate price of an inverter was found off of a retail webpage, The Solar Panel Store (Store). A summary of the maintenance and replacement costs per year is described in Table 20.

Table 20: Maintenance Costs

Maintenance Costs	Traditional	Green
Total Initial Construction Cost	$238,261	$257,157
Maintenance Cost per year	$2,383	$2,571
Replacement Cost (10-year interval)	$0	$2,150

7.4 Life Cycle

The life cycle cost estimation uses financial data to determine the present value of each design, including operations and maintenance. This method also incorporates the time value of money. Using formulas and tables from the text Life Cycle Costing for Design Professionals (Kirk & Dell'Isola, 1995), the sum of money presently needed to cover the 20-year life cycle of the structures was calculate. Table 21 summarizes the findings from the life cycle analysis. The first part of the table summarizes the construction costs, utility costs, and the rebates. The traditional design is initially about $18,300 cheaper than the green design. The time value money calculations used an assumed discount rate of 3%. The discount rate was estimated because it is always changing depending on the current rate set by the Federal Reserve Bank (Forbes). The present worth calculations for utility, maintenance and replacement costs is also summarized in Table 21. As described in equation 1, the present value of the utility and maintenance costs was calculated by multiplying the yearly costs by the Present Worth Annuity factor. The replacement cost only occurs once after 10 years. Using equation 2, the future cost of the replacement is multiplied by the Single Present Worth after 10 years.

Table 21: Life Cycle Cost Analysis Summary

INITIAL COSTS	Traditional	Green
Construction	$227,000	$237,000
Utilities	$11,138	$25,632
Rebates	$0	-$6,155
TOTAL	$238,138	$256,477
Initial Savings	$18,300	

Traditional Present Worth					
	Per Year	n	i	PWA	P
Utility Costs (eq 1)	$3,238	20	3%	14.877	$48,168
Maintenance Costs (eq 1)	$2,381	20	3%	14.877	$35,428
Replacement Costs (eq 2)	$0	10	3%	0	$0
				TOTAL	$83,600

Green Present Worth					
	Per Year	n	i	PWA	P
Utility Costs (eq 1)	$1,561	20	3%	14.877	$23,216
Maintenance Costs (eq 1)	$2,633	20	3%	14.877	$39,173
Replacement Costs (eq 2)	$2,153	10	3%	0.7441	$1,602
				TOTAL	$64,000

#	Equations
1	P=A*PWA(20 yr, i=3%)
2	P=F*PW(10 yr, i=3%)

Definitions
A= Uniform Sum of Money
FV=Future Value
n= Number of Years
P= Present
PV=Present Value
PW(10 yr,i=3%)=0.744
PW=Single Present Worth
PWA(20yr,i=3%)=14.877
PWA= Present Worth Annuity

The initial savings associated with the traditional design can be invested and used towards the life cycle cost. If the $18,300 is invested at an interest rate of 3% over 20 years, a total of $33,000 can be earned as demonstrated in Table 22. If this is included in the life cycle cost, it greatly increases the margin between the cost of the green and the traditional design, making the traditional design look like a better investment. As an alternative to investing, the initial savings can be considered to reduce the annual mortgage payments.

Table 22: Investment Summary for Traditional Design Savings

Investing Initial Savings of $18,300 from Traditional Design			
n	**i**	**Equation**	**Total After 20 yr**
20	3%	$FV = PV(1+i)^n$	$33,000

The final cost analysis summary is provided in Table 23 and Figure 43: Summary of Life Cycle Graph Figure 43. This analysis shows that the traditional design is a better financial investment than the green design if the initial savings are invested. There is a $31,800 difference between the green design and the traditional design, if the initial savings are invested. However, if the initial savings are not invested, the green design costs approximately $1,200 less than the traditional design in total life-cycle costs.

Table 23: Final Summary of Cost Analysis

SUMMARY	**Traditional (T)**	**Green (G)**	**Difference (G-T)**
Initial Costs	$238,138	$256,477	*$18,338*
Operating and Maintenance Costs	$83,596	$63,991	*-$19,604*
Investing Savings	-$33,121	0	*$33,121*
TOTAL with Investing	$288,613	$320,468	*$31,854*
TOTAL without Investing	$321,734	$320,468	*-$1,266*

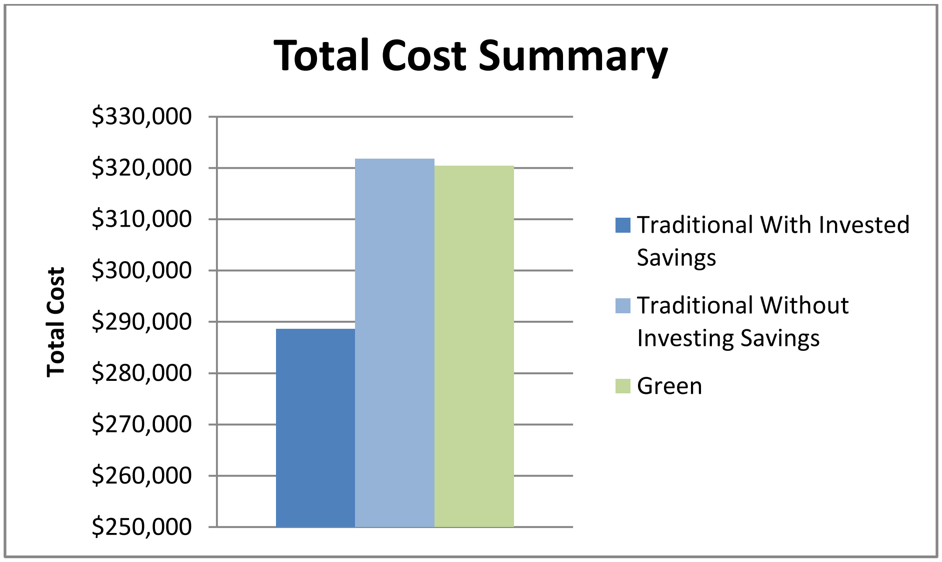

Figure 43: Summary of Life Cycle Graph

8 Conclusion and Recommendations

The motivation for this project stems from recent green trends. Green technologies are rapidly developing and readily available. Throughout each step of the design, the project focused on green alternatives to traditional construction practice. The goal of the project was to reveal the potential that sustainable living has to become standard practice.

The first stages of the project involved the design of both traditional and sustainable residential structures. One of the important features of the design is its flexibility. The structure was designed to have no interior bearing walls to allow the structure to be easily modified. The interior walls can be relocated without disturbing the structural integrity of the building. This allows the owner to easily customize the floor plan.

The design process incorporated concepts from various civil engineering courses and library research. Although it is common to design trusses and compute bending forces in members in structural design courses, it is rare to design an entire structure from roof to foundation. This project unveiled the relationship between roof trusses, bearing walls, floor joists, columns and foundations. Many of the structural design challenges faced during this project were due to the lack of bearing walls inside of the structure. For example, the large span between exterior walls prevented the use of traditional ridge beams and rafters. This encouraged the team to think creatively about alternative design methods for both the traditional and green design.

Constructability was another important aspect of the project. The site selection for the project was not limited. All of the design parameters are average values for the New England area. Therefore, the homes can be constructed anywhere in New England.

In addition to the relationship between members, the variations between building materials were also explored. The project put an emphasis on the strength and thermal resistance of building materials to create a structure that is not only energy efficient, but durable.

The fire sprinkler system provides a factor of safety for both residential designs. If a fire were to occur, the occupants would be able to escape safely and their belongings would not entirely be lost.

Green alternatives are costly compared to traditional design materials and products. Through government and industry initiatives, rebates and discounts are offered to help make sustainable living more affordable. One has to consider the life cycle cost benefits of resources such as solar power or geothermal heating which will significantly reduce the annual utilities bill.

The cost analysis for this project determined that the green structure is initially more expensive to construct. Using data from RSMeans and various manufactures, the initial construction, utility, and appliance cost estimation for the traditional design is $238,000. The green design cost estimation is $256,000.00. The total twenty-year, life-cycle cost of the traditional and green designs when considering present value is $322,000 and $320,000 respectively. If initial savings are invested, an additional $32,000 reduction can be applied to the traditional design cost.

With rebates, renewable energy savings, and no investment return on the initial savings, after 20 years the green structure costs about $1,200 less than the traditional structure. Although it is only slightly less expensive, it reduces energy usage and conserves natural resources. The green design ultimately creates a more sustainable living environment.

Further investigation for this project is possible. More accurate cost estimations for several of the green technologies could be identified through additional case studies and manufacturer participation. The estimated energy use for both structures could be expanded upon to provide a more accurate evaluation. This would entail doing an analysis on energy use in homes of a similar size with similar appliances. It would also require an analysis of the family living within the home. The energy and resource use could be higher or lower depending on how conscious they are of their energy use. Overall there are many additional factors that could be investigated.

To reduce the cost of the green design, it would be recommended to remove the PV shingles. Although they create renewable energy and can be used to get LEED accreditation points, they are extremely expensive. They cost of the system is estimated at $15,000 with inverter replacement costs of about $2,100 every 10 years. If the PV system is removed from the design, there is a smaller difference between the cost of the traditional design and the green design.

Sustainable residential structures are important for not only saving money, but improving quality of life. Reducing energy use, improving building efficiency, and conserving natural resources are a few of the small steps that can be taken towards preserving the environment.

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9 Appendix A: Proposal

9.1 Abstract

The goal of the project is investigate sustainable residential constructing. A cost analysis including a 20-year payback and a comparison of two residential structures will be completed. The first structure will incorporate traditional design methods and the second will include sustainable design, as specified by LEED. A fire protection system will be integrated into the sustainable structure.

9.2 Introduction

Green buildings are becoming increasingly common for both residential and commercial structures. The high demand for green design spurs from a greater than ever world consciousness for the environment and sustainability. In many cases as well, green structures may provide a lower lifetime cost alternative to conventional building methods. Although green technology is more expensive than traditional technologies, it has the potential to have a shorter payback period. With the current economic status, cost-effective designs will certainly drive the market forward.

The idea of green is still a new concept. Therefore, the definition of what is, and what is not green is somewhat ambiguous. Since 1998 a rating system for green design called LEED has existed. LEED (Leadership in Energy and Environmental Design) was developed by the U. S. Green Building Council and provides a checklist of sustainable building design. Features in the checklist include a range of construction aspects from site selection, to energy sources, to materials of construction. Energy-efficient appliances, alternative heating/cooling sources, solar energy and water conservation all contribute to what is widely considered to be green. (U.S. Green Building Council, 2008)

The aim of this project is to design two similar houses and compare them. One design will use traditional construction methods that are still widely used today; the other design will use particular environmentally sustainable methods as defined by the LEED standard. The house is a one story home with 10 rooms and a two-car garage. The traditional home will be built to meet the International Residential Code (IRC) and will use standard wood-frame construction. The green home will employ new technology and practices to meet certification by LEED standards for green design while also meeting the criteria set by the IRC. The cost benefits and payback over a twenty-year period will be considered in the comparison of the two homes.

A fire protection system will also be developed and implemented into both designs. In 2007, there were 399,000 house structure fires in the United States. The fires caused 2,865 deaths and $7.4 billion in property damage. Because of the rising statistics, the International Code Council (ICC) members voted in support of residential fire sprinkler requirements for all new homes(National Fire Protection Association, 2008). Therefore, in addition to designing a safer home, the project will conform to the new fire protection standards in the 2009 edition of the IRC. An objective for the fire protection system is to incorporate it into the green aspects to prove its sustainability in not only homes but in any type of building.

The project will include two building designs complete with design drawings, calculations, and cost analyses. The traditional building will be designed with post and beam construction while the green building will make use of structurally insulated panels. The green building will incorporate LEED certified appliances and finishes, geothermal heating systems, solar hot water systems, and graywater recycling systems to add to the buildings sustainability and to meet LEED standards. The heating and water systems designs will include drawings and demand calculations.

The last objective of the project is to create a comparison between the traditional and green structures. The comparison will include an initial cost analysis, a life cycle cost analysis, and a 20 year payback analysis. The structures will be compared to determine which one creates a healthier and more sustainable environment.

9.3 Scope

The scope of the project is defined in the following diagram, table, and bar chart. The table describes each task and the necessary subtasks that need to be completed. The design aspects are listed as "design" or "associated cost". The design designation means that we will create the design and calculate costs based on the design. The associated cost designation indicates that we will select the appropriate appliances or building materials but we will not design them.

