Energy Efficiency of Historic Meetinghouse on Pleasant Street

Interactive Qualifying Project Report submitted to the Faculty of Worcester Polytechnic Institute in partial fulfillment of requirements for the Degree of Bachelor of Science Submitted by:

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1. Abstract

With increasing fuel prices, energy consumption is a huge factor in the cost of heating a house. The goal of the project “Energy efficiency of Worcester Friends Meetinghouse” was to reduce overall energy consumption of the entire building. The main focus of research included the heating system, thermostat, windows, and insulation. Another focus was to identify how the residents interacted with the building in regards to energy usage. Afterwards recommendations were made that can be implemented both in this building and others like it in order to improve energy efficiency.

2. Executive Summary

The 901 Pleasant Street Meetinghouse was built in the late 1800s as a country estate. Over the last couple hundred years, the city of Worcester grew and the house still remains today. There is no longer a farm; instead several groups from the surrounding area meet at the house. These include the Worcester Monthly Meetings, New England Yearly Meeting, Center for Non-Violent Solutions, The First Day School, and MassCare. The problem these groups are faced with is the cost to heat this old meetinghouse as it is not designed to modern standards.

After conducting background research on energy efficiency, we met David Legg who is involved with the house. He acted as an energy consultant because of his prior experience with deep energy retrofits for residential housing. Deep energy retrofitted homes use high quality insulation, windows, walls, and heating systems in order to minimize thermal leakage. Dave was especially helpful as he took us on a full tour of the meetinghouse and pointed out flaws in the building design and upkeep to help focus our efforts.

Through our tour and inquiries with David, we came up with ideas of how to improve several areas of the house including making changes to insulation, windows, the heating system, and the thermostat. Because we do not own the meetinghouse or have the available funds to optimize the energy usage, our suggestions are laid out in our report. However we were fortunate enough to make a few minor changes to the house.

The meetinghouse's insulation is out of date and demonstrates a relatively low R-value due to the lack of maintenance. A glaring concern is that the fiberglass insulation in eave one of the building is no longer sealed by aluminum foil. The rips and tears in the foil not only make the insulation leak heat, but the fine fiberglass particles pose a health risk when inhaled. The R-value of the attic can be increased from below 19 to 45 by replacing the damaged fiberglass insulation with new fiberglass batt insulation. Additionally, a 1 in layer of polyisocynurate should be placed on the interior surface of this insulation to improve heat retention. These changes could be made to the attic for under $1000, and could take hundreds of dollars off from a yearly heating bill.

Thanks to the Civil and Environmental Engineering Department, a thermal imaging camera was used to capture heat loss through various windows in the house. With this information, the best course of window repair could be advised. Some of the windows in the basement were actually cracked and repaired using 3-M home solution window covering. This plastic film sealed the cracks as well as reduced heat loss through these windows. Windows throughout the house can be sealed with this film, and leaks between frame and window can be sealed with caulk.

In the current heating system, the meetinghouse has two heating zones. One is the first day school classroom on the third floor. The other one is the rest of the house from the first floor to the third floor. The meetinghouse is not occupied every day and not all of the space is used when people have an event there. Thus, installing only one zone in most of the spaces in the meetinghouse leads to overuse of energy. The best way to fix this problem is to divide the house into 3 zones, one per floor. This is beneficial as a group meeting on the first floor can increase the temperature without changing the settings on the other two floors. Using multiple zone heating and cooling is more efficient than attempting to maintain a constant temperature throughout the meetinghouse.

One of the changes implemented was upgrading the thermostat to a WiFi programmable one. This was beneficial as the old thermostat was programmable but no longer working. Once the WiFi function is setup to the house network, temperature can be controlled from remote locations to minimize heat loss. Adding a WiFi thermostat involved wiring a C wire to allow for 24VAC signal transmission. The temperature schedule for the thermostat was designed by interviewing members of the groups to see when they met at the house. Although this is a good start, ideally three thermostats should be used in order to control separate zones on each floor.

The purpose of this project was to evaluate the current heating system, window condition and insulation system in the meetinghouse and give recommendations for improving the current house conditions and reducing energy use. Not only was the energy condition of the meetinghouse analyzed, but also some work was done to improve the efficiency of the building and reduce leakage. This work included sealing basement windows with the 3-M home solution, replacing the thermostat, updating floor plans, and determining areas of leakage. The problem of energy efficiency and building heating costs is universal and widespread. The results of this project and the concept of energy retrofitting can be applied to buildings around the world.

3. Introduction

901 Pleasant St. in Worcester was built as a country estate. Today, the house is used as an office and meeting space by different non-profit organizations. The estate is over a hundred years old and only a few changes have been made to improve the facility over time. As a result, the energy costs have increased dramatically, and the house is becoming too expensive and impractical for these groups to use. Groups using the house include Masscare, the Center for Non-violent Solutions, Worcester Monthly Meeting, and New England Yearly Meeting.

This project involved analyzing different aspects of energy efficiency throughout the building to create a solution for these non-profit groups. Research was conducted concerning the heating system, thermostat, windows, and insulation throughout the house to determine the main causes of heat and energy loss. The project also involves a social aspect concerning user preferences that prohibit energy efficient alterations. Interviewing different stakeholders to gain a better understanding of their situation will help to determine which improvements will better the users.

Originally used as a residential house, the meetinghouse has a typical interior layout as other American residential houses. The first and second floors have similar layouts. On the first floor, the living room is used as a meeting room. The room by the entrance, facing the meeting room, is the reading room. A kitchen and a dining room is designed on the other side. The bathroom is placed under the staircase, which uses the spare space very efficiently. On the second floor, there are four offices and one classroom. At the left hand of the stair is a full bathroom. On the third floor, there are one first-day school classroom and one office room that are used by the Center for Non-violent Solutions.

3.1 Glossary of Quaker Terms

Meetinghouse – Quaker house of worship

Monthly Meeting – close group of people that meet for worship and once a month for business

Quaker – unofficial name of a member of the Religious Society of Friends

Quarterly Meeting – collection of monthly meetings and worship groups in an area who meet four times annually for business and worship

Yearly Meeting – collection of monthly and regional meetings who meet at least once a year to conduct business

4. Background

4.1 Literature Review

The energy consumption of buildings has steadily increased over time in the U.S. and all over the world. Heating, Ventilation, and Air Conditioning (HVAC) systems are the largest energy consumers in the building industry. 42% of residential energy use and 39% of commercial energy use is for HVAC system. 32% of residential energy use is for space heating and 10% is for space cooling. The energy use by HVAC systems amounts to 20% of total energy consumption in the U.S. (Shonder). Strategies for reducing the energy consumption by HVAC system will be very beneficial for each family and the whole society.

Researches have been done on building energy consumption and the way to reduce the consumption. The application of new technology in residential houses for energy saving has been studied. Installing photovoltaic panels is an environmental-friendly method of on-site electricity generation. When considering to apply a new technology, both the environmental aspect and the economic aspect should be considered. The efficiency of different types of photovoltaic systems had a significant increase from 1975 to 2007. As a result, the cost had a significant decrease which made the residential installation of solar panels more practicable. However, the photovoltaic system was still an expensive choice for a typical American family. The system that provides all needed electricity to a typical American residential house costs approximately $50,000 to $60,000. (Bebel, Hagopian, Larson, 2007) This number came out in 2007. After 7 years, the cost has been reduced a lot. Another interactive qualifying project, “Green building design” focused on designing residential houses in a sustainable way. The energy efficiency, water efficiency, energy conservation, and indoor air quality in Friendly House, Worcester, were analyzed. Using different energy sources, including solar energy, was recommended. Sarna roofing material was recommended as an alternative choice for energy savings because it had a highly reflective surface which can reduce the cooling load by reflecting more solar energy. For the heating system, high efficiency boilers manufactured by Burnham were recommended. (Baker, Foss, Gillet, Medeiros, 2003) These researches were based on the existing technology and products at that time. Today, building technology has been improved a lot and a lot of new and more efficient products have been put into the market. When more choices are provided to consumers, how to choose those products wisely became a very interesting topic and is worth studying.

4.2 Heating System

Existing heating systems were studied to understand their differences. These studies helped to decide which heating systems are more appropriate for a two-story house from an energy-saving aspect.

Heating systems in the U.S. can be classified as gas-fueled heating systems, electricity-fueled heating systems, active solar heating systems, and radiant heating systems. Gas-fueled heating systems can be sub-divided to two common types by heating equipment: furnaces and boilers. Portable heating is a heating method when additional heating is needed for a specific area. The advantage of it is it is portable and very flexible and it can be used to heat a specific area when additional heating is needed. Electrical resistance heating is among the most expensive heating methods. Although it converts almost all electricity to heat, the electricity used for heating is generated from other fuels that account for the energy loss. Compared with other heating approaches, furnaces and boilers are the most common choice for residential houses in the U.S. (Department of Energy). Furnaces and duct systems usually work together, and boiler, metal pipes and radiators usually work. In the steam boiler heating system, steam is distributed through pipes to the steam radiators. In the hot water boiler heating system, hot water is distributed to the space via either baseboard radiators or radiant floor systems.

4.2.1 Gas-fired Heating system

Natural gas is the most commonly used fuel for residential heating in U.S. The main component of natural gas is methane (CH_4). In a complete combustion, oxygen and CH_4 react with each other and produce CO_2 and H_2O. If O_2 is less than the required amount and the chemical reaction is not complete, the products will have CO which is highly toxic. Thus, in order to reach complete combustion and avoid CO being produced, excess intake air is needed for combustion.

4.2.1.1 Gas-fired Furnaces

Furnaces are heating facilities that are commonly installed in U.S. compared with boilers and electric baseboard heaters. The fuels commonly used in furnaces is gas, while oil and electricity can also be used as fuel. Different furnaces have different annual fuel utilization efficiency (AFUE). AFUE is the ratio of annual heat output of the furnace or boiler compared to the total annual fossil fuel energy consumed by a furnace or boiler. (Department of Energy) The gas-only furnace has an AFUE of 92% to 95%, which is very energy-efficient (Janis, Richard R.).

For the forced-air furnace, a fan is used to force the heated air into the duct system. There are two inlets and one outlet. The combustion air is taken into the furnace through the combustion air inlet pipe. The return air is returned to the furnace through the return duct. The heated air and reheated air are delivered through the supply duct. Residential houses are where the furnaces are commonly installed. Because the heat is distributed by natural convection, the heat loss is pretty high. For this reason, the efficiency is relatively low (Janis, Richard R.).

The other type of furnaces is the condensing furnace. The special parts of a condensing furnace are two heat exchangers, the primary heat exchanger and the condensing heat exchanger. In the primary heat exchanger, heat is transferred from the combustion gas inside the heat exchanger to the circulating air outside the heat exchanger. The exhaust

(Figure 1) Steam boiler
(Source: http://energy.gov/energysaver/articles/furnaces-and-boilers)

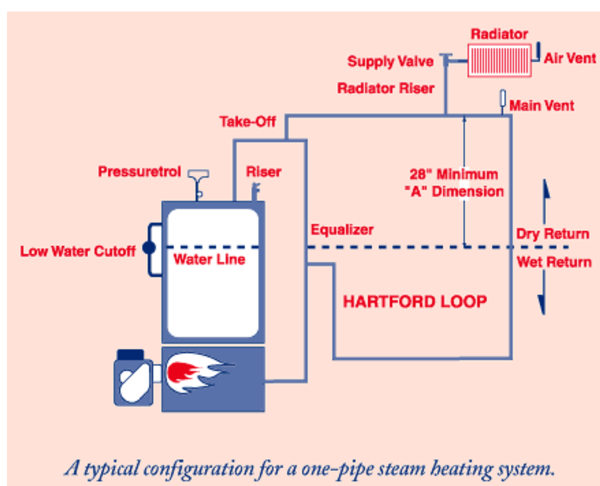
gas then goes through the condensing heat exchanger. In the condensing heat exchanger, additional heat is transferred to the supply air by condensing the water vapor in the exhaust gas. (Harvey M. Sachs, Sandy Smith) As a result, the AFUE of the condensing furnaces can be 10% higher than the AFUE of non-condensing furnaces. (Department of Energy) Thus, condensing furnace is more energy-efficient than general forced-air furnace.

The heating system is not limited to the furnace, but also includes the distribution system. The heated air produced by furnace will first go through the duct system. The exhaust air is also sent back by duct. The ducts are distributed in each area of the interior space. Diffusers and registers connect the duct and interior space to distribute air into the space. They can be either mounted on ceilings, walls, or floors.

4.2.1.2 Gas-fired Boilers

Hot water boilers usually use either natural gas or oil as fuel. The cold water is heated in the boiler and then pumped by the circulator to different areas in the house through pipes and radiators. (Department of Energy)

A steam boiler (Figure 1) consists of steam valves, gauge glass, low-water cutoff, automatic water feeder, pressure relief valve and steam limit control. In the boiler, the intake water is heated to be steam and the steam is distributed through the pipes and radiators in the space.