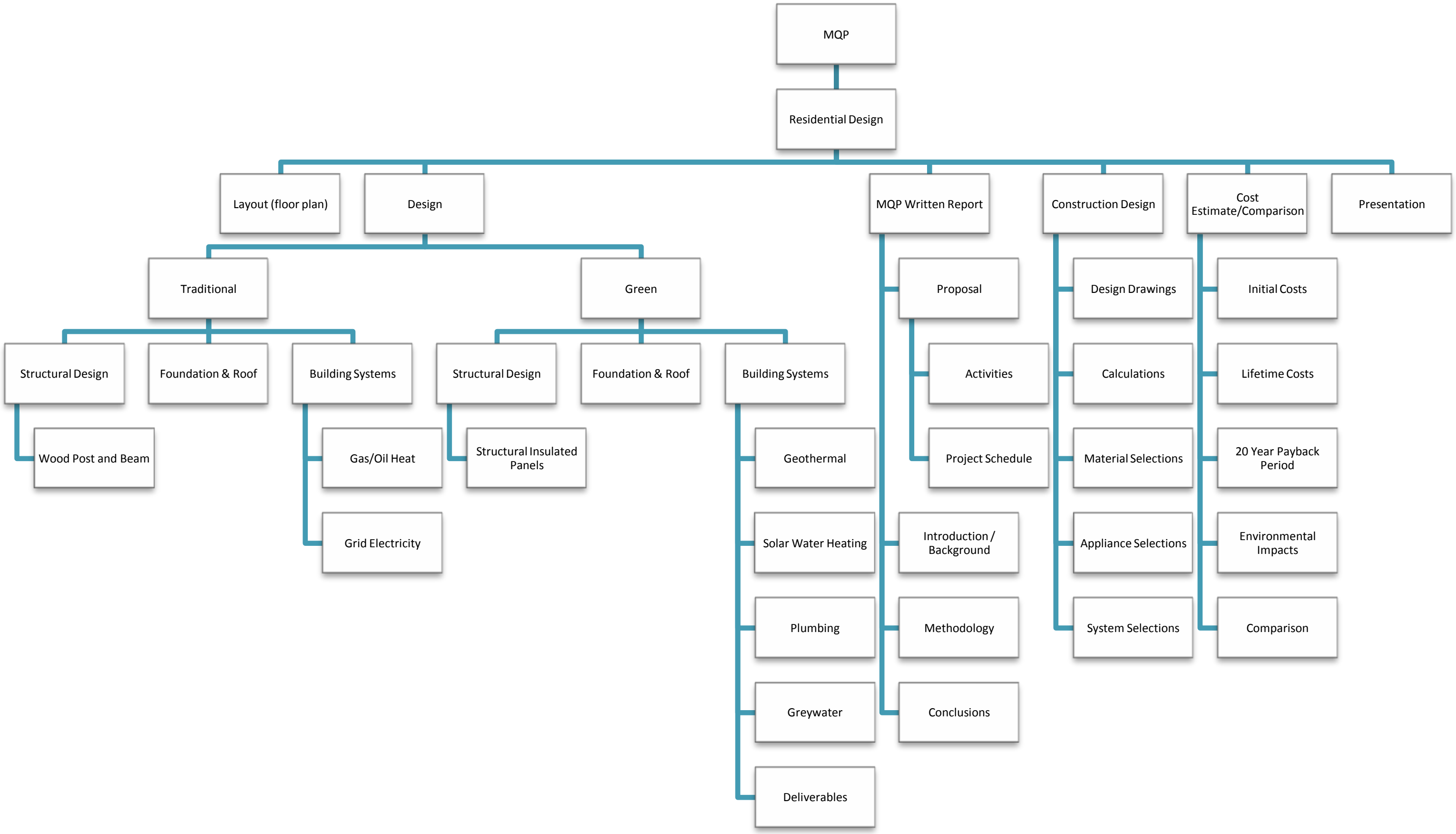


Figure 44: Project Outline

Table 24: List of Activities

Task	Description	Responsibility
Identify Schedule	Identify tasks	All
	Identify dates associated with tasks	Tracy
	Create Gnatt chart in Microsoft Project	Tracy
Create Abstract	Identify the project goals	All
	Write abstract	All
Design Building Layout	Create Floor Plan w/dimensions	Meghan
Research Design	Select building code	Tracy
	Research foundation	Tim
	Research wood design	Meghan
	Research alternative green design attributes	All
	Research traditional design attributes	All
	Research CSI List format	Tracy
Research Background	Select CSI List	Tracy
	Research each area in CSI List	All
	Research LEED Design criteria	Meghan
	Research fire protection systems	Tracy
	Identify additional codes and standards to follow	All
Green Structure	Perform wood design	Meghan
	Perform footing design	Tim
	Design for lateral, vertical, wind, snow, and earthquake loads	All
	Perform roof design	Tim
	Identify traditional design aspects	
	01 General Requirements	Tracy

	03 Concrete	Tim
	Design footings + Cost	
	06 Wood, Plastics, and Composites	Meghan
	Associated Cost of Selected Items	
	07 Thermal and Moisture Protection	Meghan
	Associated Costs of Selected Items	
	08 Openings	Meghan
	Associated Costs of Selected Items	
	09 Finishes	Tracy
	Associated Costs of Selected Items	
	11 Equipment	Tim
	Associated Costs of Selected Items	
	21 Fire Suppression	Tracy
	Design sprinkler systems + Cost	
	Select Alarm/Detection systems	
	22 Plumbing	Tracy
	Design Plumbing system with grey water system + Cost	
	23 Heating, Ventilating, and Air-Conditioning	Tim
	Design HVAC system-Geothermal + Cost	
	32 Exterior Improvements	Tim
	Associated Costs	
	41 Material Processing and Handling Equipment	Tim
	Associated Costs of Selected Items	
	42 Process Heating, Cooling, and Drying Equipment	Tim
	Associated Costs of Selected Items	
	48 Electrical Power Generation	Meghan
	Associated Cost of Selected Items	

"Traditional" Structure	Perform wood design	Meghan
	Perform footing design	Tim
	Design for lateral, vertical, wind, snow, and earthquake loads	All
	Perform roof design	Tim
	Identify traditional design aspects	All

	01 General Requirements	
	03 Concrete	
	Design footings + Cost	
	06 Wood, Plastics, and Composites	
	Associated Cost of Selected Items	
	07 Thermal and Moisture Protection	
	Associated Costs of Selected Items	
	08 Openings	
	Associated Costs of Selected Items	
	09 Finishes	
	Associated Costs of Selected Items	
	11 Equipment	
	Associated Costs of Selected Items	
	21 Fire Suppression	
	Design sprinkler systems	
	Select Alarm/Detection systems	
	22 Plumbing	
	Design Plumbing system	
	23 Heating, Ventilating, and Air-Conditioning	
	Design HVAC system	
	32 Exterior Improvements	
	Associated Costs of Selected Items	
	41 Material Processing and Handling Equipment	
	Associated Costs of Selected Items	
	42 Process Heating, Cooling, and Drying Equipment	
	Associated Costs of Selected Items	
	48 Electrical Power Generation	
	Associated Cost of Selected Items	

Gather Cost Data	Determine construction costs using RS Means Construction Data	All
	Determine costs associated with each CSI division (traditional and green)	(See assoc. CSI list)

Perform Cost Analysis	Calculate the 20 year payback	All

	Determine the necessary costs/leasing rates to improve 20 year payback	All
	Compare green cost data to traditional cost data	All

Research Environmental Data	Use resources to determine average:	All
	Home water usage and costs	
	Home heating usage and costs	
	Home electric usage and costs	

Perform Environmental Analysis	Calculate the reduced water, heating, electric usage for green design	All
	Calculate the savings involved with the reduced usage	All

Perform Write Up	Introduction	All
	Background	All
	Methodology	All
	Layout	All
	Structural Design	All
	Foundation	All
	Project Management (Cost Analysis)	All
	Fire Protection System	All
	LEED Design	All
	Conclusions	All
	Appendices	All
	Glossary	All
	References	All

Prepare Presentation	Create PowerPoint presentation for project presentation day	All

ID	Task Name	Duration	Start	Finish
2	Create Abstract	3 days?	Thu 8/28/08	Mon 9/1/08
3	Research Design	48 days?	Tue 9/2/08	Thu 11/6/08
4	Research Background	81 days?	Tue 9/2/08	Tue 12/23/08
21	Create Floor Plan	29 days?	Tue 9/2/08	Fri 10/10/08
11	Write MQP Intro	56 days?	Mon 9/1/08	Mon 11/17/08
20	Write Appendices, Glossary and References	135 days?	Mon 9/1/08	Fri 3/6/09
1	Identify Schedule	6 days?	Wed 9/10/08	Wed 9/17/08
9	Research Environmental Data	92 days?	Wed 9/10/08	Thu 1/15/09
12	Write MQP Background	109 days?	Wed 9/10/08	Mon 2/9/09
13	Write MQP Methdology	64 days?	Wed 9/10/08	Mon 12/8/08
23	Write MQP Proposal	20 days?	Mon 9/22/08	Fri 10/17/08
24	Create End of Term Submittal (A)	13 days?	Wed 10/1/08	Fri 10/17/08
5	Structural "Green" Design	44 days?	Mon 10/20/08	Thu 12/18/08
6	Structural "Traditional" Design	44 days?	Mon 10/20/08	Thu 12/18/08
7	Gather Cost Data	64 days?	Mon 10/20/08	Thu 1/15/09
18	Write MQP LEED Design	71 days?	Mon 10/27/08	Mon 2/2/09
14	Write MQP Structural Design	56 days?	Mon 11/3/08	Mon 1/19/09
15	Write MQP Foundation	56 days?	Mon 11/3/08	Mon 1/19/09
25	Create End of Term Submittal (B)	12 days?	Thu 12/4/08	Fri 12/19/08
17	Write MQP Fire Protection System	16 days?	Mon 12/22/08	Mon 1/12/09
8	Perform Cost Analysis	13 days?	Fri 1/16/09	Tue 2/3/09
10	Perform Environmental Analysis	13 days?	Thu 1/15/09	Mon 2/2/09
16	Write MQP Cost Analysis	11 days?	Wed 2/4/09	Wed 2/18/09
19	Write MQP Conclusions	15 days?	Mon 2/16/09	Fri 3/6/09
22	Prepare Presentation	5 days?	Mon 3/9/09	Fri 3/13/09

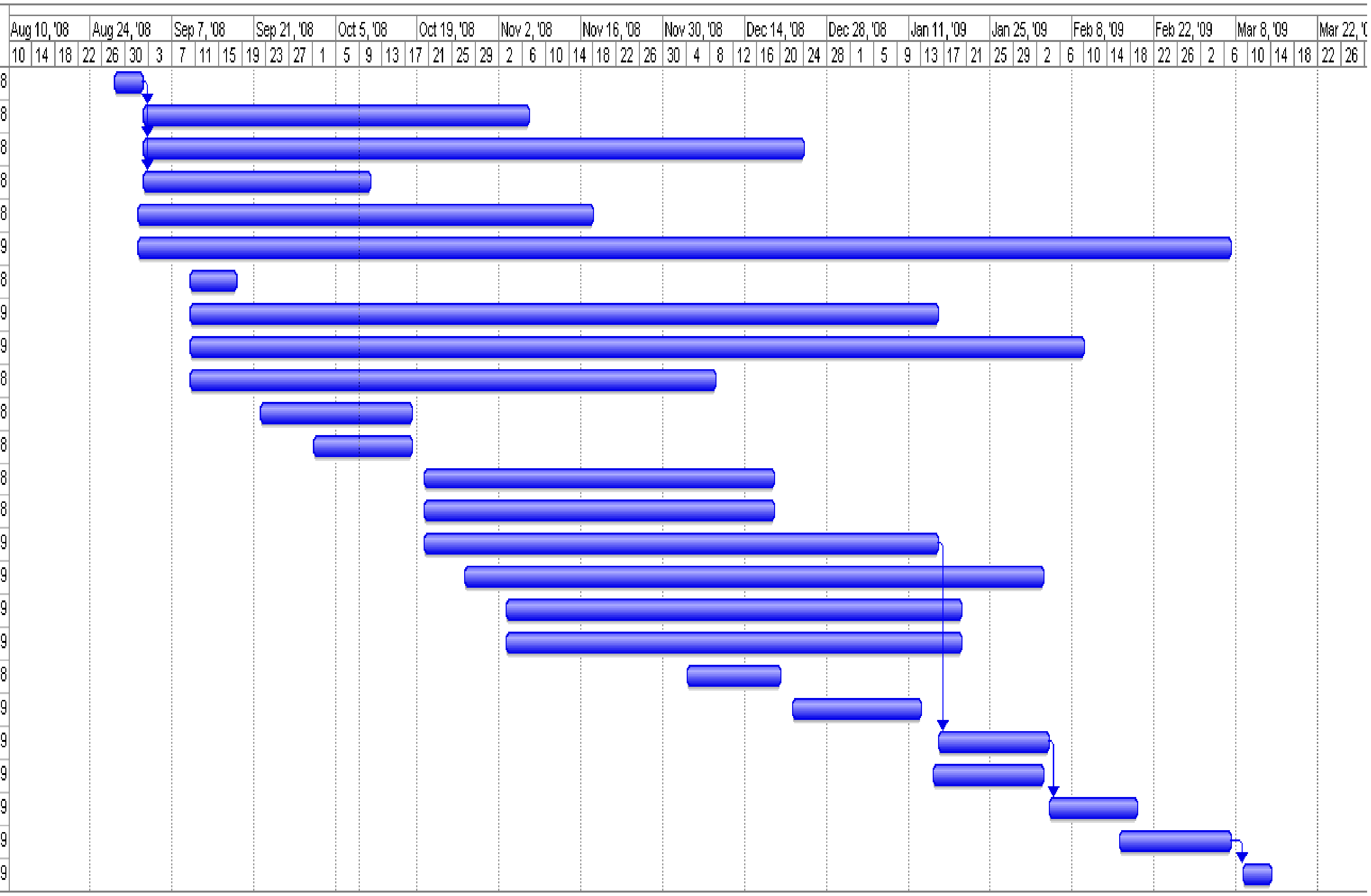


Figure 45: Bar Chart of Activities

10 Appendix B: Design Calculations

10.1 Roof Design Calculations

Roof design

		psf
DL =	Roofing 3ply	1.5
	Plywood ½"	1.5
	Insulation (loose)	0.5
	Shingles · Asphalt ¼"	2
	Framing (2×4 truss)	1.9
	Ceiling (Gyp wallboard)	2.5
		10 psf