(Figure 2) Steam boiler
(Source: http://Oilheatamerican.com)

In the distribution system, the hot water or steam is sent to the radiators, which are located at different spaces from boilers through the metal pipe systems. After the steam or hot water passes through the radiators, it will be returned to the boiler through the return pipe system. The heat from the water or steam is first transferred to the coil inside the radiator and is then transferred to the space from the coil by radiation.

4.2.2 Heating system fueled by electricity

Electric resistance heaters are highly efficient. Most of the electricity is converted to heat. But based on this information, the conclusion that electric resistance heaters are energy-efficient cannot be made because electricity is a secondary energy resource which is generated from other fuels, including oil, natural gas, coal, wave energy, solar energy and wind energy. Energy losses occur during electricity generation and delivery. (Department of Energy) As a result, the overall efficiency of the electric resistance heaters is much lower than other types of heaters.

Electric resistance heaters consist of electric furnaces, electric baseboard heaters, electric wall heaters, radiant heating system and electric thermal storage. A built-in thermostat is designed in the heaters to prevent overheating. In case of emergency, the thermostat can shut off the electric heaters.

Electric baseboard heaters are one of the popular electric resistance heaters commonly installed in buildings like the residential houses and school dorms. They are usually put near the exterior wall or exterior windows. It works under natural convection. Metal pipes are inside of it, and the electric heating elements are enclosed in metal pipes. When the air near the pipes is heated, the warm air rises and the cold air from the windows falls down to the bottom of the heater to be heated. Another type of electrical heaters is a standard electric wall heater which has an electric resistance element, a reflector, and a fan. It is usually mounted on the interior wall because the installation of electric wall heaters will damage the wall to some extent. If install it on the exterior wall, the damage to the building envelope will definitely affects the building's insulation system. (Department of Energy)

4.2.3 Active solar heating system

Active solar heating system consists of solar liquid (or air) collectors and a storage tank or a heat exchanger. The flat plate collectors are put on the roof to absorb solar energy. When the liquid flows through the collectors, it will be heated to a specific temperature. The liquid can be water, antifreeze, or other types of fluid which are able to absorb solar heat. The fluid can be heated to a higher temperature by reducing the volume of the fluid which flows through the collectors. However, when the volume of the fluid is reduced in order to have a higher temperature, more solar heat will be lost during this heat transfer process. (Department of Energy) The heat carried by the fluid is then transferred to the distribution system through the heat exchangers. (Chan, Hoy-Yen) Active solar heating system is an environmental-friendly heating solution; however, it has limitations. Without alternative heating system installed, heating in the cloudy days will become a problem.

4.2.4 Radiant heating system

Radiant heating system, heating the space by infrared radiation from the radiant panels, instead of by radiator or forced air, is another choice for residential heating. Typically, radiant heating approach is classified as radiant floor heating system and radiant ceiling panels heating system. The radiant heating eliminates the possibility of allergens being taken into the house by air and thus is preferred by people who have allergies. Different from the radiant heating, the forced-air heating may bring the allergens into the house. Generally, the radiant panels work with boilers, geothermal system, or other hot-water or electricity generators (Department of Energy).

In the radiant ceiling panels heating system, the hot water or electric resistance cables are the heat sources in this circulation system. The hot water goes through the tubes which are hidden behind the ceiling panels. The tubes are attached to the panels in order to transfer the heat from the hot water to the panels. Then the ceiling panels which have a lager surface area than the tubes will distribute heat to the space. In the electric radiant heating system, the hot water is replaced by electric resistance cables (Janis, Richard R.).

The radiant floor heating system also has two types, the electric system and the hydronic system. In the electric radiant floor heating system, the heat is produce by the electric cable. The hydronic radiant floor heating system is similar to the hydronic heating system mounted on the ceilings. Hot water is used to carry heat in this circulation system (Janis, Richard R.).

If the house has already been built and it currently has another heating system, it is difficult and more expensive to replace the current one by the radiant heating system. Thus, the radiant heating system is not recommended to the Worcester Friends meetinghouse.

4.2.5 Current meetinghouse heating system

In the current heating system, the meetinghouse has two heating zones. One is the first day school classroom on the third floor. The other one is the rest of the house from the first floor to the third floor. In the First-day School Classroom on the third floor, electrical baseboards are installed on the window side and it is controlled by a switch near the door (Figure 4). The other rooms in the meetinghouse are heated by steam radiators (Figure 5) and the temperatures are controlled by a thermostat on the first floor. The gas-fired steam boiler is located in the basement, installed with a no. RVGP-KS 8-BKF gas vent damper which is operated at 24VAC, 60/50 Hz. and 80mA. The steam is circulated in a loop through boiler, pipes, and radiators located in different rooms.

(Figure 3) Electric resistance heaters in the classroom on the third floor

(Figure 4) Radiator on the first floor in Worcester Friends Meetinghouse

4.2.6 Energy aspect of heating system

The electricity in the meetinghouse is delivered by Grid Electricity. The table below shows National Grid's electricity pricing in Massachusetts.

Customer charge	$4.00/month
Distribution charges: First 600 kWh Excess of 600 kWh	 3.539 cents/kWh 4.201 cents/kWh
Transmission charge	2.132 cents/kWh
Transition charge	0.160 cents/kWh
Energy efficiency charge	0.942 cents/kWh
Renewables charge	0.050 cents/kWh

(Table 1) National Grid Electricity pricing – regular residential R-1

(Source: http://www.nationalgridus.com/masselectric/home/rates/4_res.asp)

The natural gas used in the meetinghouse is delivered by NSTAR. The table below shows the natural gas pricing.

Customer charge		$6.50/month
Distribution	November - April: First 20 Therms Over 20 Therms	 68.71 cents per Therm 42.58 cents per Therm
	May - October: First 10 Therms Over 10 Therms	 62.25 cents per Therm 36.12 cents per Therm

(Table 2) NSTAR Gas Schedule of Rates – regular residential R-1

(Source: http://www.nstar.com/docs3/tariffs/420.pdf)

4.2.7 Alternative renewable energy

While grids deliver most of the electricity used in buildings, the electricity can also be generated on site. Many commercial buildings have their own on-site electricity generators for emergency. For small-size buildings, the Photovoltaic system can be an alternative approach to producing electricity on site.

As a sustainable solution to residential heating, photovoltaic panels can convert solar energy to electricity, and the generated electricity can be used for space heating. Nowadays, photovoltaic technology has already been used in residential houses. In Europe, they have been widely used in residential houses for electricity and heat supply. Not far away from Worcester Friends Meetinghouse, a residential house in Worcester has already installed photovoltaic panels.

(Figure 5) a residential house with solar panels on the roof, Worcester

A Photovoltaic (PV) system includes PV panels, one or more batteries, an inverter, a charger regulator and wirings. Solar cells on the PV panels absorb photons from the Sun and convert solar energy to direct current (DC). Then DC goes through the inverter in which it is converted to alternating current (AC). If the produced electricity cannot be used up immediately, the part that isn't used can either be stored in the batteries or go into the electrical grid through a net energy meter. The normal batteries used for storage are Lead Acid Batteries. The net energy meter records how much electricity goes into the electrical grid and how much electricity from the grid is consumed. The family only need to pay for the net electricity consumption from the electrical grid. (State of California, California Energy Commission & California Public Utilities Commission) As this indicates, installing PV system on residential houses becomes more economically practicable.

4.3 Programmable Thermostat

4.3.1 Line-Voltage vs Low-Voltage Thermostats

A variety of thermostats are currently available for consumer use. They can be broken down into two main categories: line-voltage thermostats and low-voltage thermostats. Before digital thermostats were invented, temperature of a structure was regulated through the conductance of a mercury switch controlled by a bimetallic strip. This technology involved using two different types of metal (attached together) with differing coefficients of thermal expansion. Depending on the amount and direction of the bending, the thermostat would compensate by turning on or off the heating system (Nice 1-2). These line-voltage thermostats are comparatively outdated as they use 120V or 240V in series with heaters or radiators to regulate a single heating system. However the classroom on the third floor of the meetinghouse contains a line-voltage thermostat to regulate temperature in that one room. Current flows directly into the thermostat and then into the heater in this system. They can be inaccurate if the thermostat reaches the set temperature before a heater in another room reaches its set temperature and shuts off. The low-voltage thermostat fixes many of these inefficiencies as they operate at a lower voltage, usually between 24V and 50V and have more programming controls. Low-voltage thermostats can be used in many heating systems including gas, oil, and electricity (Different 1). Regardless of structure or functionality, thermostats can be grouped into one of these two categories. Up-to-date thermostats of both types are digital and work through the concept of a thermistor. A thermistor is a resistor whose resistance varies with temperature. A microprocessor inside of the thermostat can read this resistance value and match it to a corresponding temperature. This is how the thermostat decides when to tell the heating system to turn on or off (Jackson 3-4).

4.3.2 Programmable Thermostats

Programmable thermostats are becoming more and more popular as they allow users control over the temperature of their home or work environment. This brings both options of comfort and energy efficiency to a consumer. Most residential thermostats have four setpoints per day. These setpoints are scheduled temperatures throughout the day. They are usually programmable for morning (wake up), day (when at work or out of the house), evening (returning home), and night (sleep) (Jackson 8). The current thermostat in the meetinghouse is a Honeywell programmable thermostat with four setpoints that are in essence set at the same temperature. They are labeled heat, leave, return, and sleep and correspond to the four setpoint described above. The thermostat in the meetinghouse (Figure 6 on next page) is visibly broken as it displays 69 degrees

Fahrenheit but when touring the house, it was significantly warmer. It is partially programmable but ineffective, as it is broken. Rather than cooling or heating the building to the programmed temperature, the heating system attempts to keep the house at a constant high temperature. Additionally, the house is controlled by single zone heating. This is inefficient as the thermostat in the first floor atrium determines whether the boiler is on or off. The problem with single zone heating is that the boiler may shut off when the first floor is warm but other areas in the house are still cold. Replacing this thermostat may have a significant effect on the energy efficiency of the house.

(Figure 6) The Current programmable thermostat in the meetinghouse

A WiFi programmable thermostat is a high-end version of a digital thermostat. These are the newest types of thermostats and are gaining popularity based on convenience and comfort. A WiFi thermostat provides all of the same features of a programmable thermostat with the addition of being able to change settings from any location. As long as a homeowner has internet access, he or she can adjust the heat settings. For this project, digital thermostats were exclusively considered because of their effectiveness and practicality.

4.4 Windows

Each window has a unique problem which leads to failed insulation, however most of the issues can be easily fixed at a low cost. By recommending small changes and modifications to the current window, a significant amount of heat and energy will be saved.

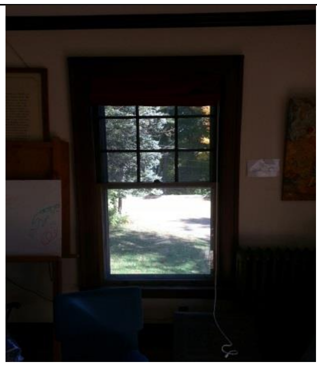
Due to the age of the house, traditional window styles are primarily used. There are 42 windows in total throughout the house featuring four different types of windows.

The most common type of window throughout the house are double hung windows. This is a design featuring two vertically sliding sashes. There are 29 double windows in the meetinghouse and they are all made of softwood. This softwood design requires regular maintenance to prevent wear.

The windows located in the basement and staircases are fixed windows. These windows are not made to open and can be designed in any size or shape. The house has ten fixed windows.

In the living room, there are two bow windows overlooking the road. The protruding designs of these windows are designed to create interior spacing. Both are a combination of a middle stationary window with two double hung windows.

Perhaps the most aesthetically pleasing window in the house is the custom casement screened window on the staircase of the second floor. Metal grilles are used to separate the window into divided lites, which adds to the historic feel of the meetinghouse.

Type of Window	Window Example	Number of Windows	Location(s)
Bow		2	1st Floor
Casement Screened		1	2nd Floor
Double Hung		29	1st-3rd Floors
Fixed		10	Basement-2nd Floors

(Table 3) Examples of different windows in the meetinghouse

4.5 Insulation

In warmer areas, insulation is used to prevent heat from entering and in cool climates to keep the heat in. Insulation is found all over homes, such as, inside the walls, the attic or roof, under the floor and near the foundation of the house. Usually the ventilation and heating systems—water or air—are insulated too. There are so many different kinds of insulation, and each has different properties and values around the house.

Different types of insulation are normally compared using the R-value or Resistance-value. The higher the R-value, the better the insulating ability. For example, a common brick has an R-value of 0.20 per inch, while fiberglass batt insulation has an R-value of 3.17 per inch (Fegan). Both materials can be used to insulate a home, but fiberglass does a much better job (15 times more effective than brick). According to the North American Insulation Manufacturer's Association (NAIMA), for every $1 spent on insulation will save $12 in energy costs (Home Energy Solutions).

During this project, different types of insulation were researched and compared in order to find the most suitable fit throughout the meetinghouse. The building has outdated, damaged insulation in the attic areas, walls, and the basement is lacking in the proper protection in order to retain the heat. For a modern New England home, the cost of energy for the house is enormous compared to the homes in the area and steps need to be taken in order to make the home more cost effective. There are many types of insulation, each with their own unique purpose, that when combined correctly can protect around the meetinghouse and reduce cost and energy consumption.

R-Value Table

Material	R/ Inch	R/ Thickness
Insulation Materials		
Fiberglass Batt	3.14	
Fiberglass Blown (attic)	2.20	
Fiberglass Blown (wall)	3.20	
Rock Wool Batt	3.14	
Rock Wool Blown (attic)	3.10	
Rock Wool Blown (wall)	3.03	
Cellulose Blown (attic)	3.13	
Cellulose Blown (wall)	3.70	
Vermiculite	2.13	
Air-entrained Concrete	3.90	
Urea terpolymer foam	4.48	
Rigid Fiberglass (> 4lb/ft3)	4.00	
Expanded Polystyrene (beadboard)	4.00	
Extruded Polystyrene	5.00	
Polyurethane (foamed-in-place)	6.25	
Polyisocyanurate (foil-faced)	7.20	
Construction Materials		
Concrete Block 4"		0.80
Concrete Block 8"		1.11
Concrete Block 12"		1.28
Brick 4" common		0.80
Brick 4" face		0.44
Poured Concrete	0.08	
Soft Wood Lumber	1.25	
2" nominal (1 1/2")		1.88
2x4 (3 1/2")		4.38
2x6 (5 1/2")		6.88
Cedar Logs and Lumber	1.33	

(Figure 8) R value measurements for different building materials

(Source:http://www.allwallsystem.com/design/RValueTable.html)

Batt insulation-Fiberglass

Batt or blanket insulation is very widely used today. It has a high R-value of 3.14, according to the figure above. It is a fluffy product that can be purchased in different thicknesses and widths. While rock wool was very popular before World War II, fiberglass is now the most popular in residential housing. Both are considered man-made mineral fibers and are referred to as mineral wool. Cotton-batt insulation is a relatively new product originally designed to appeal to the environmentally conscious individual. Residential batt insulation is usually sold either without facing, or with an asphalt-coated Kraft-paper. Some manufacturers offer plastic or aluminized-paper facings. The facing is designed to act as a diffusion retarder. In some cases, builders will install a separate diffusion retarder over unfaced batt insulation.

Construction workers installing both rock wool and fiberglass often suffer from itching and tiny cuts in the skin due to the fibers (An Introduction to Indoor Air Quality). Itching can also result from an allergic reaction to the binder used to hold the insulation together. The manufacturers recommend the following work practices related to such materials: wear a respirator; avoid contact with skin and eyes; wear long-sleeved clothing, gloves, and eye protection; wash with soap and water after handling; wash work clothes separately from other clothes; and wipe out the washing machine after washing exposed items.

In most modern houses, the migration of fibers into the living space is negligible. In tightly constructed houses, insulation of all types is well separated from the occupants. Moisture in insulation can also lead to biological growth and reduced insulating ability (Fegan). When done properly, tight construction minimizes these hidden moisture problems.

Fiberglass

Fiberglass insulation is manufactured by melting inorganic materials (often sand) and spinning them into glass fibers, where the fibers are then held together by a formaldehyde-based binder. According to the figure, the R-value of Fiberglass is 2.20 and 3.20 for attic and wall materials, respectively. Fiberglass is generally contaminated with fewer impurities than rock wool, thus having a lower cost. Most of the fiberglass insulation manufactured today is either pink or yellow, and contain approximately 5% of a resin binder. The pink variety, made by Owens Corning, also contains less than 1% dye to give it the pink color (Fegan). Other than Owen's Corning, Johns-Manville Corp. has a fiberglass insulation that uses an acrylic resin, rather than a formaldehyde-based resin. It is wrapped with a perforated polyethylene, which can minimize the release of fibers in applications such as above dropped ceilings.

In the case of a fire, fiberglass itself is fairly inert, giving off little to no toxins. The resin, however, can decompose in a fire and produce small amounts of ammonia, carbon dioxide, carbon monoxide, carbon particulates, and traces of hydrogen cyanide. It is very important to keep fiberglass insulation well contained away from the living space. One report found that nearly 13 workers in an office reported various symptoms apparently related to glass fibers entering the air due to improper ventilation and construction methods (An Introduction to Indoor Air Quality). Symptoms include itchy rash, burning eyes, sore throats, coughing, and malaise. After the insulation was sealed behind plastic foil, the health complaints ceased.

Heating natural basalt rocks or industrial steel-mill slag in a furnace produces rock wool which has an R-value of 3.14. As the material melts, it is drawn out into fibers and formed into felts, blankets, or batts (Fegan). For the most part, fiberglass insulation replaces the use of rock wool in homes across the nation. Rock wool is better at reducing sound transmission and has a higher fire resistance, but the cost exceeds that of the fiberglass insulation. It is typically bound into batt form by the use of a phenolic resin. When directly exposed, these materials can cause irritation (An Introduction to Indoor Air Quality).

Loose-fill and blow-in insulation

Loose-fill and blow-in insulations come in several forms. Some can be simply poured out of a bag while others are blown through a specially designed machine, then through an applicator hose. Cellulose and chopped fiberglass are the most common types with R-values of 3.70 and 3.20 respectively. Both are generally blown in place but they can also be poured out and placed by hand.

Chopped fiberglass can be installed in a manner similar to cellulose. It is composed of small fibers of glass, similar to fiberglass-batt insulation, but in a loose form so that it can be blown into wall cavities or attic spaces. Glass is inherently non-combustible and is not threatened by being eaten by pests, so it is not chemically treated like cellulose (Fegan). Several manufacturers make a chopped fiberglass blowing insulation.

Sometimes the only way to insulate the walls of an existing house is to drill holes in the walls and blow some type of insulation into the wall cavities. Existing attics can be insulated in a variety of ways, but blow-in insulations are often quicker and cheaper to install than batts. Some lumber yards rent blowing machines to individuals wanting to do it themselves. When carefully blown into sidewalls, insulation can help to tighten a house, thus minimizing infiltration while maximizing energy efficiency and comfort (Fegan).

For new construction, there is a Blow-In-Blanket system ("BIBS"), licensed by Ark Seal International that uses either cellulose or chopped fiberglass (Home Energy Solutions). With this approach, a mesh is stapled up over the studs on the interior. This process takes place after the wiring and plumbing are in place, but before the drywall. Then cellulose insulation (or chopped fiberglass) is blown into the stud cavities. This will fill voids quite well around electrical boxes and plumbing pipes, and it is often faster than using batts.

Cellulose

Cellulose insulation is a very popular product today which is made by chopping old newspapers into a fine, fluffy material. Newspapers naturally come with an array of potential problems: they are very combustible, insects can eat them, or rodents use them as nesting material. Due to such reasons, cellulose insulation must be chemically treated. In attic areas, roof trusses are often held together with metal plates, and corrosion of these plates could lead to deterioration of the roof system. Cellulose insulation standards today take these potential problems into consideration, but many older products could contain flammable or corrosive material. A sample of the insulation can often be obtained from the attic and placed near a flame to test for flammability, and an examination of any exposed metal will reveal any corrosion.

Symptoms reported after the installation of cellulose insulation include rashes, hair loss, and digestive and respiratory disorders (An Introduction to Indoor Air Quality). Individuals with intolerance to newspapers will easily be bothered by this insulation. Because cellulose insulation is so finely ground and powdery, it can filter through very small openings into the living space. Installers without protective clothing or respiratory protection can experience red and sloughing skin, lung irritation, coughing, bronchitis, and pneumonitis.

In most cases, cellulose insulation is installed conscientiously and it remains inside building cavities presenting no health problems to the occupants. However, small amounts can be blown into the living space of an existing house during installation, so the workers must clean up thoroughly (An Introduction to Indoor Air Quality). New houses can also be insulated with cellulose, and if they are constructed tightly, the insulation will not be able to migrate into the living space. There are many manufacturers of cellulose insulation, and it can be purchased through lumberyards or insulation contractors.

Polystyrene

Polystyrene foam insulation is made in two types, expanded and extruded with R-values of 4.00 and 5.00 respectively. Expanded polystyrene consists of small beads fused together inside a mold and is often called beadboard. Extruded polystyrene is made by pushing a chemical mixture through a rectangular die to form sheets after cooling. Both types of polystyrene will deteriorate when exposed to ultraviolet light, so they must be protected from sunlight.

Polyurethane and Polyisocyanurate

The basic ingredients of polyurethane foam are isocyanates, polyol resins, and an amine catalyst (Fegan). Other additives can be used. A blowing agent causes the mixture to expand, creating foam. Polyurethane can be made into flexible foam, as used in upholstery, or rigid foam used in insulation (R-value of 6.25). Polyurethane is flammable and must be separated from the living space by some form of sheet rock.

Polyurethane insulation has a higher R-value than most other insulations because of the blowing agent trapped in its pores (Home Energy Improvements). Other insulations use trapped air to retard the flow of heat, but the gas used in polyurethane functions as a better insulator. Over time, the R-value of the polyurethane decreases due to lost gasses. It will take on water when in a damp environment or used underground, so it must be adequately protected with a suitable diffusion retarder.

Polyisocyanurate foam insulation is very similar to polyurethane, but is slightly more stable. It must be protected from sunlight and moisture and has similar characteristics when burned. It is often supplied with a foil facing to protect it from degradation. While workers in manufacturing plants can be exposed to a variety of chemicals, polyurethane and polyisocyanurate insulations are fairly inert once cured (An Introduction to Indoor Air Quality).

Reflective-foil insulation

Radiant energy can be reflected back where it came from by means of a shiny foil. The foil does not need to be exposed directly to the radiant source; it can be placed inside a wall cavity and still function. For example, radiant heat can pass through drywall, strike the foil, and be reflected back where it came from. The only requirement is that an air space exists in front of the foil (Fegan).

Reflective-foil insulation is also called “builder’s foil,” (Home Energy Solution). Its products are sometimes perforated to allow moisture to pass through. The perforated products will function as reflective insulation, but not as a diffusion retarder (Fegan). Moisture migration is an important issue with reflective-foil insulations, because if you choose the wrong product for a particular application, you can end up with a moisture-condensation problem hidden inside a wall cavity. These types of materials are often not very sturdy, and they can get torn in some applications.

The current insulation in the home is fiberglass insulation with reflective aluminum foil. The meetinghouse’s insulation is out of date and demonstrates a relatively low R-value due to the lack of maintenance. The attic is split into three eaves, where eaves 2 and 3 are extremely inaccessible. Eave 1 has 15 bays, each measuring 19-¼’’ width, 96’’ height and 6-¼’’ depth. The eaves’ existing material is an Owen’s Corning Fiberglass Building Insulation with Reflective Aluminum Foil to seal the bays shut. This is done in order to stop the fiberglass from traveling around the air space and prevent exposure to the lungs. The rips and tears in the foil of every bay in eave one need to be attended to or replaced so the home can increase energy efficiency and ultimately lower the cost of heating.

4.6 Deep Energy Retrofit Workshop

On October 25th, two members from this project group went to the Deep Energy Retrofits Workshop in Providence, RI. This workshop talked about deep energy retrofits in the New England area and lessons about residential house retrofits were given. Deep energy retrofit considers: indoor air quality, comfort and quiet, elimination of air leaks, even temperature and efficient attic and basement area with low humidity. To be qualified as an energy efficient house, insulation requirements for the deep energy retrofits were specified.