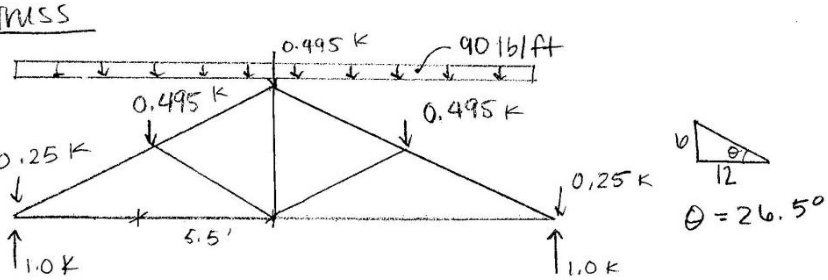
using Table A-B in Wood Design text

LL = for all areas = 40 psf

$SL = C_s\, 0.7\, C_e C_t I p_g$

$= 1(0.7)(1)(1)(1)(50) = 35\ psf$

Garage Truss



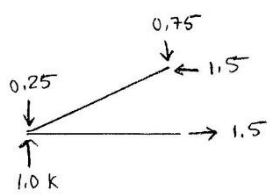
trusses spaced 24" O.C made from 2×4 No. 1 Spruce-Pine-Fir

D = 10 psf

S = 35 psf

45 psf (2'/truss) = 90 lb/ft

P = 90(5.5') = 495 lb = 0.495 K



$F'_t = 450(1.15)(1.5) = 776.25$

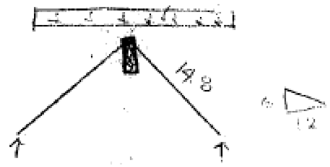
$Req\ A_n = \frac{P}{F'_t} = \frac{1500}{776.25} = 1.93$

$A_g = A_n + A_h = 1.93 + 1.5(3/4 + 1/16) = 3.15\ in$

$2\times4 = 5.25\ in^2 > A_g$ ✓ OK use 2×4 spaced 24" O.C

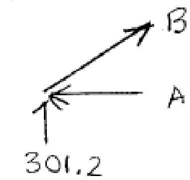
Garage Building Roof Design

Ridge Roof



DL = ridge beam = 33.5 (4/12)(8/12) ÷ 11 = 0.67
2x8 16" o.c. = 1.9
Sheathing = 1.5
Shingles = 2
6.07 psf

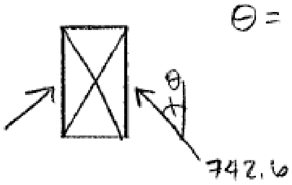
(6.07+35)(16/12) = 54.76 lb/ft
$\frac{54.76(11)}{2}$ = 301.18



ΣFy = 301.2 · B(sin 26.6) = 672.7
ΣFx = A − 672.7(cos 26.6) = 601.5

Check compression stress

θ = 63.4°



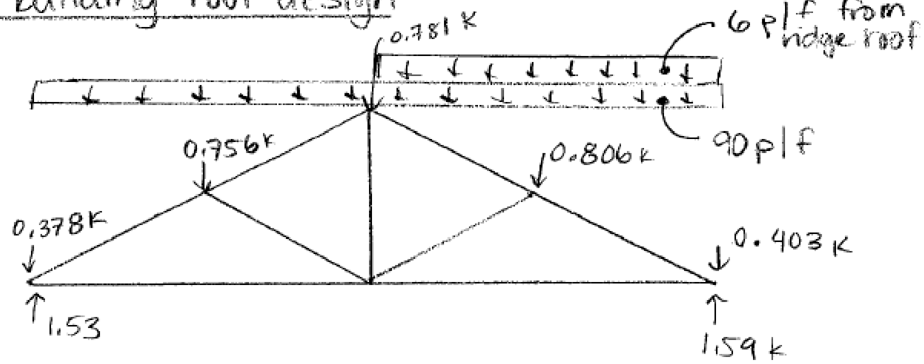
fθ = P/A ≤ F'θ bearing @ ∡ other than 90 or 0
P/A = 672.7/A = 672.7/10.88 = 61.83
$F'\theta = \frac{135(425)}{135\sin^2 63.4 + 425\cos^2 63.4} = 297.66$
F'θ > fθ ✓ OK

Use 2x10 ridge beam to allow space for nailing and proper connection.

16" o.c.

Meets requirements of IBC Table R802.5.1(1)

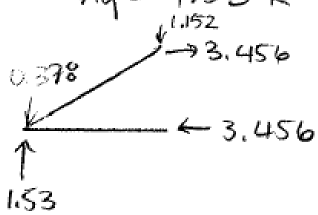
Main building roof design

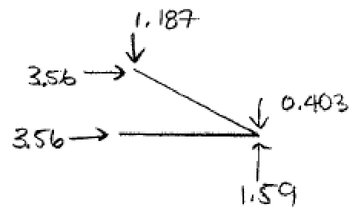


$D = 10\text{ psf}$
$S = 35\text{ psf}$
$45\text{ psf}\,(2'\text{o.c.}) = 90\text{ plf}$

$P = 90\text{ plf}\,(8.4') = 756\text{ lb} = 0.756\text{ K}$

$\Sigma M_a = 0.756(8.4) + 0.781(16.8) + 0.806(25.2) + 0.403(33.6) - B_y(33.6) = 0$
$B_y = 1.59\text{ K}$
$\Sigma F_y = 0.378 + 0.756 + 0.781 + 0.806 + 0.403 - 1.59 - A_y = 0$
$A_y = 1.53\text{ K}$





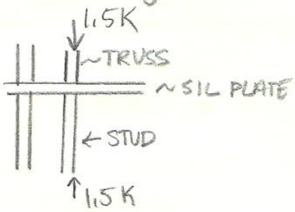
No. 1 Spruce-Pine-Fir

$F_t = 450(1.15)(1.5) = 776.25$
$\text{Req } A_n = \frac{P}{F'_t} = \frac{3560}{776.25} = 4.59\text{ in}^2$
$A_g = A_n + A_h = 4.59 + (3/4 + 1/16)(1.5) = 5.8\text{ in}$

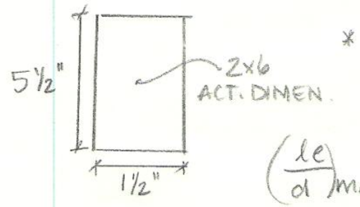
$2\times6\ 24''\text{ O.C} = A = 8.25\text{ in}^2 > A_g$ ✓ OK

10.2 Wall Design Calculations

Stud Wall Design



$F_c = 725$ psi (STUD GRADE)
$E_{MIN} = 440{,}000$
$A = 8.25 \text{ in}^2$



* NDS: STUDS ATTACHED TO SHEATHING/DRYWALL → USE DEPTH FOR WEAKEST SIDE (NDS 2001 APPX A (A:11.3)).

$$\left(\frac{l_e}{d}\right)_{MAX} = \frac{K_e L}{d} = \frac{1(10')(12''/ft)}{5.5} = 21.82$$

$$E'_{min} = E_{min}(C_M C_t C_T C_i) = 440{,}000(1) = 440000$$

$$F_{cE} = \frac{0.822 E'_{min}}{(l_e/d)^2} = \frac{0.822(440{,}000)}{(21.82)^2} = 759.65 \text{ psi}$$

$$F^*_c = F_c C_D C_M C_t C_F C_i = 725(1.25)(1)(1.1)(1.0) = 996.875 \text{ psi}$$

$$\frac{F_{cE}}{F^*_c} = \frac{759.65}{996.88} = 0.762$$

$$\frac{1 + F_{cE}/F_c}{2c} = \frac{1 + 0.762}{2(0.8)} = 1.476$$

$$C_p = 1.476 - \sqrt{(1.476)^2 - \frac{0.762}{0.8}} = 0.368$$

$$F'_c = F_c C_D C_M C_t C_F C_p C_i = 725(1.25)(1.0)(1.0)(1.1)(0.368) = 366.85 \text{ psi}$$

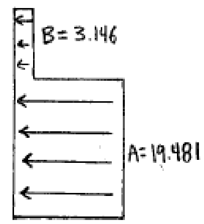
$$P = F_c' A = 0.367(8.25) = 3.03\text{ K} > 1.5\text{ K} \checkmark \text{ OK.}$$

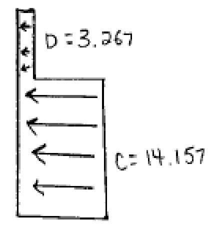
USE 2X6 STUD GRADE SPF 16" O.C

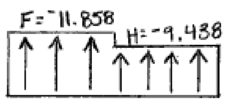
House : 18.43° roof slope

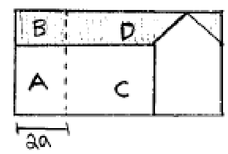
Basic Wind Speed = 90 mph (V_{3S} = 110 = V_{fm} = 90 mph) ⇒ Fig. 1609, Table 1609.3.1)

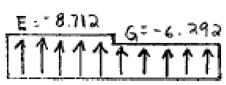
ZONE	$P_{S,30}$	I	λ	P_S (psf)
A	16.1	1.0	1.21	19.481
B	2.6	↓	↓	3.146
C	11.7			14.157
D	2.7			3.267
E	-7.2			-8.712
F	-9.8			-11.858
G	-5.2			-6.292
H	-7.8			-9.438

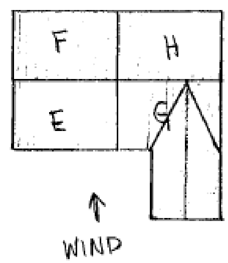












GARAGE : 26.5° roof slope

Basic Wind Speed = 90 mph (V_{3S} = 110 = V_{fm} = 90 mph)

ZONE	$P_{S,30}$	I	λ	P_S (psf)
A	16.1	1.0	1.21	19.481
B	2.6	↓	↓	3.146
C	11.7			14.157
D	2.7			3.267
E	-7.2			-8.712
F	-9.8			-11.858
G	-5.2			-6.292
H	-7.8			-9.438

tributary wall height : $\frac{1}{2} \times 10' = 5'$

height to reference point : 10'

h_{mean} : $10 + \frac{1}{2}(5.5') = 12.75'$

$.4 h_{mean} = 5.1'$

least horizontal bldg dimension = 22' = b

$.1 \times b = 2.2'$

end zone dimension = 2a, a = lesser of $.4 \times h_{mean}$ OR $.1 \times b$

= 2.2', 2a = 4.4'

tributary height to roof diaphragm = tributary wall height below reference point + height of parapet wall + projected roof height above parapet wall

10.5' = 5' + 0 + 5.5

$w_{end} = (19.481)(5+0) + 3.146(5.5) = 114.708$ lb/ft

$w_{int} = (14.157)(5) + 3.267(5.5) = 88.754$ lb/ft

$W = w_{end}(2a) + w_{int}(L-2a) = (114.708)(4.4) + (88.754)(L=50-4.4)$: $\underline{W = 4551.9 \text{ lb}}$

R_A vs. R_B

ΣM_B: $R_A = (w_{end})(2a)(L-a)(1/L) + (w_{int})(L-2a)(L/2-a)(1/L)$

$R_A = (114.708)(4.4)(50-2.2)(1/50) + (88.754)(50-4.4)(50/2-2.2)(1/50) = \underline{R_A = 2328.02}$

$R_B = W - R_A$: $4551.9 - 2328.02 = \underline{R_B = 2223.88}$

$w_{min} = p_s \times$ (trib. height to roof diaphragm) $= 10$ psf $\times 10.5 = \underline{w_{min} = 105 \text{ lb/ft}}$

$W_{min} = w_{min} \times L = 105 \times 50 = \underline{W_{min} = 5250 \text{ lb}}$

$R_A = R_B = 1/2\, W_{min} = \frac{1}{2}(5250) = \underline{R = 2625}$

∴ min wind pressure of 10 psf governs

$2625 = R = V$

$v = V/b = \frac{2625}{22} = 119.318$ lb/ft $= v$
SHEAR

Table 2306.4.5 :