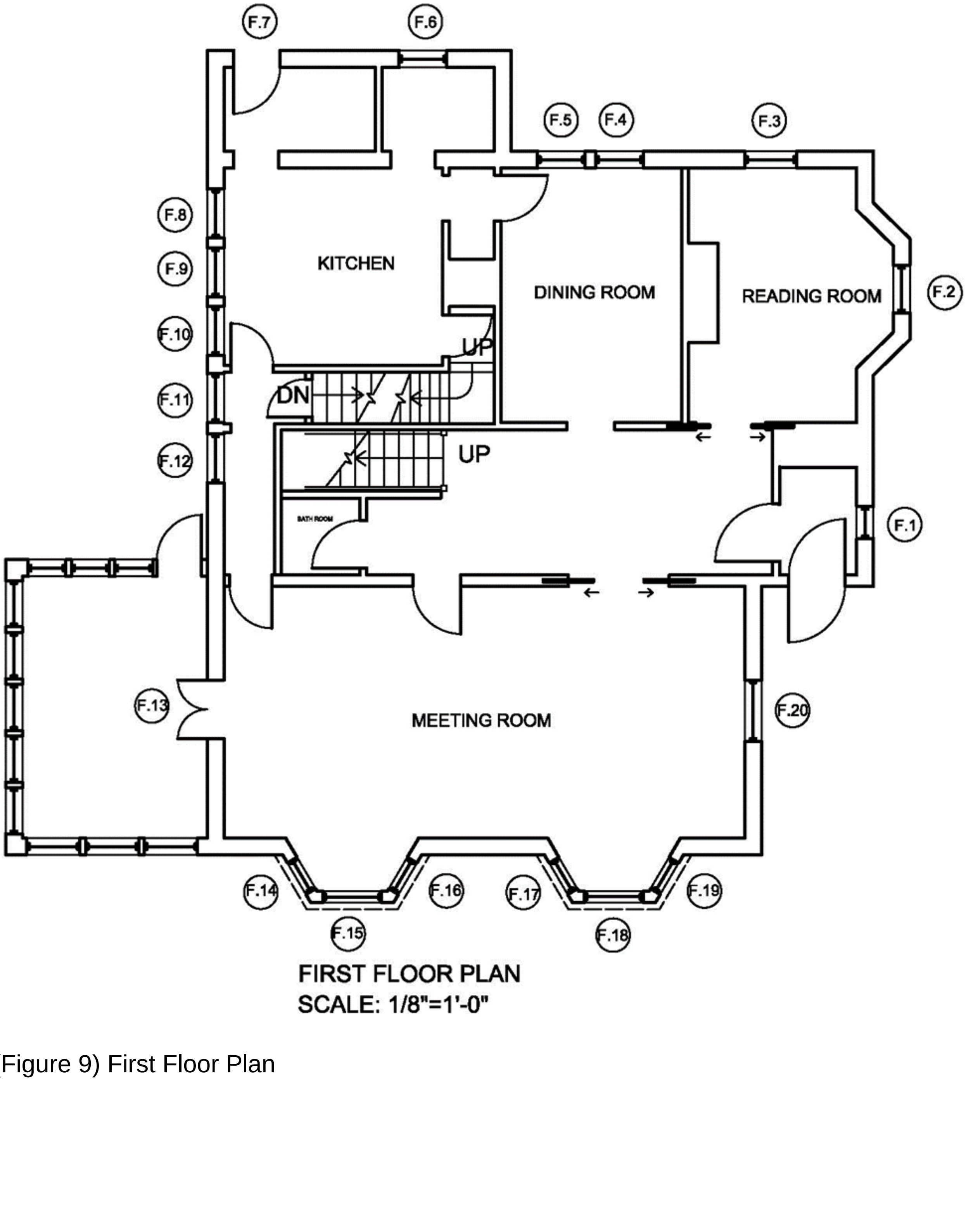
Section	Minimum R-value
Roof	R-60
Above grade wall	R-40
Below grade wall	R-20
Basement floor	R-10

(Table 4) Insulation requirement for deep energy retrofits

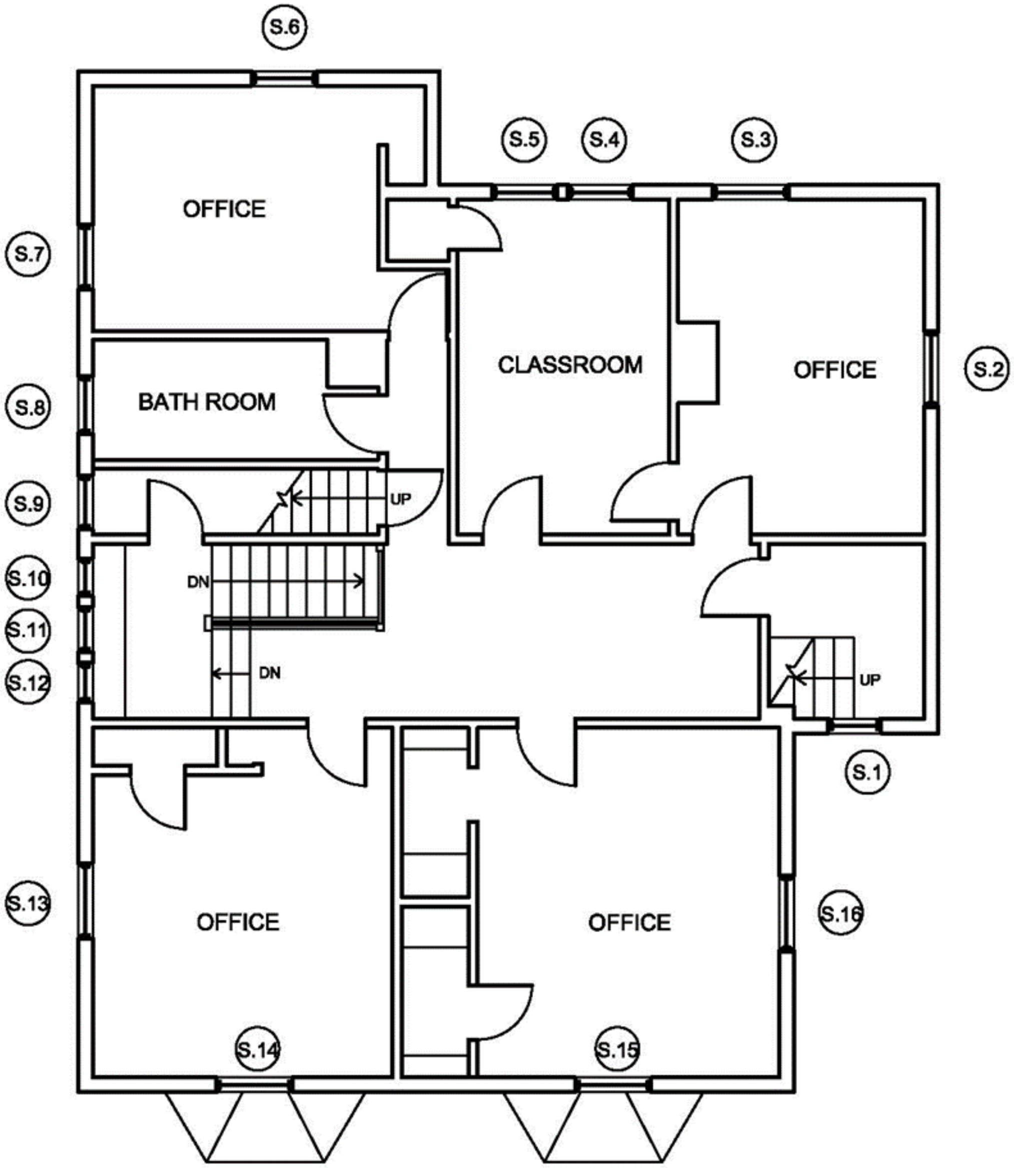
For the building enclosure, the importance of air barrier and vapor barrier were discussed in this workshop. Air barrier was used to control the air leakage through the building envelope. Vapor barrier could significant change the humidity in the basement or foundation. For windows, low-e window was strongly recommended. When adding a new window to the existing historic window, the window with high R-value should be put outside. For the heating system, the best choice for a low energy building was Japanese Mini-split heat pumps. Radiant heating system is good for occupants' health. However, because of its high costs, radiant heating system is not the best choice. In addition, when the furnaces or boilers are used for heating, combustion safety should be considered and sealed combustion was required.

4.7 Floor Plan

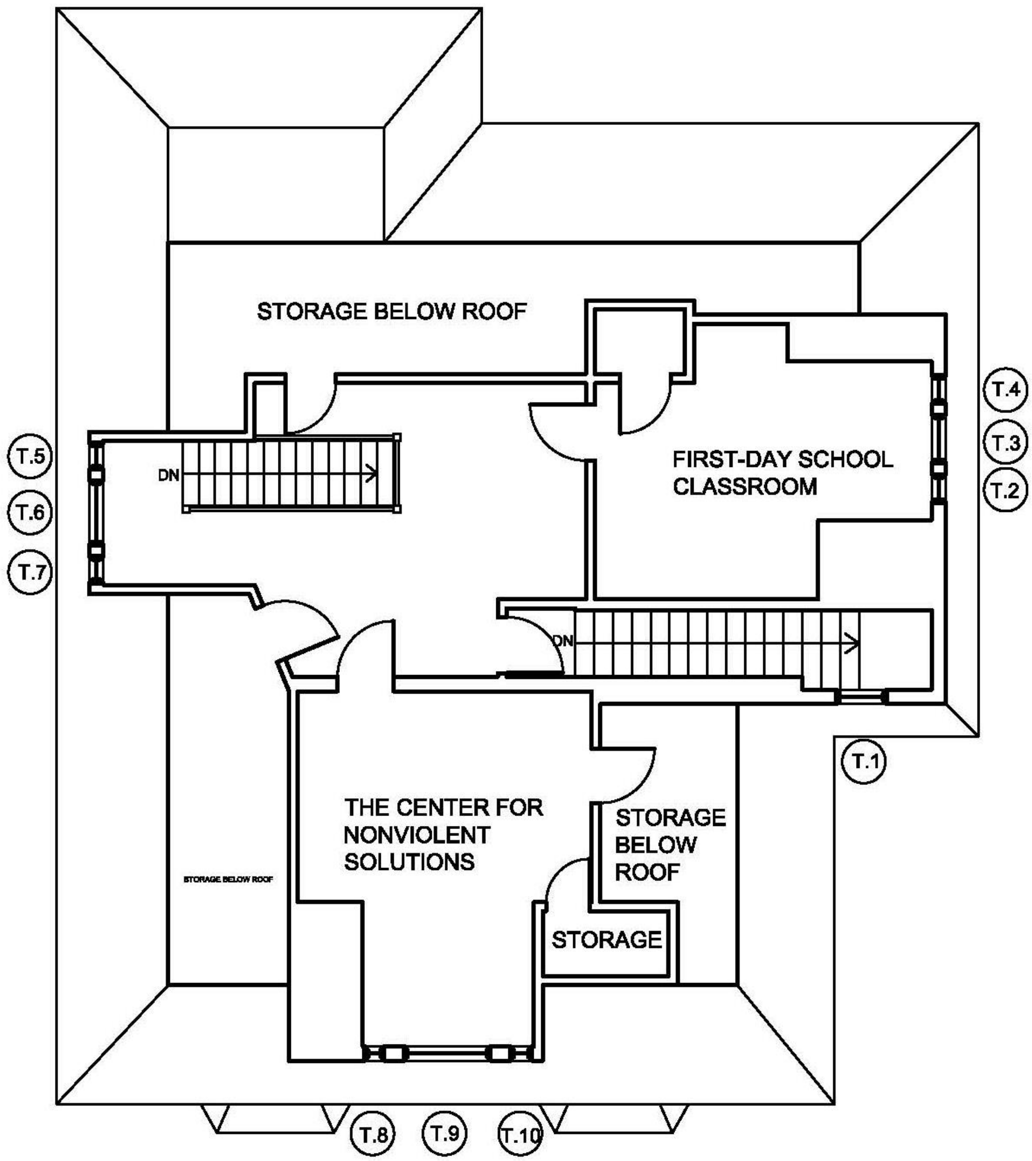
Floor plans for the four levels of the building were constructed for graphical representation. These figures are included below and the process in developing them is outlined in the methodology.