Use: gypsum wall board (1/2")
blocking
shear value : 150 plf
max. fastener spacing: 4"
min. fastener size: 5d cooler or wall board
0.120" nails (min. 3/8" head, 1 1/2" long)
OR
16" gage staple (1 1/2" long)

10.3 Floor Design Calculations

girder design

$G_1 = 11.2 \times 12.5 = 140 \ ft^2$
$G_2 = 140 \ ft^2$
$G_3 = 140 \ ft^2$
$G_4 = 140 \ ft^2$
$G_5 = 140 \ ft^2$
$G_6 = (5.6 \times 12.5) + (5.2 \times 12.5) = 135 \ ft^2$
$G_7 = (5.6 \times 12.5) + (2 \times 5.2) + (0.9 \times 10.5) = 89.85$
$G_8 = (0.9 \times 12.5) + (5.6 \times 12.5) = 81.25$

DL = 16.7 psf
LL = 40 psf

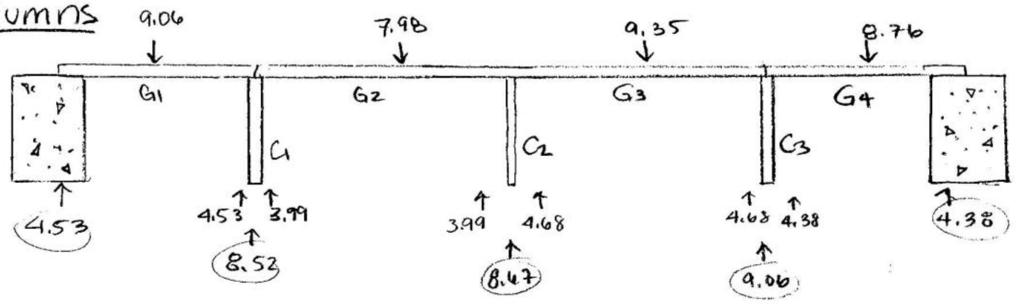
interior wall DL =

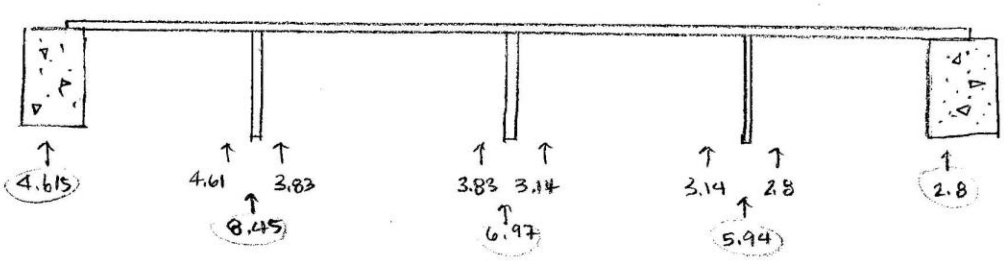
$G_1 = 5.9(19 \times 10) = 1.12 \ K$
$G_2 = 5.9(1 \times 10) = 0.059 \ K$
$G_3 = 5.9(24 \times 10) = 1.416 \ K$
$G_4 = 5.9(14 \times 10) = 0.826 \ K$
$G_5 = 5.9(22 \times 10) = 1.298 \ K$
$G_6 = 5.9(0) = 0$
$G_7 = 5.9(20 \times 10) = 1.18 \ K$
$G_8 = 5.9(17 \times 10) = 1.0 \ K$

total loading =

$G_1 = 140 \ ft^2 (16.7 + 40) + 1120 \ lb = 9.06 \ k$
$G_2 = 140 \ ft^2 (16.7 + 40) + 59 \ lb = 7.98 \ k$
$G_3 = 140 \ ft^2 (16.7 + 40) + 1416 \ lb = 9.35 \ k$ ← governing
$G_4 = 140 \ ft^2 (16.7 + 40) + 826 \ lb = 8.76 \ k$
$G_5 = 140 \ ft^2 (16.7 + 40) + 1298 \ lb = 9.23 \ k$
$G_6 = 135 \ ft^2 (16.7 + 40) + 0 \ lb = 7.65 \ k$
$G_7 = 89.85 \ ft^2 (16.7 + 40) + 1180 \ lb = 6.27 \ k$
$G_8 = 81.25 \ ft^2 (16.7 + 40) + 1000 \ lb = 5.60 \ k$

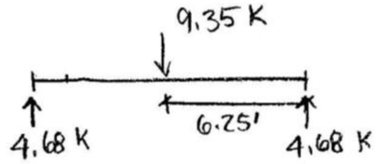
Columns





Girder Bending Check

Use $2(4 \times 14s) = 8 \times 14$



$V = 4.68$

$M = \frac{1}{2}(4.68)(6.25) = 14.63$ ft-K

14.63 ft-K $= 175$ in-K

Check Bending

$$f_b = \frac{M}{S} = \frac{175000 \text{ in-lb}}{227.8 \text{ in}^3} = 768.2$$

$$F'_b = F_b C_d C_m C_t C_L C_F C_r C_i = 1250(1.15)(1) = 1437.5 > f_b \checkmark \text{ OK}$$

Check Shear

$$f_v = \frac{1.5V}{A} = \frac{1.5(4680)}{101.3} = 69.3$$

$$F'_v = F_v C_D C_m C_t = 135(1.15) = 155.3 > f_v \checkmark \text{ OK}$$

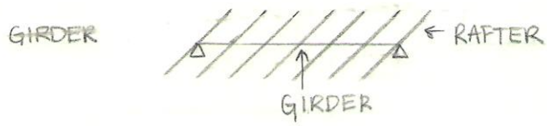
Check Deflection

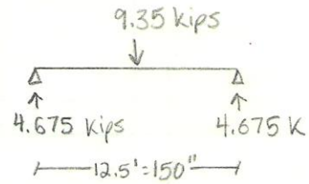
$$E' = E\, C_m C_t C_i = 1{,}500{,}000(1)(1)(1) = 1{,}500{,}000 \text{ psi}$$

$$\Delta_{TL} = \frac{5 w_i L^4}{384 E' I} = \frac{5(748 \text{ lb/ft})(12.5^4)(1728 \text{ in}^3/\text{ft}^3)}{384(1500000)(474.6)} = 0.577 \text{ in}$$

$$\Delta_{TL} = \frac{L}{240} = \frac{12.5 \times 12}{240} = 0.625 > 0.577 \text{ in} \checkmark \text{ OK}$$

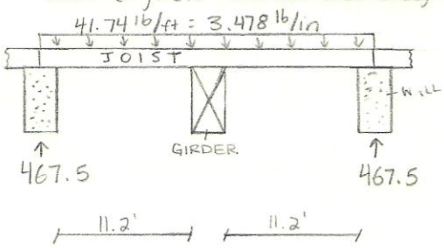
Use select Structural S-P-F 8×14 or $2, 4 \times 14s$





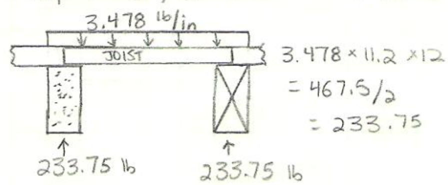
$\frac{9350\ lb}{10\ rafters} = 935\ lb \div 2 = 467.5$

$\frac{935\ lb}{22.4'\ (2\ joists \to one\ on\ each\ side)} = 41.74\ ^{lb}/_{ft} = 3.478\ ^{lb}/_{in}$

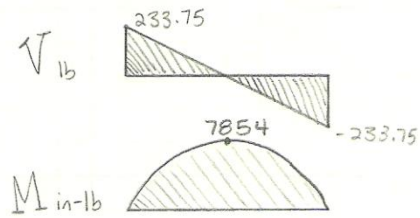


TRY 2 × 8, 16" O.C.

$\frac{150''}{16''} = 9.375 \sim 10$ JOISTS



$3.478 \times 11.2 \times 12 = 467.5/2 = 233.75$



TRIAL SIZE: 2 × 8 (#1 S-P-F), 16" O.C.

$C_D = 1.0$ floor LL $C_L = 1.0$
$C_r = 1.15$ $C_F = 1.1$
$C_m = 1.0$ $C_i = 1.0$
$C_t = 1.0$

BENDING

$F'_b = F_{bx} C_D C_T C_m C_t C_L C_F C_i$

$F'_b = (875\ psi)(1.0)(1.0)(1.0)(1.0)(1.0)(1.1)(1.15)$

$F'_b = 1106.875\ psi$

$Req\ S = \frac{M}{F'_b} = \frac{7854}{1106.875} = 7.096\ in^3 > 13.14\ in^3$ (Table 1B)

$f_b = \frac{M}{S} = \frac{7854\ in\text{-}lb}{13.14\ in^3} = 597.717 < F'_b = 1106.875\ psi$ OK

SHEAR

$f_v = \frac{1.5V}{A} = \frac{(1.5)(233.75)}{10.88} = 32.23\ psi$

$F'_v = 135\ psi > f_v = 32.23\ psi$ OK

$F'_v = F_v C_D C_m C_t C_i = (135)(1.0)(1.0)(1.0)(1.0) = 135\ psi$

DEFLECTION

$E' = E C_m C_t C_i$ $E = 1.4E6$ (Table 4A)

$E' = 1.4E6$

$\Delta L = \frac{5 w_L L^4}{384 EI} = \frac{(5)(40 \times 1.33)(11.2^4)(1728\ in^3/ft^3)}{(384)(1.4E6)(47.63)} = 0.2825\ in$

allow $\Delta_L = \frac{L}{240} = \frac{(11.2)(12)}{240} = 0.56\ in > \Delta_L = 0.2825\ in$ OK

BEARING

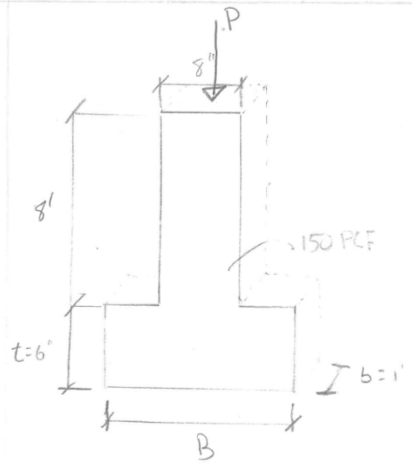
$F'_{c\perp} = F_{c\perp} C_m C_t C_b = (425)(1.0)(1.0) = 425 \text{ psi}$

$\text{Req'd } A = \frac{R}{F'_{c\perp}} = \frac{233.75}{425} = 0.55 \text{ in}^2$

$\text{Req'd } l_b = \frac{A}{b} = \frac{.55 \text{ in}^2}{1.5 \text{ in}} = 0.367 \text{ in}$ OK

10.4 Foundation Design Calculations

Foundation Design Calculations



Assume B = 3ft

$P = 4.6^{K}$ (Wall & Roof load)

$W_f = 8ft \times 8/12\ ft \times 1ft \times 150PCF = 800\ lb$
$+ 0.5' \times 2 \times 1 \times 150PCF = 150\ lb$
$= 1150 lb$

From IRC

Sand $q = 2000 lbs$

Check $q_t < q$

$$q_t = \frac{P + w_f}{B}$$

$$q_t = \frac{4.6 k/ft + .95 k/ft}{3ft} = 2.28\ K > 2k$$ use larger footing

Assume B = 3.5 ft $w_f = 1025$

$$q_t = \frac{4.6 k/ft + 1.02 k/ft}{3} = 1.88$$

10.5 Column Design Calculations

Steel pipe columns

IRC, minimum nominal pipe diameter ; 3"

Ext diameter 3.5 radius = 1.75
int diameter 3.07 radius = 1.535

P_{cr} = critical load

$P_{cr} = \frac{\pi^2 EI}{KL^2}$

E = Modulus of Elasticity
I = Moment of Inertia
K = Adjustment factor for fixed-pin connection
L = length of column

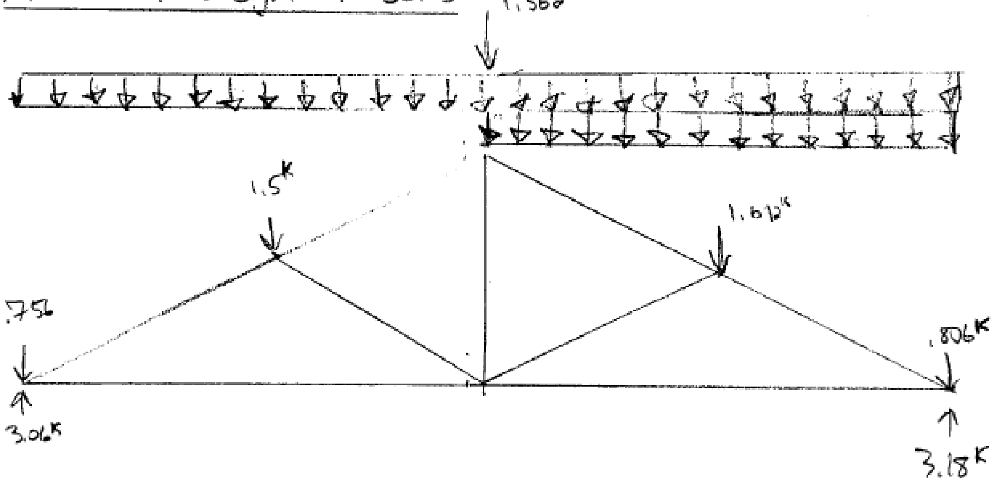
$$P_{cr} = \frac{\pi^2 (29\times10^3)(\frac{1}{4}\pi 1.75^4 - \frac{1}{4}\pi 1.535^4)}{0.7(8\times12)^2} = 133^k$$