(Figure 9) First Floor Plan

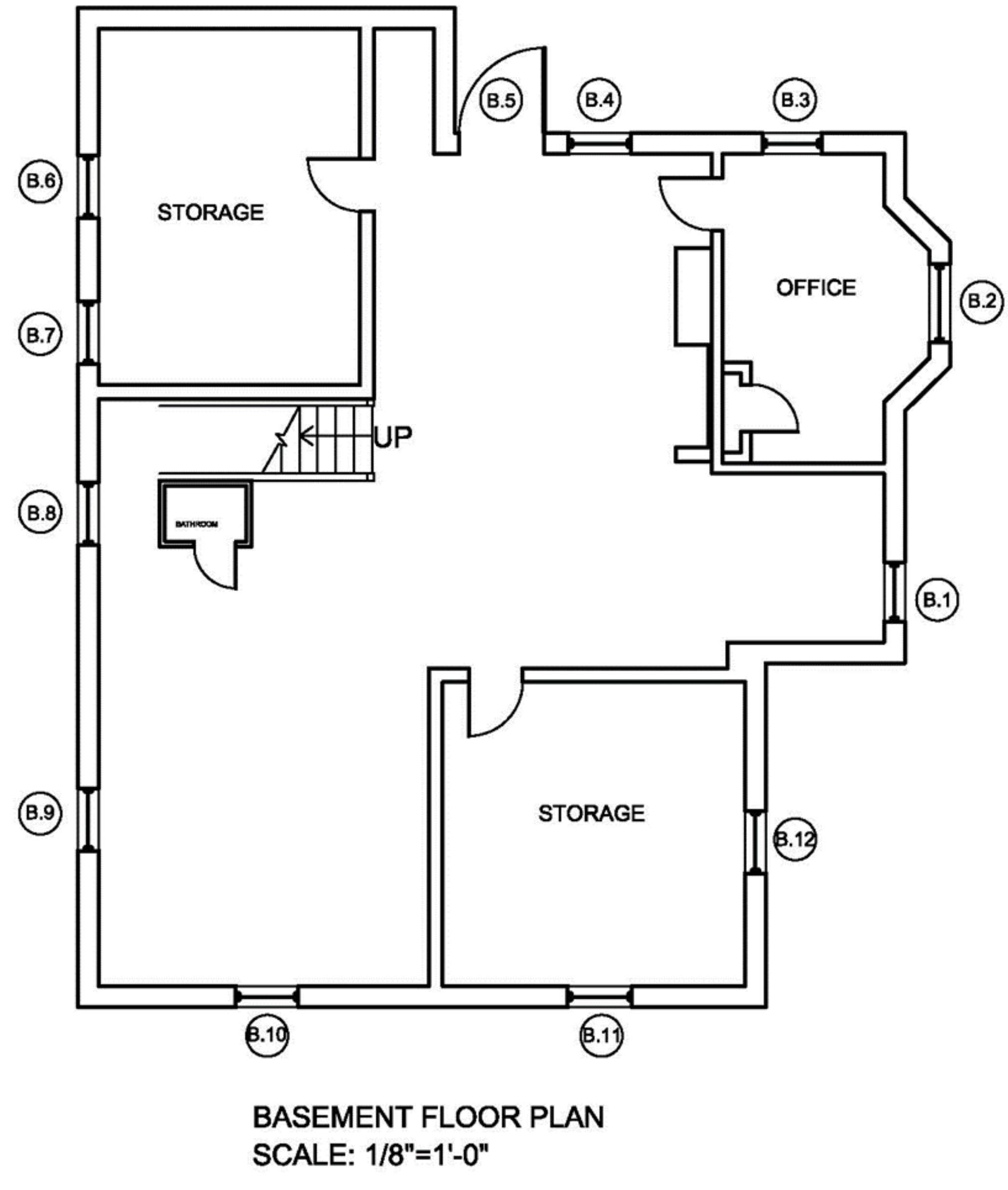


(Figure 10) Second Floor Plan



THIRD FLOOR PLAN
SCALE: 1/8"=1'-0"

(Figure 11) Third Floor Plan



(Figure 12) Basement Floor Plan

5. Methodology

After conducting background research on energy efficiency, the building was toured with David Legg, an energy consultant. Dave has experience energy retrofitting homes throughout New England and was quick to point out flaws in the meetinghouse. The walk through it guided the focus for improvement on the heating system, programmable thermostat, windows, and insulation. The methodology section of this report outlines the steps and analysis procedures taken to make changes as well as recommendations for the building.

5.1 Heating System

The heating system in the meetinghouse includes a gas-fired steam boiler, metal pipes and steam radiators. In this project, the current heating methods in the U.S. were analyzed and compared, and the heating system in the meetinghouse was analyzed based on the gas usage, boiler efficiency, and national and Massachusetts building energy codes. The gas usage from November 2011 to November 2012 were used for analysis. The efficiency of the existing heating system were measured by annual fuel utilization efficiency (AFUE) based on gas usage and thermal data.

According to Massachusetts Department of Public Health (MDPH), the recommended indoor temperature is 70^{o} F to 78^{o} F. (“Indoor Air Quality Assessment” MDPH) In Massachusetts, the design temperature is 70^{o} F in the winter and 78^{o} F in the summer. The indoor temperature over a period of days were measured to see if the indoor temperature fall in the comfort range.

According to U.S. Department of Energy, “AFUE is the ratio of annual heat output of the furnace or boiler compared to the total annual fossil fuel energy consumed by a furnace or boiler. An AFUE of 90% means that 90% of the energy in the fuel becomes heat for the home and the other 10% escapes up the chimney. AFUE does not include the heat losses of the duct system or piping, which can be as much as 35% of the energy for output of the furnace when ducts are located in the attic, garage, or other partially conditioned or unconditioned space" (Furnaces and Boilers, 2012). A high AFUE value means the heater has a higher efficiency. The evaluation of the heating systems was based on the following requirements provided by Department of Energy (Department of Energy).

Product class	Minimum AFUE rating
gas-fired hot water boiler*	82%
gas-fired steam boiler*	80%
oil-fired hot water boiler*	84%
oil-fired steam boiler	82%

(Table 5) Minimum AFUE Requirement for boilers

* gas-fired boilers are not permitted to have a constant burning pilot, and hot water boilers are required to have an automatic means for adjusting the water temperature to match the heating load.

(Source:http://energy.gov/energysaver/articles/furnaces-and-boilers)

Product class	Minimum AFUE rating
Non-weatherized gas furnaces (not including mobile home furnaces)	80%
Mobile home gas furnaces	80%
Non-weatherized oil-fired furnaces (not including mobile home furnaces)	83%
Mobile Home oil-fired furnaces	75%
Weatherized gas furnaces	81%
Weatherized oil-fired furnaces	78%
Electric furnaces	78%

(Table 6) Minimum AFUE Requirement for furnaces

(Source:http://energy.gov/energysaver/articles/furnaces-and-boilers)

Heating systems with different efficiency	Equipment features	AFUE rating
Old, low-efficiency heating systems	• Natural draft that creates a flow of combustion gases • Continuous pilot light • Heavy heat exchanger	56%-70%
Mid-efficiency heating systems	• Exhaust fan controls the flow of combustion air and combustion gases more precisely • Electronic ignition (no pilot light) • Compact size and lighter weight to reduce cycling losses • Small-diameter flue pipe	80%-83%
High-efficiency heating systems	• Condensing flue gases in a second heat exchanger for extra efficiency • Sealed combustion	90%-98.5%

(Table 7) Heating system efficiency

(Source:http://energy.gov/energysaver/articles/furnaces-and-boilers)

In addition, the gas-fired steam boiler's efficiency were evaluated according to Massachusetts State Building Energy Code, 780CMR, as well. Based on 780CMR, the minimum efficiency required for gas steam boiler is at least 89% of thermal efficiency.

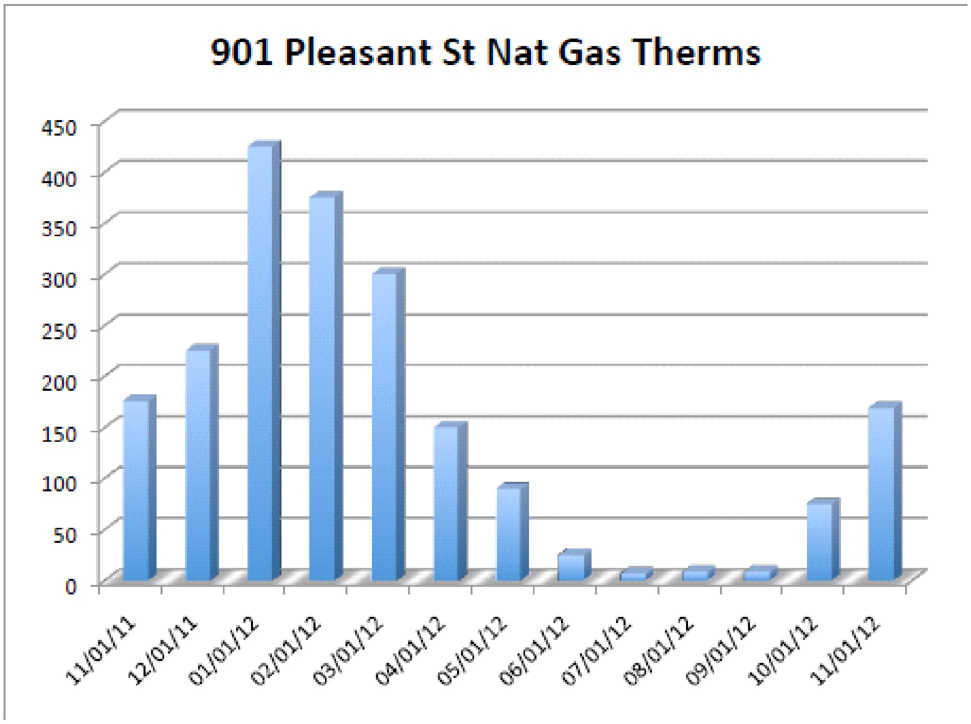
First, based on the data, the efficiency of the heating system in Worcester Friends Meetinghouse was evaluated. Then its efficiency was compared with the average efficiency of gas-fired boiler and the average efficiency of other types of heating systems used in residential houses in U.S. The meetinghouse's occupancy and how people use it were analyzed based on the information collected from the interview and by observation. In the end, suggestions for heating system improvements were given based on the analysis of current heating system, the frequency of utilization, and the energy codes and energy efficiency analysis.

5.2 Programmable Thermostat

A programmable thermostat is an important aspect to consider when looking to energy retrofit a building. Thermostats play a vital role in energy efficiency as they are responsible for monitoring the temperature of the structure and making adjustments accordingly. They work as sensors and turn heat on when temperature falls below a setpoint and off when the temperature exceeds the point (Jackson 3). The current thermostat in the meetinghouse is a Honeywell programmable thermostat but is old and does not function well. Although it can be programmed limitedly through a series of a few buttons, the thermostat keeps the house at a constant warm temperature and does not conserve gas. Below is a table for a year's worth (11/11 to 11/12) of natural gas usage by the meetinghouse. The monthly bill date is in the left column, the number of Therms used in the center, and the total cost in the far right column. Note that 1 Therm is equivalent to 100,000 BTUs or 1.055 x 10^8 joules and the cost per Therm during the period was $0.94 as indicated in (Table 8).

Date	Number of Therms Used	Cost in USD (1 Therm = $0.94)
11/16/12	169	158.55
10/15/12	75	70.36
9/15/12	9	8.44
8/16/12	9	8.44
7/17/12	7	6.57
6/17/12	25	23.45
5/18/12	90	84.43
4/18/12	150	140.72
3/18/12	300	281.45
2/17/12	375	351.81
1/18/12	425	398.72
12/19/11	225	211.09
11/19/11	176	165.12
Total (All Natural Gas)	2035	1909.17
Total (Heat Only)	1669	1778.48

(Table 8) Natural Gas Usage in Therms and Cost (Source: David Legg)



(Figure 13) Pleasant Street Natural Gas Usage Chart (Source: David Legg)

The above figure is a graphical display of the number of Therms of natural gas used during the same time period detailed in the table. Here it is easy to see the trend of energy usage where the amount of heat peaks in the winter months and is almost negligible in the summer months. This collected data from the gas bill acted as a control group or a baseline measurement before energy retrofitting changes took place. Because the cost of heat alone was calculated ($1778.48) for the year, the gas bills in future years will help determine the heat and money saved. However it is possible that if the wrong thermostat is chosen, the building occupants do not know how to properly use the thermostat, or comfort (heat constantly cranked up) is a concern savings may not be seen.

According to a Massachusetts study, 48% of residential homes use manual thermostats while a 37% use programmable thermostats. The trend is moving toward the new technology that programmable thermostats provide and can help save consumers money through reducing energy costs. When used on default energy saving settings, (just opened from the package) consumers can save upwards of $175 annually (Sachs 1).

Dave Legg suggested looking into replacing the current thermostat with a WiFi programmable thermostat for the high functionality and ease of access. To do this however, a few factors need to be examined. The first is the overall effectiveness of the thermostat, is it reliable? Does it constantly need replacement parts or servicing? A key point to note is that oftentimes energy efficient thermostats with setback temperatures and other scheduling functions do not end up saving the customers money. One case study done in Revere, MA was performed to compare limited programmable thermostats to highly functioning programmable thermostats (Sachs 12). Researchers who were part of the study found that people tended to program their thermostats to keep the home warm in their absence rather than trim bills.

5.3 Windows

The first step in this process was to conduct a full energy assessment. The energy assessment must include an expensive air-sealing process. However due to the low budget, an inexpensive way to obtain these results was needed. We began by contacting the Worcester Regional Environmental Council. This organization offers a community-service program, Weatherize Worcester, which offers a full energy assessment at no cost to Worcester residents. The audit would have covered the basement and the attic, where most of the heating losses occur. Unfortunately the audit only covers residential home so there opportunity was not available for the meetinghouse (Weatherize Worcester).

To analyze the condition of each window there were two options. The first option was to conduct testing methods by using household items such as candles and flashlights. Although these tests are not incredibly accurate, they are extremely inexpensive and could have provided enough information to make a recommendation for change.

Each window would have been checked for warm or cool spots on the glass. If these areas were found, it meant they are not insulated properly. Then each window would be checked for a draft using a lit candle. If the candle flickered when held close to the window, there is a draft. The wooden window frames would be tested with a flat blade screwdriver. If the wood was soft and rotting, it is recommended to replace each window. Finally the operation of the window would have been checked. If a frame was being propped open using a yardstick or suspended by makeshift rope, the window should be replaced. This is important because it means the frame is not fit correctly and is leaking heat through small gaps in the frame (Aguecheek). In addition to the glass and inner frames, the outer frames and caulking work must be tested as well. Running a flashlight along the length of each frame would test for any openings (Aguecheek).

Another option was to use a thermal imaging camera provided by the WPI Civil Engineering department. This test would be much more effective and would provide more user-friendly data. However, when beginning this project it was unsure if the equipment would be available for use in this project. If the thermal imaging camera could be obtained, it would be a much more effective way to analyze heat loss.

After determining the flawed aspects of the window, the method recommended would be based on the energy efficiency, appearance of the finished product and the overall cost.

Afterwards, data would be compiled on the effectiveness in the changes to window insulation. This information will give us a greater understanding of whether these changes are impractical or necessary for increasing the energy efficiency of the home.

5.4 Insulation

(Figure 14) Current insulation in the meetinghouse attic

The house includes a large amount of attic space that currently lacks the proper up-to-date insulation. The existing insulation is an Owen's Corning fiberglass insulation with an aluminum reflective wrapper, which is insulation from the 70's. This poses a problem with regards to heat loss in the existing attic areas. In the winter, large amounts of heat will escape through these poorly insulated sections of the roof, which is where all the heat rises. This will increase the use of natural gas, thus increasing the cost of heating. With a simple change to the attic space, the upstairs could maintain a better heat controlled space and additionally create two-three closets that could store anything from office supplies to children's toys.

To test the current insulation, the R-value of the material needs to be discovered. The R-value is the thermal resistance of a material and most lumber yards use it to determine performance level of the material. R-value can be calculated two ways: R=1/c-value or R= thickness/k-value. In this case, due to the lack of funds in the budget, this will be done by taking the measurements of the insulation and matching up the dimensions with a table of current Owen's Corning insulation. By identifying the section of the house, the measurements of the insulation, and the type of product we are working with, the R-value can be obtained. After discovering the R-value, future recommendations can be made as to which insulation should be used.

Initially, the plan was to replace eave one's insulation and test how much more effective the new insulation was compared to the other eaves, but due to budget and time constraints it was not feasible. Thermal images of the upstairs will be taken prior to the change in insulation, so the new insulation can be visually compared with the old images. Based on cost and resistance values of current materials, a new form of insulation will be obtained. The square footage will be taken and the cost of new material will be determined. The easiest installation as well as the most cost effective insulation will be decided based upon the research obtained through the study.

5.5 Interviews

To analyze the practicality of these changes, the team interviewed different groups who hold conferences in the meetinghouse. This social aspect gave insight to the users' perspective of the building. This also identified any other changes these groups believed should be a priority.

The Worcester Monthly Meetings was the main focus of these interviews. This group meeting is held once a week throughout the entire year. Interviews were also arranged with MassCare, the New England Yearly Meeting and all other groups who hold meetings in the house.

Sample questions that will be asked throughout the interviews will be:

- Do you think the heating system in the meetinghouse is energy-efficient?
- Is the interior temperature appropriate and comfortable when you come to the meetinghouse during winter?
- Do you have any other comments on the current heating system?
- Are you aware of the cost to heat the meetinghouse?

- What appliances in the house do you most often use?
- How comfortable is your program with using technology and the internet?
- Do you regularly make adjustments to the thermostat during your time in the house?
- Do you believe the energy costs are reasonable for how much the house is being used?

5.6 Identifying leakages

To identify where the leakage happens, thermal photos of each window and specific parts of the insulation under the attic in the meetinghouse were taken. The thermal camera was used for taking these thermal photos. In each photo, the white and red parts have higher temperature, while the purple parts have lower temperatures. For most of the windows, where the leakage happens is purple. However, in some cases, especially for the windows in the basement, although the thermal image of the window is not purple, the window is actually in bad condition. In addition, because the color scale is auto-set, different images have different color scales. The corresponding color scale is put on the side of each thermal image.

5.7 Floor Plan

In order to show the current house design and the layout on each floor, the floor plans were drawn in AutoCAD. AutoCAD is a computer-aided design software used to draw architectural drawings. The floor plans were also used for identifying the position of the windows and doors on each floor. Each of the windows and several doors, where leakage may happen, was labelled by a letter and a number. When identifying the leakages, the labels were used.

The meetinghouse was redesigned by Dixon Salo Architects, Inc. in 2007. Three proposed floor plans for the redesign were provided by Clarence Burley, including the proposed first floor plan, proposed second floor plan, and proposed third floor plan. These floor plans were used as references to draw the floor plans of the current building. On the proposed floor plans, many parts of the house were re-designed, so the current dimension of those parts cannot be obtained from the proposed floor plans. Additional measurements were thus needed to be taken in the house in order to complete the floor plans.

No basement floor plan was available to which to refer. So, in order to complete the basement floor plan, measurements were taken and it was drawn in the AutoCAD.

After finishing the first draft of the floor plan, the meetinghouse was visited again to make sure all the dimensions on the floor plans were correct.

6. Results and Recommendations

6.1 Heating System

The meetinghouse is not occupied every day and not all of the space is used when people have an event there. Thus, installing only one zone in most of the spaces in the meetinghouse leads to overuse of energy.

Events	schedule	Room
Midweek worship	Every Wednesday, 7pm-8pm	Library (Reading room)
First-day school	Every Sunday	Classroom on the second and third floors
Meeting for business	Monthly on Second Sundays, 9:00 am	Meeting room
Worcester Monthly Meeting	Twice/week	Entire first floor
New England Yearly Meeting	Once/week	Library (Reading room)
Non-Violent Solutions	Three times/week	Library (Reading room) /Office on the third floor

(Table 10) Schedule for different meetinghouse events

To deal with this problem within the existing heating system, the main zone can be split into several heating zones in order to reduce the use of gas. There are two suggestions. The first suggestion is to divide the main zone into 3 zones. Each floor is a zone. Usually, only one floor is occupied when events are going on in the meetinghouse. The advantage of it is each floor has even temperature. So people won't feel the change of temperature when they walk though different spaces on the same floor. However, the disadvantage is, because the existing zone is split into three separate zones, the distribution system needs to be reorganized and additional piping is needed. Additional cost will occur due to the re-piping.

The second suggestion is to put multiple heating units in the offices and classrooms. The existing heating system will remain in the house and keep the house conditioned at a relatively lower temperature, around 55F, in the cold days. When weekly or monthly events are going on in the meetinghouse, instead of the existing heating system, the multiple heating units installed in the specific rooms will be turned on to warm up the space. The advantage of it is that only the heating units in the occupied rooms are turned on, so the use of gas is hugely reduce by this method. However, people may feel uncomfortable because of the temperature difference in each zones. In this case, additional heating units, such as mini-split heat pumps or portable electric radiators, will be added to the office rooms and classrooms. As a result, the initial cost for buying and installing equipment can be high and the electricity use will be increased.

6.1.1 One zone for each floor

The meetinghouse used to be a residential house. So the interior arrangement is similar to many other residential houses in Massachusetts. However, the rooms are used as offices, classrooms, and a library instead of bedrooms and living rooms. For a residential house, because of the different levels of use, we can split the heating zones into three groups. The first group is the bedrooms. The second group is the living room. The third group includes kitchen, dining room, bath rooms and hallway. The living room, kitchen, and dining area are occupied during the evenings and daytime on weekends. The bedrooms are usually occupied at night and early mornings. (United Design Associates, n.d.)

In the meetinghouse, the room occupancy is different. The house is not occupied every day. First day school uses the second and third floors on Sundays. Non-profit organizations' offices are located on the second and third floors. The first floor is used for meetings. The events are usually limited to one or two floors. Thus, dividing the current one heating zone into 3 zones is a possible solution. Instead of one thermostat, three thermostats will be used in the meetinghouse. Each of the thermostats controls each separate floor.

6.1.2 Multiple zones - Multiple heating units

Heat pump system offers an acceptable alternative option for residential heating (K.J. Chua, 2010). Its Coefficient of Performance (COP) is high and its performance has been improved a lot recently due to the use of heat-driven ejector and better compressor technology.

(Figure 15) Mitsubishi Heat Pump (outdoor unit)

(Source: http://www.mitsubishicomfort.com/en/consumer/how-it-works/advanced-technology)

(Figure 16) Mitsubishi air handler (indoor unit)

(Source: http://www.mitsubishicomfort.com/en/consumer/how-it-works/advanced-technology)

The most common and well-accepted heat pump is made by Mitsubishi Electric, a company that provides multiple heating and cooling solutions for new residential, commercial and industrial buildings and building retrofitting. The Mitsubishi M-Series Multi-zone is a recommendation for Worcester Meetinghouse. The Mitsubishi M-Series

Multi-zone heat pumps are suggested to be installed in each office room and classroom on the second and third floors and the meeting room and library on the first floor. The first day school classroom on the third floor is an exception. It will not have the indoor unit because it already has the electric baseboard installed with a controlling switch, and the baseboard works well. So it's not necessary to install the heat pump indoor unit in this room.

6.2 Programmable Thermostat

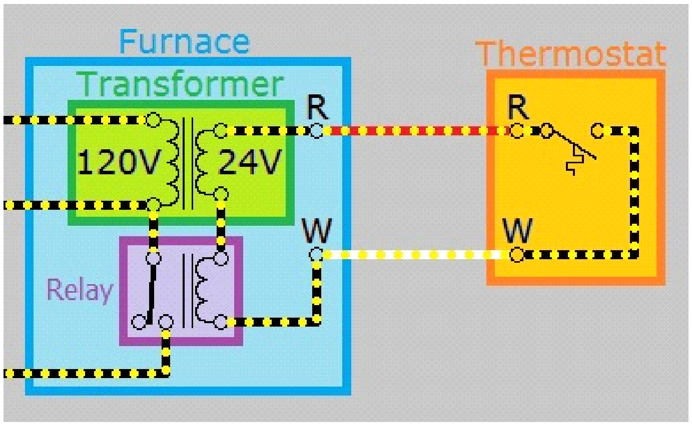
Dave Legg provided a set of requirements that a replacement thermostat for the house should meet. These included WiFi capability, a touch screen, and a one year warranty for the unit. Because the building is not used daily, it is most important that the thermostat be WiFi controllable. A WiFi option makes sense as a seven day schedule can be set and temperature can also be controlled from a remote location. Satisfying this is also beneficial to the Pleasant Street building as gas companies like NStar give out energy efficiency rebates.

The table below shows the differences between a Wi-Fi programmable thermostat and an ordinary programmable thermostat. Based on its flexibility, a Wi-Fi thermostat is suggested and one Wi-Fi thermostat has been installed in Worcester Friends Meetinghouse.

	Wi-Fi thermostat	Ordinary programmable thermostat
Cost	Roughly $200	Roughly $25-50
Advantages	1) Remote control 2) Very flexible temperature setting options	1) Inexpensive 2) 2 programs for weekdays and and weekends 3) 4-6 periods per day
Disadvantages	Expensive	Limited temperature setting options
Example	Wi-Fi VisionPRO Thermostat $149.99	Honeywell Home/Building Center RTH2300B1012 5/2-Day Programmable Thermostat $25.25

(Table 11) Comparison of Wii-Fi thermostat and Ordinary programmable thermostat

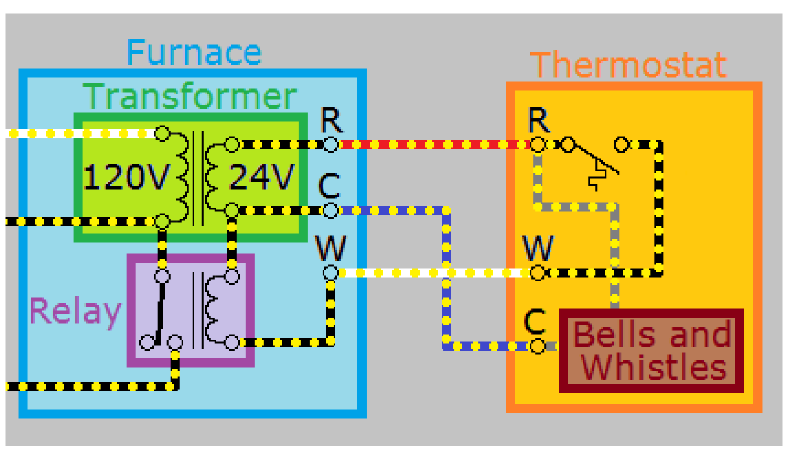
After analyzing several options, a thermostat that would be a good fit was selected for the meetinghouse. This original thermostat choice was the Honeywell VisionPRO (~$300 list price). This is a high end model and is expensive as it is compatible for up to three heating and two cooling zones. The major obstacle with implementing the thermostat in the building dealt with the outdated heating system. The boiler in the house was configured to only use R and W wires. The R wire is the 24V AC input that is stepped down from the 120V AC wall power through a transformer. This provides power to the thermostat while the W wire goes to the relay switch to control heat. When the relay closes the circuit completes and the boiler turns on. Conversely, when the relay switch is open the boiler is off and not being called. (Fig 15) below visually demonstrates this concept.