$P_{cr} = 133^k$

11 Appendix C: Green Design Calculations

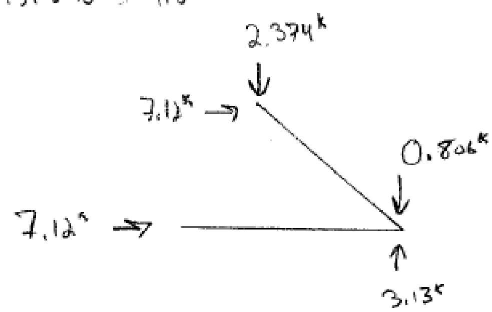
11.1 Roof Design

Main Roof Design → SIP's



D = 10 psf
S = 35 psf
45 psf (4' o.c.) = 180 PLF

180 PLF (8.4') = 1512 lb = 1.5K



NO.1 Spruce Pine Fir

$F'_t = 450(1.15)(1.5) = 776.25$

$\text{Req } A_n = \frac{P}{F'_t} = \frac{7120}{776.25} = 9.17$

$A_g = A_n + A_h = 9.17 + 1.5(3/4 + 1/16) = 10.4$

Use 2x8 $A = 11.25 in^2 > 10.4$ ✓ ok

11.2 Wall Design

GREEN - SIP WALL DESIGN

minimum thickness: 4.5"

Panel Height: 10'

From Table1: Allowable Transverse Loads of Wall Panels

Panel Height: 10.875 ft

Panel thickness: 4.5 inches ∴ Allowable Transverse load: 24 psf

Deflection Limit: L/240

Maximum wind load in any location: 19.481 psf OK!

4.5" thick SIPs × 10' high × 4' wide

12 Appendix D: Sprinkler System Pipe Specifications

(BlazeMaster)

BlazeMaster® Fire Sprinkler Pipe and Fittings - **United States and Canada***

PART 1 - GENERAL

1. 0 PRODUCT DESCRIPTION

BlazeMaster® CPVC fire sprinkler pipe and fittings are extruded/molded from CPVC compounds manufactured by Lubrizol Advanced Materials. The pipe and fitting compounds shall meet cell class 23547 and 24447, respectively, as defined by ASTM D1784, and shall be certified by NSF International for use with potable water. Both pipe and fitting compounds shall be pressure rated by Plastics Pipe Institute (PPI).

1. 1 PIPE AND FITTINGS

A. Pipe shall meet or exceed the requirements of ASTM F442 in standard dimension ratio (SDR) 13. 5.

B. Fittings shall meet or exceed the requirements of ASTM F437 (schedule 80 threaded), ASTM F438 (schedule 40 socket) and ASTM F439 (schedule 80 socket).

C. Both pipe and fittings shall be Listed by Underwriters Laboratories for use in wet automatic fire sprinkler systems and shall bear the logo of the Listing Agency. See UL Fire Protection Equipment Directory, categories VIWT and HFYH.

1. 2 SOLVENT CEMENT

A. All socket type joints shall be made up employing solvent cements that meet or exceed the requirements of ASTM F493. The standard practice for safe handling of solvent cements shall be in accordance with ASTM F402. Solvent cement shall be listed by NSF International for use with potable water, and approved by the manufacturers. The solvent cements shall be compatible with their CPVC pipe and fittings.

B. Follow manufacturer's instructions for set and cure times for solvent cement joints. Avoid significant stresses during set and cure times. Do not apply any stress that will disturb an un-dried joint. Sprinkler fittings shall be allowed to cure in accordance with the manufacturer's guidelines and the contractor shall assure the outlets are clear of any excess cement prior to installing sprinklers.

1. 3 BASIC USE

CPVC pipe and fittings shall be listed by UL and also either ULC or C-UL for use in:

A. Light Hazard Occupancies as defined by NFPA 13.

B. Ordinary hazard rooms of otherwise light hazard occupancies where the room does not exceed 400 ft^2, per section 6. 3. 6. 2 of NFPA 13, 2007 Edition.

C. Residential Occupancies up to four stories in height as defined by NFPA 13R.

D. One and two family dwellings and manufactured homes as defined by NFPA 13D.

E. Air handling (plenum) spaces as defined by NFPA 90A.

F. Underground water pressure service as defined by NFPA 24.

G. Maximum design temperature/pressure rating shall not be less than 175 psi at 150°F.

H. Refer to UL and FM** (if applicable).

I. Refer to CPVC pipe and fitting manufacturers' installation instructions.

1. 4 QUALITY ASSURANCE

Installer Qualifications:

Contractor Training Certificates for Chlorinated Polyvinyl Chloride (CPVC) Fire Sprinkler Systems. Fire Sprinkler Contractor must submit to the Contracting Officer documentation that lists personnel assigned to this project prior to beginning construction who have successfully completed formal CPVC fire sprinkler systems training conducted by an authorized CPVC manufacturer's representative. The Contractor Training Certificates shall be specific to the manufacturer of the pipe and fittings. Personnel's training certificates must be current and have been updated within the past two (2) years. (Note: this training does not imply compliance with any local or state contractor certification or licensing laws.)

PART 2 – PRODUCTS

2. 0 MATERIAL

The piping systems (pipe and fittings) shall be constructed from materials extruded/molded by manufacturers using the same compound manufacturer (i. e. BlazeMaster® CPVC compound).

2. 1 MANUFACTURERS

Harvel Plastics, Inc. Kuebler Rd. , PO Box 757 Easton, PA 18044 Phone (610) 252-7355 FAX (610) 253-4436

IPEX, Inc. 6810 Invader Crescent Mississauga, ON L5T 2B6 Phone (905) 670-7676 FAX (905) 670-5295

NIBCO INC. 1516 Middlebury Street Elkhart, IN 46516 (574) 295-3000 FAX (574) 295-3307

Tyco Fire & Building Products 451 N. Cannon Avenue Lansdale, PA 19446 (215) 362-0700 FAX (215) 362-5385

The Viking Corporation 210 N. Industrial Park Drive Hastings, MI 49058 (269) 945-9501 FAX (269) 945-4495

PART 3 – EXECUTION

3. 0 SYSTEM DESIGN

A. System design shall be in accordance with standard industry practice for fire sprinkler systems and the manufacturer's instructions. The design shall take into consideration such factors as pressure and flow requirements, friction loss, operating temperatures, support spacing, joining methods, and thermal expansion and contraction.

B. The fire sprinkler piping system shall be hydraulically calculated using a Hazen-Williams C Factor of 150, and designed in accordance with the Standard for Installation of Sprinkler Systems, NFPA 13.

C. The maximum design temperature/pressure rating shall not exceed 175 psi at 150°F.

3. 1 INSTALLATION PROCEDURES

Installation practices such as pipe support spacing, bracing, allowance for thermal expansion/contraction, solvent cementing and handling and storage shall be in accordance with the manufacturer's instructions and the UL Listing which includes installation limitations.

3. 2 LIMITATIONS

BlazeMaster® CPVC pipe and fittings are intended for use at a maximum working pressure of 175 psi at 150°F in accordance with the manufacturer's instructions and appropriate listing agencies.

3. 3 TECHNICAL DATA

A. APPLICABLE STANDARDS

a. ANSI/NSF Standard 14 Plastic Piping Components and Related Materials
b. ANSI/NSF Standard 61 Drinking Water System Components – Health Effects
c. ASTM D1784 Specification for Rigid Poly(Vinyl Chloride)(PVC) Compounds and Chlorinated Poly(Vinyl Chloride)(CPVC) Compounds
d. ASTM F402 Practice for Safe Handling of Solvent Cements, Primers and Cleaners Used for Joining Thermoplastics Pipe and Fittings
e. ASTM F437 Specification for Threaded Chlorinated Poly(Vinyl Chloride) CPVC Plastic Pipe Fittings, Schedule 80
f. ASTM F438 Specification Socket-Type Chlorinated Poly(Vinyl Chloride) CPVC Plastic Pipe Fittings, Schedule 40
g. ASTM F439 Specification Socket-Type Chlorinated Poly(Vinyl Chloride) CPVC Plastic Pipe Fittings, Schedule 80
h. ASTM F442 Specification Chlorinated Poly (Vinyl Chloride) CPVC Plastic Pipe (SDR-PR)
i. ASTM F493 Specification for Solvent Cements for Chlorinated Poly(Vinyl Chloride) CPVC Plastic Pipe and Fittings
j. NFPA 13 Standard for Installation of Sprinkler Systems
k. NFPA 24 Installation of Private Fire Service Mains and Their Appurtenances
l. NFPA 25 Standard for the Inspection, Testing and Maintenance of Water Based Extinguishing Systems
m. NFPA 13R Standard for Installation of Sprinklers in Residential Occupancies up to Four Stories in Height
n. NFPA 13D Standard for Installation of Sprinkler Systems in One and Two Family Dwellings
o. NFPA 90A Standard for Installation of Air Conditioning and Ventilating Systems
p. UL 1887 Fire Test of Plastic Sprinkler Pipe for Flame and Smoke Characterization
q. UL 1821 Outline of Proposed Investigation for Thermoplastic Sprinkler Pipe and Fittings for Fire Protection Service

B. APPLICABLE CODES

a. BOCA, Basic Building and Mechanical Codes
b. ICC, International Building and Mechanical Codes
c. ICBO, Uniform Building and Mechanical Codes
d. SBCCI, Standard Building and Mechanical Codes
e. NBC, National Building Code of Canada

3. 4 TESTING

After the system is installed and any solvent cement is cured per the manufacturer's installation instructions, the systems shall be hydrostatically tested per the requirements of the applicable NFPA Standard (NFPA 13, 13R or 13D).

3. 5 MAINTENANCE

Maintenance shall be in accordance with the Standard for Inspection, Testing and Maintenance of Water Based Extinguishing Systems as defined by NFPA 25.

3. 6 WARRANTY

Consult the manufacturer for specific warranty information.

* Not intended to be a stand alone specification. The above specifications are to be added within your company's

standard fire sprinkler systems specifications to specify the use of BlazeMaster® CPVC pipe and fittings.

** As manufactured by Harvel, IPEX, NIBCO, Tyco Fire & Building Products, and The Viking Corporation

April 2007

13 Appendix E: Sprinkler Head Specification

tyco / Fire & Building Products

Technical Services: Tel: (800) 381-9312 / Fax: (800) 791-5500

rapidresponse®
HOME FIRE SPRINKLER SYSTEM

Series LFII Residential Pendent Sprinklers 3.0 K-factor

General Description

The Tyco® Rapid Response™, Series LFII (TY1234) Residential Pendent Sprinklers are decorative, fast response, frangible bulb sprinklers designed for use in residential occupancies such as homes, apartments, dormitories, and hotels. When aesthetics and optimized flow characteristics are the major consideration, the Series LFII (TY1234) should be the first choice.

The 3.0 (43,2) K-factor of the Series LFII (TY1234) has been selected to optimize flows (i.e., avoid over discharging) specifically for small coverage areas up to 14 ft x 14 ft. (4,3 m x 4,3 m). The required residential flow rates can then be delivered with the use of smaller pipe sizes and reduced water supply requirements.

The Series LFII are to be used in wet pipe residential sprinkler systems for one- and two-family dwellings and mobile homes per NFPA 13D; wet pipe residential sprinkler systems for residential occupancies up to and including four stories in height per NFPA 13R; or, wet pipe sprinkler systems for the residential portions of any occupancy per NFPA 13.

The recessed version of the Series LFII (TY1234) is intended for use in areas with finished ceilings. It employs a two-piece Style 20 Recessed Escutcheon. The Recessed Escutcheon provides 1/4 inch (6,4 mm) of recessed adjustment or up to 1/2 inch (12,7 mm) of total adjustment from the flush ceiling position. The adjustment provided by the Recessed Escutcheon reduces the accuracy to which the pipe nipples to the sprinklers must be cut.

The Series LFII (TY1234) has been designed with heat sensitivity and water distribution characteristics proven to help in the control of residential fires and to improve the chance for occupants to escape or be evacuated.

IMPORTANT
Always refer to Technical Data Sheet TFP700 for the "INSTALLER WARNING" that provides cautions with respect to handling and installation of sprinkler systems and components. Improper handling and installation can permanently damage a sprinkler system or its components and cause the sprinkler to fail to operate in a fire situation or cause it to operate prematurely.