(Figure 17) Wiring Setup for 2 Wire Heating System

However for the WiFi thermostat to be operational, it needed a C wire, or a 24V AC ground to constantly provide power to the thermostat (completing the 24V loop from the transformer). This C wire needed to run from the 24V AC ground of the transformer to the C terminal on the back of the thermostat. (Figure 18) below visually shows the placement of this wire.

Adding this C wire involved purchasing a new electrical wire pairing for a few dollars. It was decided that buying a wire pair was preemptive as if an additional wire is needed in the future it will be readily available. The C wire was not easy to implement as the boiler is outdated and does not have a printed circuit board with labeled terminals. In an attempt to get this AC common voltage, one end of the C wire was connected to the back of the thermostat and the other to the 24V AC ground from the ignition circuit. This was done using a two to one wire connector to add this new wire into the terminal already containing the ground wire from the ignition stage. The picture below (Figure 19) shows terminals of the ignition circuit including 5 the 24V AC ground.



(Figure 18) Wiring Setup for 3 Wire Heating System

(Figure 19) Ignition Stage Terminals

Running the C wire to the ignition stage seemed feasible from an electrical standpoint as the two wires were terminating at the same node. However when installation of the VisionPRO was attempted, it was unsuccessful. The thermostat was returned to the store as its connections were flimsy and possibly broken. A new thermostat, the Honeywell RTH8580WF, was purchased and successfully installed on December 16, 2013. It was about a hundred dollars cheaper as it is less versatile and cannot control multiple heat pumps. The thermostat can only provide conventional heat as currently in the meetinghouse or heat from a single heat pump. This does not cause a problem with the current setup of the house and still met the requirements set by Dave.

(Figure 20) One group members with energy expect David Legg

The installation of the RTH8580WF required some troubleshooting to come up with a new method. The proposed idea of wiring the C wire to the ignition stage 24V ground was not effective as the thermostat failed to turn on. After going through various manuals and guide videos with Dave, it was found that it may be possible to get this ground directly off of the transformer (120V to 24V step down). Dave had initially tried this and demonstrated how he connected the R, W, and C wires. The reason the thermostat was not receiving power was because he had the R wire and W wires connected to the transformer on the boiler controlling the relay switch. He connected a wire to the wall transformer common in an attempt to make a C wire. This did not work because the R and C wire loop was never complete and the two transformers were never interacting. To fix this the R and C wire were moved to the 24V AC hot and 24V AC common sides of the wall transformer. These efforts proved valid and when the power was turned back on, the thermostat display lit up. The current schedule for the meetinghouse thermostat is listed in the table below. Note that the wake, leave, and return times are slightly different on Sundays due to hours of worship and more activity.

State	Time	Sun	Mon	Tues	Wed	Thurs	Fri	Sat
Wake	7am	64 (8am)	64	64	64	64	62	62
Leave	8am	69 (9am)	67	67	67	67	64	64
Return	5pm	60 (3pm)	60	60	60	60	60	60
Sleep	10pm	62	62	62	62	62	62	62

(Table 12) Weekly temperature schedule for WiFi thermostat

At this time, the WiFi connection is still being set up as the thermostat was missing the registration card in the box. Because of this, the temperatures (in degrees Fahrenheit) in the table above do not vary much unless someone is in the house and sets a manual hold. The best way to analyze the effect of replacing the thermostat is to compare future bills to ones previously collected. Although some data of heat usage was collected in the background section, various groups in the house have been contacted in search of old bills. Comparing bills from before and after the thermostat installation will allow the groups to see if in fact there were any benefits. As seen in the Massachusetts case study, if those using the house turn up the heat comfortably warm or use the thermostat incorrectly, they may end up paying more on their heating bills than before. This is a concern as one evening Dave arrived at the meetinghouse to find it empty but with a temperature hold at 72 degrees. If he had not cancelled this hold, (as the person who set it should have when they left) a significant amount of energy would have been wasted heating the house. In order to inform the groups of how to properly use the new thermostat, a concise user guide was placed next to it. Hopefully, this will prevent mistakes of overheating or accidently messing up the schedule.

6.2.1 Suggested WiFi Thermostat Control

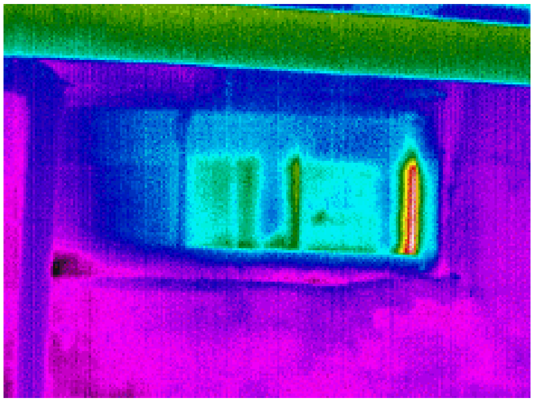
Although the Honeywell RTH8580WF model was installed, it is not the ideal thermostat for optimal energy efficiency. The idea of installing this thermostat was to increase the current efficiency in the house as the current programmable thermostat did not function properly. Also changing the current heating system in the home will take considerable time, money, and work. The suggested setup is outlined in the heating section above and includes implementing three zones, one for each floor. Additionally heat pumps are suggested to control the temperatures for different rooms on each floor. The RTH8580WF thermostat is only capable of controlling one pump and so the Honeywell VisionPRO would be the best choice. Using three of these, one per floor, would allow for more programming and heating options to control comfort and energy usage. The VisionPRO is the optimal solution as it is compatible with any type of residential heating system that uses at least three wires.

6.3 Windows

Since the thermal imaging camera was obtained, the candle and flashlight methods were unnecessary to our project. This camera will provide far more detail and accurate data collection than the other methods.

Images of each window in the meetinghouse were taken. It was assumed that each window group would have the same issues, however, it was important to test the windows individually to see if wear was a factor.

The small basement windows were relatively similar. They all had significant heat leaking from the thin inner pane as well as heat leaking from the wooden frames. An example of these windows is shown below.



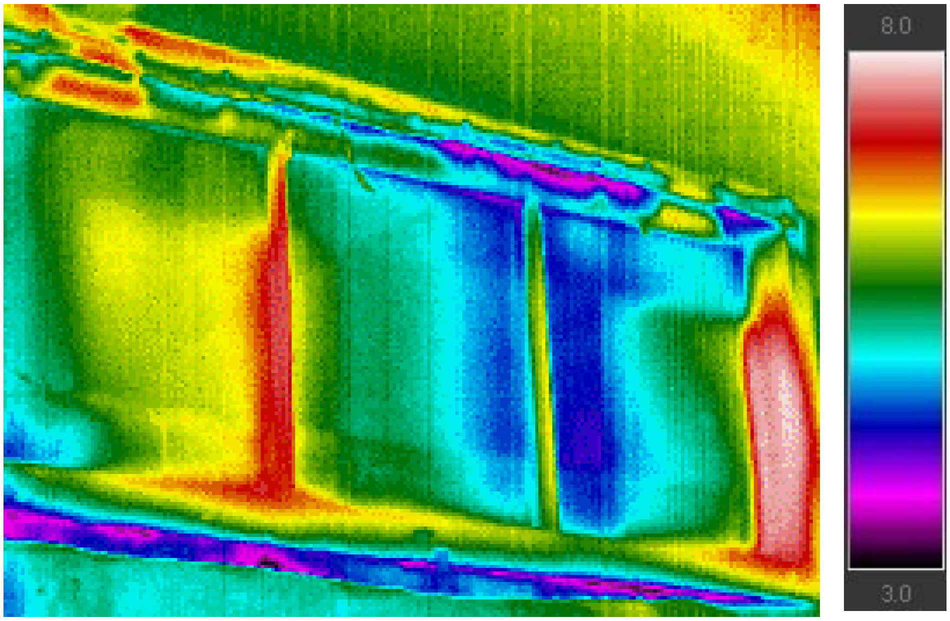

(Figure 21) Window B-8

To counter the thin frame, the best method would be to use the 3-M home solution window covering. This method will act as a second pane which we help present heat loss through the glass. To remedy the cracks in the window frame, caulking can be applied to seal the wood and prevent heat from leaking outside

To gain a better understanding of how significant the heat leakage improvement would be as a result of our recommendation, we decided to carry out one of the tests and compare the conditions before and after.

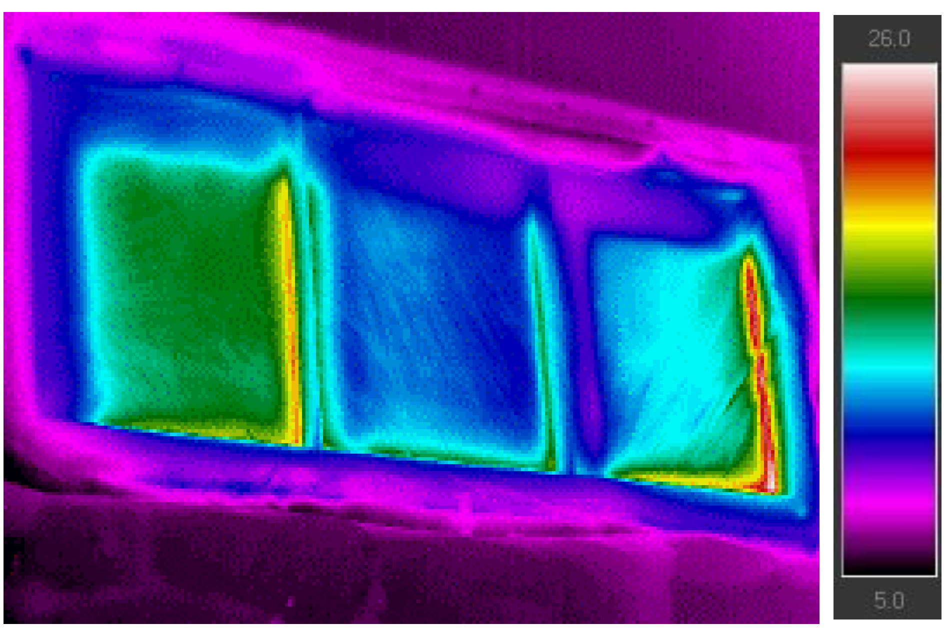
(Figure 22) Window B-11

To window B-11, the 3-M home solution was applied. After applying double-sided tape to the window frame, a thin plastic film was used to cover the entire window. Afterwards we used a hair dryer to tighten the film.



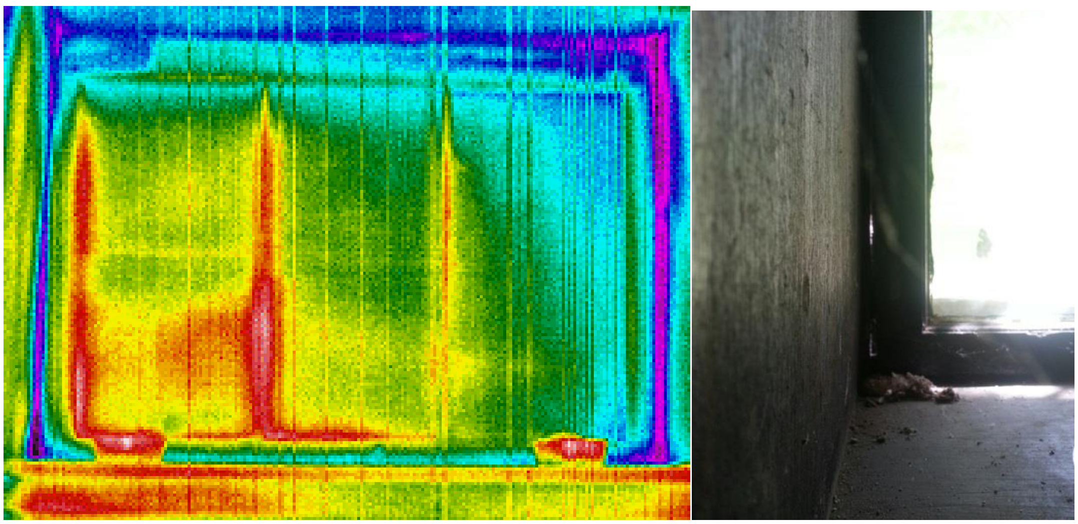
(Figure 23) B-11 before plastic application

Before the 3-M solution was applied, it was apparent that the right glass pane of the window (Figure 23) was much colder than the inner wall. After examination, it became obvious that the outer glass pane was fractured. This crack allowed cold air to enter the window system and cool down the inner pane. This eventually led to severe heat loss through that area.