WARNINGS
The Series LFII (TY1234) Residential Pendent Sprinklers described herein must be installed and maintained in compliance with this document, as well as with the applicable standards of the National Fire Protection Association, in addition to the standards of any other authorities having jurisdiction. ***Failure to do so may impair the performance of these devices.***

The owner is responsible for maintaining their fire protection system and devices in proper operating condition. The installing contractor or sprinkler manufacturer should be contacted with any questions.

Sprinkler/Model Identification Number

SIN TY1234

(Tyco Fire and Building Products)

Maximum Coverage Area [a] Ft. x Ft. (m x m)	Maximum Spacing Ft. (m)	Minimum Flow [b] and Residual Pressure For Horizontal Ceiling (Max. 2 Inch Rise for 12 Inch Run) 155°F/68°C or 175°F/79°C
12 x 12 (3,7 x 3,7)	12 (3,7)	8 GPM (30,3 LPM) 7.1 psi (0,49 bar)
14 x 14 (4,3 x 4,3)	14 (4,3)	11 GPM (41,6 LPM) 13.4 psi (0,92 bar)
16 x 16 (4,9 x 4,9)	16 (4,9)	13 GPM (49,2 LPM) 18.8 psi (1,29 bar)

(a) For coverage area dimensions less than or between those indicated, it is necessary to use the minimum required flow for the next highest coverage area for which hydraulic design criteria are stated.

(b) Requirement is based on minimum flow in GPM (LPM) from each sprinkler. The associated residual pressures are calculated using the nominal K-factor. Refer to Hydraulic Design Criteria Section for details.

TABLE A
NFPA 13D AND NFPA 13R WET PIPE HYDRAULIC DESIGN CRITERIA FOR THE SERIES LFII (TY1234) RESIDENTIAL PENDENT AND RECESSED PENDENT SPRINKLERS

Technical Data

Approvals:
UL and C-UL Listed.

Maximum Working Pressure:
175 psi (12,1 bar)

Discharge Coefficient:
K = 3.0 GPM/psi$^{1/2}$ (43,2 LPM/bar$^{1/2}$)

Temperature Rating:
155°F/68°C or 175°F/79°C

Finishes:
White Polyester Coated, Chrome Plated, or Natural Brass

Physical Characteristics:
Frame . . . . Brass
Button . . . . Bronze
Sealing Assembly . . . . Beryllium Nickel w/Teflon†
Bulb . . . . 3 mm dia. Glass
Compression Screw . . . . . Bronze
Deflector . . . . Bronze
Ejection Spring . . . . Stainless Steel
†DuPont Registered Trademark

Operation

The glass Bulb contains a fluid that expands when exposed to heat. When the rated temperature is reached, the fluid expands sufficiently to shatter the glass Bulb allowing the sprinkler to activate and flow water.

Design Criteria

The Tyco® Rapid Response™, Series LFII (TY1234) Residential Pendent Sprinklers are UL and C-UL Listed for installation in accordance with the following criteria.

NOTE
When conditions exist that are outside the scope of the provided criteria, refer to the Residential Sprinkler Design Guide TFP490 for the manufacturer's recommendations that may be acceptable to the local Authority having Jurisdiction.

System Type. Only wet pipe systems may be utilized.

Hydraulic Design. The minimum required sprinkler flow rate for systems designed to NFPA 13D or NFPA 13R are given in Table A as a function of temperature rating and the maximum allowable coverage areas. The sprinkler flow rate is the minimum required discharge from each of the total number of "design sprinklers" as specified in NFPA 13D or NFPA 13R.

For systems designed to NFPA 13, the number of design sprinklers is to be the four most hydraulically demanding sprinklers. The minimum required discharge from each of the four sprinklers is to be the greater of the following:

- The flow rates given in Table A for NFPA 13D and 13R as a function of temperature rating and the maximum allowable coverage area.
- A minimum discharge of 0.1 gpm/sq. ft. over the "design area" comprised of the four most hydraulically demanding sprinklers for the actual coverage areas being protected by the four sprinklers.

Obstruction To Water Distribution. Locations of sprinklers are to be in accordance with the obstruction rules of NFPA 13 for residential sprinklers.

Operational Sensitivity.

For "Horizontal Ceilings" (maximum 2 inch rise for 12 inch run), the sprinklers are to be installed with a deflector to ceiling distance of 1-3/8 to 4 inches or in the recessed position using only the Style 20 Recessed Escutcheon as shown in Figure 2.

NOTE
To avoid obstructions to water distribution, a maximum 12 inch deflector-to-ceiling distance is permitted for NFPA 13D and NFPA 13R applications where the sprinklers are located in closets.

Sprinkler Spacing. The minimum spacing between sprinklers is 8 feet (2,4 m). The maximum spacing between sprinklers cannot exceed the length of the coverage area (Ref. Table A) being hydraulically calculated (e.g., maximum 12 feet for a 12 ft. x 12 ft. coverage area, or 16 feet for a 16 ft. x 16 ft. coverage area).

Installation

The Series LFII (TY1234) must be installed in accordance with the following instructions:

NOTES
Do not install any bulb type sprinkler if the bulb is cracked or there is a loss of liquid from the bulb. With the sprinkler held horizontally, a small air bubble should be present. The diameter of the air bubble is approximately 1/16 inch (1,6 mm).

A 1/2 inch NPT sprinkler joint should be obtained with a minimum to maximum torque of 7 to 14 ft.lbs. (9,5 to 19,0 Nm). Higher levels of torque may distort the sprinkler inlet with consequent leakage or impairment of the sprinkler.

Do not attempt to compensate for insufficient adjustment in an Escutcheon Plate by under- or over-tightening the

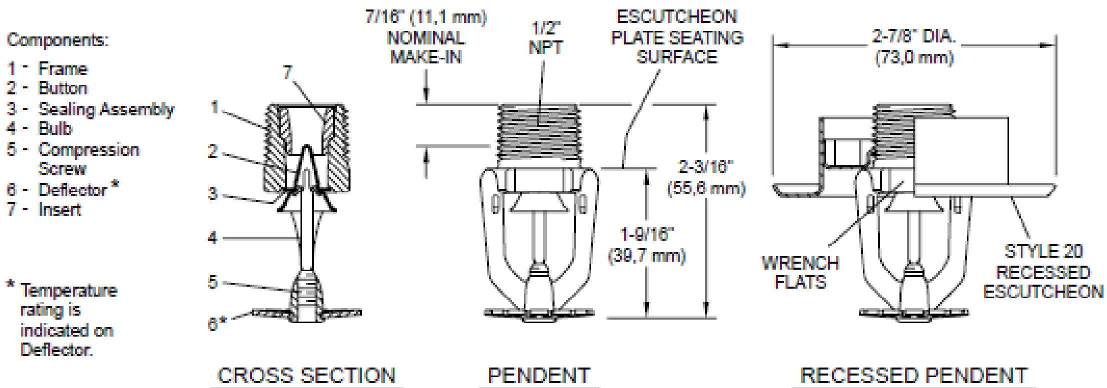


FIGURE 1
SERIES LFII (TY1234) RESIDENTIAL PENDENT AND RECESSED PENDENT SPRINKLERS

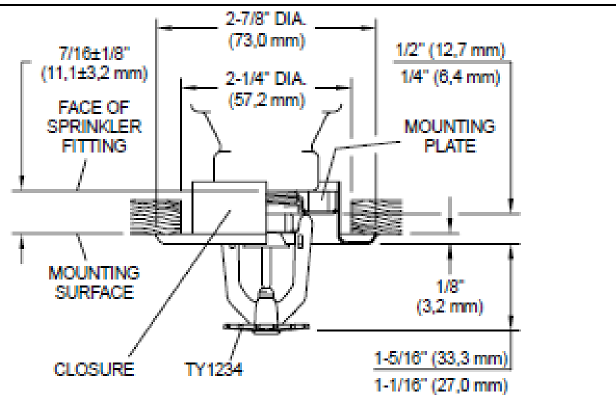


FIGURE 2
STYLE 20 RECESSED ESCUTCHEON FOR USE WITH THE SERIES LFII (TY1234) RESIDENTIAL PENDENT SPRINKLER

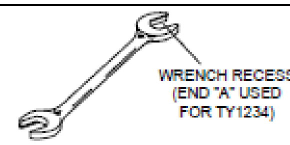


FIGURE 3
W-TYPE 6 SPRINKLER WRENCH

FIGURE 4
W-TYPE 7 RECESSED SPRINKLER WRENCH

Sprinkler. Readjust the position of the sprinkler fitting to suit.

The Series LFII Pendent Sprinklers must be installed in accordance with the following instructions.

Step 1. Pendent sprinklers are to be installed in the pendent position with the deflector parallel to the ceiling.

Step 2. With pipe thread sealant applied to the pipe threads, hand tighten the sprinkler into the sprinkler fitting.

Step 3. Tighten the sprinkler into the sprinkler fitting using only the W-Type 6 Sprinkler Wrench (Ref. Figure 3). With reference to Figure 1, the W-Type 6 Sprinkler Wrench is to be applied to the wrench flats.

The Series LFII Recessed Pendent Sprinklers must be installed in accordance with the following instructions.

Step A. Recessed pendent sprinklers are to be installed in the pendent position with the deflector parallel to the ceiling.

Step B. After installing the Style 20 Mounting Plate over the sprinkler threads and with pipe thread sealant applied to the pipe threads, hand tighten the sprinkler into the sprinkler fitting.

Step C. Tighten the sprinkler into the sprinkler fitting using only the W-Type 7 Recessed Sprinkler Wrench (Ref. Figure 4). With reference to Figure 1, the W-Type 7 Recessed Sprinkler Wrench is to be applied to the sprinkler wrench flats.

Step D. After the ceiling has been installed or the finish coat has been applied, slide on the Style 20 Closure over the Series LFII Sprinkler and push the Closure over the Mounting Plate until its flange comes in contact with the ceiling.

Care and Maintenance

The Tyco® Rapid Response™, Series LFII (TY1234) must be maintained and serviced in accordance with the following instructions:

NOTES

Absence of an Escutcheon Plate may delay the sprinkler operation in a fire situation.

Before closing a fire protection system main control valve for maintenance work on the fire protection system which it controls, permission to shut down the affected fire protection system must be obtained from the proper authorities and all personnel who may be affected by this action must be notified.

Sprinklers which are found to be leaking or exhibiting visible signs of corrosion must be replaced.

Automatic sprinklers must never be painted, plated, coated, or otherwise altered after leaving the factory. Modified sprinklers must be replaced. Sprinklers that have been exposed to corrosive products of combustion, but have not operated, should be replaced if they cannot be completely cleaned by wiping the sprinkler with a cloth or by brushing it with a soft bristle brush.

Care must be exercised to avoid damage to the sprinklers - before, during, and after installation. Sprinklers damaged by dropping, striking, wrench twist/slippage, or the like, must be replaced. Also, replace any sprinkler that has a cracked bulb or that has lost liquid from its bulb. (Ref. Installation Section).

The owner is responsible for the inspection, testing, and maintenance of their fire protection system and devices in compliance with this document, as well as with the applicable standards of the National Fire Protection Association (e.g., NFPA 25), in addition to the standards of any other authorities having jurisdiction. The installing contractor or sprinkler manufacturer should be contacted relative to any questions.

NOTE

The owner must assure that the sprinklers are not used for hanging of any objects and that the sprinklers are only cleaned by means of gently dusting with a feather duster; otherwise, non-operation in the event of a fire or inadvertent operation may result.

Automatic sprinkler systems should be inspected, tested, and maintained by a qualified Inspection Service in accordance with local requirements and/or national codes.

Limited Warranty

Products manufactured by Tyco Fire & Building Products (TFBP) are warranted solely to the original Buyer for ten (10) years against defects in material and workmanship when paid for and properly installed and maintained under normal use and service. This warranty will expire ten (10) years from date of shipment by TFBP. No warranty is given for products or components manufactured by companies not affiliated by ownership with TFBP or for products and components which have been subject to misuse, improper installation, corrosion, or which have not been installed, maintained, modified or repaired in accordance with applicable Standards of the National Fire Protection Association, and/or the standards of any other Authorities Having Jurisdiction. Materials found by TFBP to be defective shall be either repaired or replaced, at TFBP's sole option. TFBP neither assumes, nor authorizes any person to assume for it, any other obligation in connection with the sale of products or parts of products. TFBP shall not be responsible for sprinkler system design errors or inaccurate or incomplete information supplied by Buyer or Buyer's representatives.

In no event shall TFBP be liable, in contract, tort, strict liability or under any other legal theory, for incidental, indirect, special or consequential damages, including but not limited to labor charges, regardless of whether TFBP was informed about the possibility of such damages, and in no event shall TFBP's liability exceed an amount equal to the sales price.

The foregoing warranty is made in lieu of any and all other warranties, express or implied, including warranties of merchantability and fitness for a particular purpose.

This limited warranty sets forth the exclusive remedy for claims based on failure of or defect in products, materials or components, whether the claim is made in contract, tort, strict liability or any other legal theory.

This warranty will apply to the full extent permitted by law. The invalidity, in whole or part, of any portion of this warranty will not affect the remainder.

Ordering Procedure

When placing an order, indicate the full product name. Contact your local distributor for availability..

Sprinkler Assembly:

Series LFII (TY1234), K=3.0, Residential Pendent Sprinkler with (specify) temperature rating and (specify) finish, P/N (specify).

155°F/68°C or Chrome Plated	P/N 51-010-9-155
155°F/68°C White Polyester	P/N 51-010-4-155
155°F/68°C White (RAL9010)*	P/N 51-010-3-155
155°F/68°C Natural Brass	P/N 51-010-1-155
175°F/79°C or Chrome Plated	P/N 51-010-9-175
175°F/79°C White Polyester	P/N 51-010-4-175
175°F/79°C White (RAL9010)*	P/N 51-010-3-175
175°F/79°C Natural Brass	P/N 51-010-1-175

*Eastern Hemisphere sales only.

Recessed Escutcheon:

Specify: Style 20 Recessed Escutcheon with (specify*) finish, P/N (specify*).

*Refer to Technical Data Sheet TFP770.

Sprinkler Wrench:

Specify: W-Type 6 Sprinkler Wrench, P/N 56-000-6-387.

Specify: W-Type 7 Sprinkler Wrench, P/N 56-850-4-001.

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14 Appendix F: SIP Design Specifications

14.1 SIP Allowable Loads (Walls and Roof)

TABLE 1—ALLOWABLE TRANSVERSE LOADS OF WALL PANELS [1,2,3] (psf)

PANEL HEIGHT[4] (feet)	PANEL THICKNESS (inches)					
	4.50		6.50		8.25	
	L/180[5]	L/240[6]	L/180[5]	L/240[6]	L/180[5]	L/240[6]
7.875	43	38	43	43	43	43
8.875	38	34	38	38	38	38
9.875	35	28	35	35	35	35
10.875	31	24	31	31	31	31
11.875	26	20	29	29	29	29
12.875	22	17	27	27	27	27
13.875	19	14	25	25	25	25

For **SI:** 1 inch = 25.4 mm, 1 foot = 304.8 mm, 1 psf = 6.894 kPa.

[1]Allowable loads for the wall panels are based on simple span conditions.
[2]Interpolation of intermediate values is not acceptable under this report.
[3]Allowable transverse loads shall be the total loads (such as wind loads) perpendicular to wall panel height.
[4]Panel height is based on the distance between top of top plates and bottom of bottom plate where the wall panels are laterally supported.
[5]Allowable loads are based on test results using the lesser of deflection at $^1/_{180}$ of the span and the average peak load divided by 3.
[6]Allowable loads are based on test results using the lesser of deflection at $^1/_{240}$ of the span and the average peak load divided by 3.

TABLE 2—ALLOWABLE TRANSVERSE LOADS OF ROOF AND FLOOR PANELS [1,2,3,8,9,10] (psf)

PANEL SPAN[4] (feet)	PANEL THICKNESS (inches)														
	4.50			6.50			8.25			10.25			12.25		
	L/180[5]	L/240[6]	L/360[7]	L/180[5]	L/240[6]	L/360[7]	L/180[5]	L/240[6]	L/360[7]	L/1805	L/240[6]	L/360[7]	L/180[5]	L/240[6]	L/360[7]
7.875	43	38	25	79	64	43	82	82	59	106	106	77	106	106	96
8.875	38	34	23	76	57	38	73	73	52	94	94	69	106	106	85
9.875	34	28	19	64	48	32	65	65	45	84	84	59	106	106	74
10.875	31	24	16	55	41	27	59	58	38	76	76	51	106	97	65
11.875	26	20	13	47	35	24	54	50	33	70	67	45	106	85	57
12.875	22	17	11	41	31	20	49	44	29	64	59	39	94	75	50
13.875	19	14	10	35	26	18	46	38	25	59	52	35	81	67	45
14.875	NP	NP	NP	30	23	15	43	34	22	55	46	31	70	60	40
15.875	NP	NP	NP	27	20	13	39	30	20	52	41	27	61	53	36
16.875	NP	NP	NP	24	18	12	35	26	17	49	37	24	54	48	32
17.875	NP	NP	NP	21	16	10	31	23	16	44	33	22	48	43	29
18.875	NP	NP	NP	19	14	NP	28	21	14	39	30	20	43	39	26
19.875	NP	NP	NP	17	12	NP	25	19	12	35	27	18	39	35	23

For **SI:** 1 inch = 25.4 mm, 1 foot = 304.8 mm, 1 psf = 6.894 kPa.

[1]Allowable loads for the roof and floor panels are based on simple span conditions where ends of panels have a minimum $1^1/_2$-inch (38 mm) bearing length.
[2]Interpolation of intermediate values is not allowed.
[3]Allowable transverse loads shall be the total uniform dead and uniform live load exclusive of the panel self weight.
[4]Panel span is based on center-to-center distance of supports.
[5]Allowable loads are based on test results using the lesser of deflection at $^1/_{180}$ of the span and the average peak load divided by 3.
[6]Allowable loads are based on test results using the lesser of deflection at $^1/_{240}$ of the span and the average peak load divided by 3.
[7]Allowable loads are based on test results using the lesser of deflection at $^1/_{360}$ of the span and the average peak load divided by 3.
[8]For roof panels supporting 300 lbf concentrated maintenance worker live load as per Section 1607.4 and Table 1607.1 of the IBC, the available allowable uniform dead load shall be limited to the total allowable loads listed in Table 2-above-multiplied by reduction factors. The reduction factors are as follows: 0.27 for 4.5-inch-thick panel, 0.46 for 6.5-inch-thick panel, 0.72 for 8.25-inch-thick panel, 0.88 for 10.25-inch-thick panel, and 0.64 for 12.25-inch-thick panel.
[9]The allowable loads are not applicable to floor panels supporting concentrated loads.
[10]NP = Not permitted.

(ICC Evaluation Service, Inc., 2008)

14.2 SIP Fastner Schedule

Table 4.1

Fastener Schedule for SIP Construction

Building Elements	Number and Type of Fasteners [a, b, c, d]	Spacing of Fasteners
3/8" gypsum board	13 gage, 1-1/4" long, 19/64" head; 0.098 diameter, 1-¼" long, annular-ringed; or 4d cooler nail, 0.080" diameter, 1-3/8" long, 7/32" head.	Nails: 8" o.c Screws: 16" o.c.
1/2" gypsum board	13 gage, 1-3/8" long, 19/64" head; 0.098 diameter, 1-1/4" long, annular-ringed; or 5d cooler nail, 0.086" diameter, 1-5/8" long, 15/64" head, or gypsum board nail, 0.086 diameter, 1- 5/8" long, 9/32" head.	Nails: 8" o.c Screws: 16" o.c.
5/8" gypsum board	13 gage, 1-5/8" long, 19/64" head; 0.098 diameter, 1-3/8" long, annular-ringed; or 6d cooler nail, 0.092" diameter, 1-7/8" long, 1/4" head, or gypsum board nail, 0.0915 diameter, 1-7/8" long, 19/64" head.	Nails: 8" o.c Screws: 12" o.c.
Sole (sill) plate face nailed to joist or blocking	16d common nails	16" o.c.
Top plate to cap plate	16d common nails	16" o.c.
Sole (sill) plate to monolithic concrete foundation	Minimum 1/2 inch (13 mm) diameter anchor bolts	6 feet o.c. maximum
SIP wall panel to SIP wall panel corner connection	SIP screws with minimum 1 inch penetration into wood member in SIP wall panel connected to	24" o.c. maximum
SIP wall panel to top wood plate	8d common nails	6" o.c. both sides
SIP wall panel to top/bottom steel track	Min. No. 8 screw	
SIP wall panel to wood sill plate	8d common nails	6" o.c. both sides
SIP wall panel to steel track (on foundations)	Min. No. 8 screw	6" o.c.
SIP wall panel to framing or cripple studs	8d common nails	6" o.c.
SIP wall panel to SIP wall panel	8d common nails	6" o.c. each strip and each side

For SI: 1 inch = 25.4mm, 1 foot = 304.8 mm, 1 mph = 1.61 km/h, 1 ksi = 6.895 MPa *(Notes cont. on page 16)*

(Structural Insulated Panel Association, 2007)

14.3 SIP Applicability Limits

Table 1.1
Applicability Limits

ATTRIBUTE	LIMITATION
GENERAL	
Building Dimension	Maximum building width is 40 feet (12.2 m) Maximum building length is 60 feet (18.3 m)
Number of Stories	2 story (above basement)
Basic Wind Speed	Up to 130 mph (209 km/h)
Wind Exposure	Exposures B[1] (suburban/wooded) Exposures C[1] (open terrain)
Ground Snow Load	70 psf (3.35 kN/m^2) maximum ground snow load
Seismic Zone	A, B and C[1]
Building Height	Maximum 35 feet (10.7 m)
FLOORS	
Floor dead load	10 psf (0.48 kN/m^2) maximum
Floor live load First floor Second floor (sleeping rooms)	 40 psf (1.92 kN/m^2) maximum 30 psf (1.44 kN/m^2) maximum
WALLS	
Wall dead load	10 psf (0.48 kN/m^2) maximum
Load bearing wall height	10 feet (3 m) maximum
Deflection Criteria	L/240
ROOFS	
Roof dead load	10 psf (0.48 kN/m^2) maximum
Roof snow/live load	70 psf (3.35 kN/m^2) maximum ground snow load (16 psf (0.77 kN/m^2) minimum Roof Live Load).
Ceiling dead load	5 psf (0.24 kN/m^2) maximum
Roof slope	3:12 to 12:12
Rake overhang	12 inches (305 mm) maximum
Attic live load (Limited Storage)	20 psf (0.96 kN/m^2) maximum

For SI: 1 inch = 25.4 mm, 1 psf = 0.0479 kN/m^2, 1 mph = 1.61 km/hr = 0.447 m/sec, 1 foot = 0.3 m.

(Structural Insulated Panel Association, 2007)

14.4 SIP Wall Bracing Requirements

Table 4.4
SIP Wall Bracing Requirements

Seismic Design Category or Wind Speed	Condition	Amount Of Bracing
Categories A and B or 100 mph and less	One story Top of two-story	Full height SIP panel with minimum length per Table 4.4a located at each end (within 12.5 feet from each corner) and at least every 25 feet on center but not less than 16% of braced wall line
	First story of two-story	Full height SIP panel with minimum length per Table 4.4a located at each end (within 12.5 feet from each corner) and at least every 25 feet on center but not less than 16% of braced wall line
Category C or less than 110 mph	One story Top of two-story	Full height SIP panel with minimum length per Table 4.4a located at each end (within 12.5 feet from each corner) and at least every 25 feet on center but not less than 16% of braced wall line
	First story of two-story	Full height SIP panel with minimum length per Table 4.4a located at each end (within 12.5 feet from each corner) and at least every 25 feet on center but not less than 30% of braced wall line

For SI: 1 inch = 25.4 mm, 1 foot = 304. 1 mph = 1.61 km/h.

Table 4.4a
Requirements for Braced SIP walls[1,2]

Length of Braced SIP Walls (inches)			Maximum Opening Height Next to the Braced SIP wall (% of wall height)
8-Foot	9-Foot	10-Foot	
48	54	60	100%
32	36	40	85%
24	27	30	67%

For SI: 1 inch = 25.4 mm, 1 foot = 305 mm.
1 Linear interpolation shall be permitted.
2 Full-height SIP to either side of garage openings that support light frame roofs with roof covering dead loads of 3 psf or less shall be permitted to have a 4:1 aspect ratio.

(Structural Insulated Panel Association, 2007)

14.5 SIP Nominal Thickness

Table 4.2
Nominal Thickness (Inches) for SIP Walls Supporting SIP or Light-Frame Roofs Only[1]

Wind Speed (3-sec gust)			Building Width (ft)														
			24			28			32			36			40		
			Wall Height (ft)			Wall Height (ft)			Wall Height (ft)			Wall Height (ft)			Wall Height (ft)		
Exp. A/B	Exp. C	Snow Load (psf)	8	9	10	8	9	10	8	9	10	8	9	10	8	9	10
85		20	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		30	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		50	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		70	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
100	85	20	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		30	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		50	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		70	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
110	100	20	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		30	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		50	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		70	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
120	110	20	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		30	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		50	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		70	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	6.5	4.5	4.5	6.5
130	120	20	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		30	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		50	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	6.5	4.5	4.5	6.5	4.5	4.5	6.5
		70	4.5	4.5	4.5	4.5	4.5	6.5	4.5	4.5	6.5	4.5	6.5	N/A	4.5	6.5	N/A
	130	20	4.5	4.5	6.5	4.5	4.5	N/A	4.5	4.5	N/A	4.5	4.5	N/A	4.5	6.5	N/A
		30	4.5	4.5	N/A	4.5	4.5	N/A	4.5	4.5	N/A	4.5	6.5	N/A	4.5	6.5	N/A
		50	4.5	6.5	N/A	4.5	6.5	N/A	4.5	N/A	N/A	6.5	N/A	N/A	6.5	N/A	N/A
		70	4.5	N/A	N/A	6.5	N/A	N/A	6.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm, 1 mph = 1.61 km/hr.

[1] Deflection criteria: L/240.
Roof dead load: 10 psf maximum.
Roof live load: 70 psf maximum
Ceiling dead load: 5 psf maximum.
Ceiling live load: 20 psf maximum.
N/A indicates not applicable (design required).

(Structural Insulated Panel Association, 2007)

15 Appendix G: LEED Certification Checklist

LEED for Homes Simplified Project Checklist

for Homes

Builder Name:	
Project Team Leader (if different):	
Home Address (Street/City/State):	

Project Description:

Building type: Project type:

# of bedrooms: *0*   Floor area: *0*

Adjusted Certification Thresholds

Certified: *45.0*   Gold: *75.0*

Silver: *60.0*   Platinum: *90.0*

Project Point Total

Prelim: *0 + 0 maybe pts*   Final: *40*

Certification Level

Prelim: *Not Certified*   Final: *Not Certified*

Final Credit Category Total Points

ID: 1   *SS: 10*   *EA: 12*   *EQ: 7*

LL: 0   *WE: 3*   *MR: 7*   *AE: 0*

date last updated :

last updated by :

				Max Points	Project Points Preliminary Y/Pts	Maybe	No	Final Y/Pts
Innovation and Design Process (ID)		(No Minimum Points Required)		Max	Y/Pts	Maybe	No	Y/Pts
1. Integrated Project Planning	1.1	Preliminary Rating		Prereq				
	1.2	Integrated Project Team		1	0	0		*0*
	1.3	Professional Credentialed with Respect to LEED for Homes		1	0	0		*0*
	1.4	Design Charrette		1	0	0		*0*
	1.5	Building Orientation for Solar Design		1	0	0		*1*
2. Durability Management Process	2.1	Durability Planning		Prereq				
	2.2	Durability Management		Prereq				
	2.3	Third-Party Durability Management Verification		3	0	0		*0*
3.Innovative or Regional Design	3.1	Innovation #1		1	0	0		*0*
	3.2	Innovation #2		1	0	0		*0*
	3.3	Innovation #3		1	0	0		*0*
	3.4	Innovation #4		1	0	0		*0*
		Sub-Total for ID Category:		*11*	0	0		*1*
Location and Linkages (LL)		(No Minimum Points Required)	*OR*	Max	Y/Pts	Maybe	No	Y/Pts
1. LEED ND	1	LEED for Neighborhood Development	**LL2-6**	10	0	0		*0*
2. Site Selection	2	Site Selection		2	0	0		*0*
3. Preferred Locations	3.1	Edge Development	**LL 3.2**	1	0	0		*0*
	3.2	Infill		2	0	0		*0*
	3.3	Previously Developed		1	0	0		*0*
4. Infrastructure	4	Existing Infrastructure		1	0	0		*0*
5. Community Resources/ Transit	5.1	Basic Community Resources / Transit	**LL 5.2, 5.3**	1	0	0		*0*
	5.2	Extensive Community Resources / Transit	**LL 5.3**	2	0	0		*0*
	5.3	Outstanding Community Resources / Transit		3	0	0		*0*

Sustainable Sites (SS)			(Minimum of 5 SS Points Required)	OR	Max	Y/Pts	Maybe	No	Y/Pts
1. Site Stewardship		1.1	Erosion Controls During Construction		Prereq				
		1.2	Minimize Disturbed Area of Site		1	0	0		0
2. Landscaping		2.1	No Invasive Plants		Prereq				
		2.2	Basic Landscape Design	SS 2.5	2	0	0		0
		2.3	Limit Conventional Turf	SS 2.5	3	0	0		3
		2.4	Drought Tolerant Plants	SS 2.5	2	0	0		1
		2.5	Reduce Overall Irrigation Demand by at Least 20%		6	0	0		0
3. Local Heat Island Effects		3	Reduce Local Heat Island Effects		1	0	0		1
4. Surface Water Management		4.1	Permeable Lot		4	0	0		3
		4.2	Permanent Erosion Controls		1	0	0		1
		4.3	Management of Run-off from Roof		2	0	0		1
5. Nontoxic Pest Control		5	Pest Control Alternatives		2	0	0		0
6. Compact Development		6.1	Moderate Density	SS 6.2, 6.3	2	0	0		0
		6.2	High Density	SS 6.3	3	0	0		0
		6.3	Very High Density		4	0	0		0
			Sub-Total for SS Category:		*22*	*0*	*0*		*10*

LEED for Homes Simplified Project Checklist (continued)

					Max Points	Project Points Preliminary			Final
Water Efficiency (WE)			(Minimum of 3 WE Points Required)	OR	Max	Y/Pts	Maybe	No	Y/Pts
1. Water Reuse		1.1	Rainwater Harvesting System	WE 1.3	4	0	0		0
		1.2	Graywater Reuse System	WE 1.3	1	0	0		0
		1.3	Use of Municipal Recycled Water System		3	0	0		0
2. Irrigation System		2.1	High Efficiency Irrigation System	WE 2.3	3	0	0		0
		2.2	Third Party Inspection	WE 2.3	1	0	0		0
		2.3	Reduce Overall Irrigation Demand by at Least 45%		4	0	0		0
3. Indoor Water Use		3.1	High-Efficiency Fixtures and Fittings		3	0	0		3
		3.2	Very High Efficiency Fixtures and Fittings		6	0	0		0
			Sub-Total for WE Category:		*15*	*0*	*0*		*3*
Energy and Atmosphere (EA)			(Minimum of 0 EA Points Required)	OR	Max	Y/Pts	Maybe	No	Y/Pts
1. Optimize Energy Performance		1.1	Performance of ENERGY STAR for Homes		Prereq				
		1.2	Exceptional Energy Performance		34	0	0		
7. Water Heating		7.1	Efficient Hot Water Distribution		2	0	0		0
		7.2	Pipe Insulation		1	0	0		1
11. Residential Refrigerant Management		11.1	Refrigerant Charge Test		Prereq				
		11.2	Appropriate HVAC Refrigerants		1	0	0		0
			Sub-Total for EA Category:		*38*	*0*	*0*		*12*
Materials and Resources (MR)			(Minimum of 2 MR Points Required)	OR	Max	Y/Pts	Maybe	No	Y/Pts
1. Material-Efficient Framing		1.1	Framing Order Waste Factor Limit		Prereq				
		1.2	Detailed Framing Documents	MR 1.5	1	0	0		1
		1.3	Detailed Cut List and Lumber Order	MR 1.5	1	0	0		0
		1.4	Framing Efficiencies	MR 1.5	3	0	0		3
		1.5	Off-site Fabrication		4	0	0		4
2. Environmentally Preferable Products		2.1	FSC Certified Tropical Wood		Prereq				
		2.2	Environmentally Preferable Products		8	0	0		3
3. Waste Management		3.1	Construction Waste Management Planning		Prereq				

	3.2	Construction Waste Reduction		3	0	0		**0**
		Sub-Total for MR Category:		***16***	0	0		***7***
Indoor Environmental Quality (EQ)		(Minimum of 6 EQ Points Required)	*OR*	Max	Y/Pts	Maybe	No	Y/Pts
1. ENERGY STAR with IAP	1	ENERGY STAR with Indoor Air Package		13	0	0		**0**
2. Combustion Venting	2.1	Basic Combustion Venting Measures	**EQ 1**	Prereq				
	2.2	Enhanced Combustion Venting Measures	**EQ 1**	2	0	0		**0**
3. Moisture Control	3	Moisture Load Control	**EQ 1**	1	0	0		**1**
4. Outdoor Air Ventilation	4.1	Basic Outdoor Air Ventilation	**EQ 1**	Prereq				
	4.2	Enhanced Outdoor Air Ventilation		2	0	0		**2**
	4.3	Third-Party Performance Testing	**EQ 1**	1	0	0		**0**
5. Local Exhaust	5.1	Basic Local Exhaust	**EQ 1**	Prereq				
	5.2	Enhanced Local Exhaust		1	0	0		**1**
	5.3	Third-Party Performance Testing		1	0	0		**0**
6. Distribution of Space Heating and Cooling	6.1	Room-by-Room Load Calculations	**EQ 1**	Prereq				
	6.2	Return Air Flow / Room by Room Controls	**EQ 1**	1	0	0		**0**
	6.3	Third-Party Performance Test / Multiple Zones	**EQ 1**	2	0	0		**0**
7. Air Filtering	7.1	Good Filters	**EQ 1**	Prereq				
	7.2	Better Filters	**EQ 7.3**	1	0	0		**0**
	7.3	Best Filters		2	0	0		**2**
8. Contaminant Control	8.1	Indoor Contaminant Control during Construction	**EQ 1**	1	0	0		**0**
	8.2	Indoor Contaminant Control		2	0	0		**0**
	8.3	Preoccupancy Flush	**EQ 1**	1	0	0		**0**
9. Radon Protection	9.1	Radon-Resistant Construction in High-Risk Areas	**EQ 1**	Prereq				
	9.2	Radon-Resistant Construction in Moderate-Risk Areas	**EQ 1**	1	0	0		**0**
10. Garage Pollutant Protection	10.1	No HVAC in Garage	**EQ 1**	Prereq				
	10.2	Minimize Pollutants from Garage	**EQ 1, 10.4**	2	0	0		**0**
	10.3	Exhaust Fan in Garage	**EQ 1, 10.4**	1	0	0		**1**
	10.4	Detached Garage or No Garage	**EQ 1**	3	0	0		**0**
		Sub-Total for EQ Category:		***21***	0	0		***7***
Awareness and Education (AE)		(Minimum of 0 AE Points Required)		Max	Y/Pts	Maybe	No	Y/Pts
1. Education of the Homeowner or Tenant	1.1	Basic Operations Training		Prereq				
	1.2	Enhanced Training		1	0	0		**0**
	1.3	Public Awareness		1	0	0		**0**
2. Education of Building Manager	2	Education of Building Manager		1	0	0		**0**
		Sub-Total for AE Category:		***3***	0	0		***0***

for Homes

LEED for Homes Simplified Project Checklist

Addendum: Prescriptive Approach for Energy and Atmosphere (EA) Credits

Points cannot be earned in both the Prescriptive (below) and the Performance Approach (pg 2) of the EA section

Energy and Atmosphere (EA)		(No Minimum Points Required)	OR	Max Points (Max)	Project Points Preliminary (Y/Pts)	Preliminary (Maybe)	Preliminary (No)	Final (Y/Pts)
2. Insulation	2.1	Basic Insulation		Prereq				
	2.2	Enhanced Insulation		2	*0*	*0*		***0***
3. Air Infiltration	3.1	Reduced Envelope Leakage		Prereq				***0***
	3.2	Greatly Reduced Envelope Leakage		2	*0*	*0*		***0***
	3.3	Minimal Envelope Leakage	**EA 3.2**	3	*0*	*0*		***0***
4. Windows	4.1	Good Windows		Prereq				
	4.2	Enhanced Windows		2	*0*	*0*		***0***
	4.3	Exceptional Windows	**EA 4.2**	3	*0*	*0*		***0***
5. Heating and Cooling Distribution System	5.1	Reduced Distribution Losses		Prereq				
	5.2	Greatly Reduced Distribution Losses		2	*0*	*0*		***0***
	5.3	Minimal Distribution Losses	**EA 5.2**	3	*0*	*0*		***0***
6. Space Heating and Cooling Equipment	6.1	Good HVAC Design and Installation		Prereq				
	6.2	High-Efficiency HVAC		2	*0*	*0*		***0***
	6.3	Very High Efficiency HVAC	**EA 6.2**	4	*0*	*0*		***4***
7. Water Heating	7.1	Efficient Hot Water Distribution		2	*0*	*0*		***0***
	7.2	Pipe Insulation		1	*0*	*0*		***0***
	7.3	Efficient Domestic Hot Water Equipment		3	*0*	*0*		***2***
8. Lighting	8.1	ENERGY STAR Lights		Prereq				
	8.2	Improved Lighting		2	*0*	*0*		***0***
	8.3	Advanced Lighting Package	**EA 8.2**	3	*0*	*0*		***3***
9. Appliances	9.1	High-Efficiency Appliances		2	*0*	*0*		***2***
	9.2	Water-Efficient Clothes Washer		1	*0*	*0*		***1***
10. Renewable Energy	10	Renewable Energy System		10	*0*	*0*		***0***
11. Residential Refrigerant Management	11.1	Refrigerant Charge Test		Prereq				
	11.2	Appropriate HVAC Refrigerants		1	*0*	*0*		***0***
		Sub-Total for EA Category:		***38***	*0*	*0*		***12***