(Figure 24) B-11 after plastic application

After the application of the plastic film, the heat loss through the window had dramatically decreased. The thermal image now shows that the glass panes are warmer than the inner wall. Since heat leakage through the windowpanes is common in the meetinghouse, this method could prove effective when applied to all basement windows. However, the 3-M home solution did little to prevent heat leakage through the wooden frames.



(Figure 25) Window B-1

Window B-1 (Figure 25) shows a window with heat leakage through the wooden frame. The small cracks in these windows are a significant factor in heat loss and the 3-M solution would be little to remedy this. For this window, it is recommended to use caulking around the frame. However, a professional should be contacted before anyone in the meetinghouse attempts to use this method. Improper caulking can allow water to enter the cracks. When the weather gets colder this water freezes and expands which leads to potential window damages.

Moving forward, a similar analysis process should be carried out for each window in the house following the methods described in this section. After analyzing the problem areas with each window, a recommendation should be made using the information found in section 3.4.

6.4 Insulation

The meetinghouse's insulation is out of date and demonstrates a relatively low R-value due to the lack of maintenance. Eave one's existing material is an Owen's Corning Fiberglass Building Insulation with Reflective Aluminum Foil to seal the bays shut. This is done in order to stop the fiberglass from traveling around the air space and prevent exposure to the lungs. The rips and tears in the foil of every bay in eave one need to be attended to or replaced so that further health risks are significantly reduced.

This figure shows the R-values of the current insulation in the home. Using the measurements taken—19-¼'' width, 96'' height and 6-¼'' depth—the equivalent material is in the first row of the Roof/Ceiling Construction section with an R-value of 19. The R-value when measured per inch is 3.04, but because the insulation is so damaged in all 16 bays of Eave 1 in the meetinghouse that the condition of the insulation will impact the R-value, significantly decreasing it's value and overall effectiveness.

Technical Data

R-value	Width			Length		Thickness
Metal Frame Construction						
13	☐ 16"/406mm	☐ 24"/609mm			☐ 96"/2438mm	3½"/89mm
15	☐ 16"/406mm	☐ 24"/609mm			☐ 96"/2438mm	3½"/89mm
19	☐ 16"/406mm	☐ 24"/609mm		☐ 48"/1219mm	☐ 96"/2438mm	6¼"/159mm
21	☐ 16"/406mm	☐ 24"/609mm			☐ 96"/2438mm	5½"/139mm
Wood Frame Construction						
11	☐ 15"/381mm	☐ 19¼"/488mm*	☐ 23"/584mm	☐ 93"/2362mm	☐ 105"/2664mm*	3½"/89mm
13	☐ 11"/279mm*	☐ 19¼"/488mm*		☐ 93"/2362mm		3½"/89mm
13	☐ 15"/381mm		☐ 23"/584mm*	☐ 93"/2362mm	☐ 105"/2664mm	3½"/89mm
15	☐ 15"/381mm		☐ 23"/584mm	☐ 93"/2362mm	☐ 105"/2664mm*	3½"/89mm
19	☐ 15"/381mm		☐ 23"/584mm	☐ 93"/2362mm	☐ 105"/2664mm*	6¼"/159mm
19		☐ 19¼"/488mm		☐ 48"/1219mm		6¼"/159mm
21	☐ 15"/381mm		☐ 23"/584mm	☐ 93"/2362mm		5½"/139mm
Roof/Ceiling Construction						
19	☐ 15"/381mm		☐ 23"/584mm	☐ 48"/1219mm	☐ 93"/2362mm	6¼"/159mm
19	☐ 16"/406mm	☐ 19¼"/488mm	☐ 24"/609mm	☐ 48"/1219mm	☐ 96"/2438mm	6¼"/159mm
22	☐ 15"/381mm	☐ 23"/584mm*	☐ 24"/609mm	☐ 48"/1219mm*		6¾"/171mm
25	☐ 15"/381mm		☐ 23"/584mm*		☐ 96"/2438mm*	8"/203mm
25	☐ 16"/406mm	☐ 19¼"/488mm	☐ 24"/609mm		☐ 96"/2438mm	8"/203mm
30	☐ 15"/381mm		☐ 23"/584mm*	☐ 48"/1219mm*		9½"/241mm
30	☐ 16"/406mm	☐ 19¼"/488mm	☐ 24"/609mm	☐ 48"/1219mm		9½"/241mm
30C	☐ 15½"/394mm		☐ 23¾"/603mm	☐ 48"/1219mm		8¼"/209mm
38	☐ 16"/406mm		☐ 24"/609mm	☐ 48"/1219mm		12"/305mm
38C	☐ 15½"/394mm		☐ 23¾"/603mm	☐ 48"/1219mm		10¼"/260mm

* limited geographic offering.

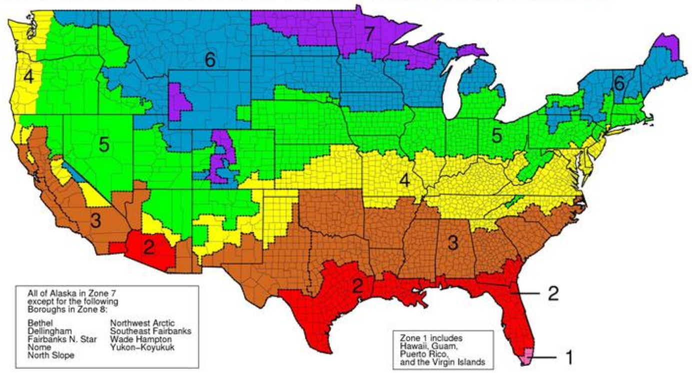
Unfaced Thermal Batt Insulation complies with the property requirements of ASTM C 665, Type I and ASTM E 136.

(Figure 26) R-Value for Different Construction Parameters

(Source: http://www2.owenscorning.com/comminsul/documents/insulation%20specification%20technical%20data%20guide.pdf)

The square footage per bay is 12.8 square feet and for the entire eave, 192 square feet. Based on the research, a feasible replacement for the eave would be using a polyisocyanurate board and fiberglass batt insulation combination. The fiberglass insulation is R-38, Owen's Corning EcoTouch Kraft Batts in Bag Insulation offered from Home Depot. For the 192 square feet, 5 bags need to be purchased at a total of $238.90. The insulation along has an R-value double that of the previous insulation which is only R-19. The R-value of the new insulation would be is 3.20 per inch vs. the damaged insulation with an R-value of 3.04 when in brand new.

Recommended insulation levels for retrofitting existing wood-framed buildings



Zone	Add Insulation to Attic		Floor
	Uninsulated Attic	Existing 3–4 Inches of Insulation	
1	R30 to R49	R25 to R30	R13
2	R30 to R60	R25 to R38	R13 to R19
3	R30 to R60	R25 to R38	R19 to R25
4	R38 to R60	R38	R25 to R30
5 to 8	R49 to R60	R38 to R49	R25 to R30

Wall Insulation: ***Whenever exterior siding is removed*** on an

Uninsulated **wood-frame wall:**

- Drill holes in the sheathing and blow insulation into the empty wall cavity before installing the new siding, and
- Zones 3–4: Add R5 insulative wall sheathing beneath the new siding
- Zones 5–8: Add R5 to R6 insulative wall sheathing beneath the new siding.

Insulated **wood-frame wall:**

- For Zones 4 to 8: Add R5 insulative sheathing before installing the new siding.

(Figure 27) Recommended Insulation Levels for Different US Zones

(Source: http://www.energystar.gov/?c=home_sealing.hm_improvement_insulation_table)

Following the insulation layer, a 1 inch polyisocyanurate Dow insulated sheet will cover the bays in order to prevent further heat and energy loss. With an R-value of 6.5 per inch, the insulated barrier will provide the necessary adjustment for the attic to be extremely energy efficient. The polyisocyanurate has the highest R-value per inch of any material offered. To cover the 192 square feet, 6 boards must be purchased at $25.26 per board for a total of $151.26. These corrections will put the R-value of the attic at R-44.5, which falls in with the recommended insulation levels for retrofitting existing wood-framed buildings (figure below). For $390.46, the homeowner can improve his/her energy efficiency by over double (2.34) the current condition. This change increases the R-value of the roof by using a new and improved R-45 insulation combination compared to the current below average and damaged R-19 insulation.

A “do it yourself” home energy audit was completed by Jeffery Adams, a home specialist and contractor, and Johnathan Adams, a member of the project team. Major areas of focus are air leaks, ventilation, insulation, lighting, and appliances/electronics (Do-It-Yourself). During the walkthrough of the home, there were leaks in the windows on the first, second and basement floors. For the above ground sections of the home, a suggested way to save on energy costs is covering the windows in a plastic wrap in order to prevent the air from entering/escaping. The potential energy savings from reducing drafts in a home may range from 5% to 30% per year (Do-It-Yourself).

The ventilation in the home is relatively up-to-date for the heating system, but there are backdrafts throughout the home. An easy way to fix this is to put door stops/jams at the bottom of doors in order to prevent heat from escaping the rooms on the second and third floor that are used more often. Also, removing objects away from the radiators and baseboard heating systems will allow for better airflow throughout the meetinghouse.

The insulation in the home is sub-par, with a large number of damages on the attic and basement levels. In the basement, the foundation has holes that can be quickly fixed to allow for a more insulated groundwork. These can be filled with spray foam and then covered by a piece of foam board insulation to better protect the home from air leakage and heat loss. In the attic, the best recommendation that can be made after research is the combination of fiberglass batt insulation with a polyisocyanurate board that has an R-value totaling at 44.5. It is recommended that the walls be further examined in order to better understand the type of insulation that is used and how to properly update that portion of the home. The walls were a lower priority when observing the house because there was no damage that indicated a large amount of heat was lost to that portion of the home and any changes would not be quick or cost-effective when upgrading the home.

Energy for lighting accounts for about 10% of the electric bill (Do-It-Yourself). The lighting of the home could be changed to incorporate new efficient bulbs such as energy-saving incandescents, compact fluorescent lamps (CFLs), or light-emitting diodes (LEDs). The appliances and electronics of the home can account for large amounts of energy being used when not properly monitored. For example, the refrigerator is old and uses large amounts of electricity. A few methods are recommended in order to save on energy usages including: unplugging an item when it is not in use to prevent phantom loads, changing the settings or using the item less often, or buying a new more energy efficient appliance. The latter of the three is an expensive, but short-term way to fix the problem.

6.5 Interviews

A list of the different groups who use this space were provided by Clarence Burley, Corresponding Clerk of Worcester Monthly Meeting. The plan was to schedule face-to-face interviews with each leader of the organization to get the answers needed in a conversation type format. However, these interviews were difficult to schedule with many leaders of the organizations. As a result, many of the interviews were done over the phone making the process much easier for the non-profit groups

The first problem arose when trying to contact John Blanchard of Masscare. Masscare is a company run out of Boston. This organization holds meetings in Worcester only once a month. As a result, they are not as invested in the potential changes of the house as many of the other organizations. After failing to speak with John at the Boston office, a phone interview was proposed but the organization was not interested. Since the organization only meets in the house once a month, it was more important to focus on the preferences of the other non-profit organizations anyways.

Afterwards, Christa Drew from the center of Non-violent Solutions was contacted. Christa explained that her organization uses the meeting space three times a week, which makes the needs of her organization very critical to the project. When asked how frequently her organization uses the thermostat, she seemed confused and responded that she never knew the thermostat was available to her. She also informed us of her concern for the exposed pink insulation on the ceiling of the third floor office space. This insulation is not currently harmful to the users but could potential cause health issues in the future. Moving forward, we recommend sealing off this insulation with sheetrock or removing the pink insulation completely and replacing it with a new product.

Next Jeff Hipp from Worcester Yearly Meeting was contacted. Jeff's organization meets once a week and mentioned that his needs were not very high. However, he seemed enthusiastic about the Wi-Fi thermostat and explained that his organization is comfortable with newer technology. He also asked why the second floor was always much warmer than the first and third floors. Since the answer to his question was unknown, it was decided that the heating system of the meetinghouse needed to and identify if different heating zones are present.

Finally, an interview was scheduled with Clarence Burley of the Worcester Monthly Meeting. Clarence explained that the group holds meetings twice a week but rarely make any changes to the thermostat. He expressed that it would be very helpful to find a more organized way to set the temperature before and after each group leaves the house. Unlike the other organizations, the Monthly Meeting holds a potluck lunch every Sunday. As a result, the dishwasher and stove are used very frequently.

Organization	Non-Violent Sol.	Yearly Meeting	Monthly Meeting
Meeting Frequency	Three times/week	Once/week	Twice/week
Appliances Used	Microwave rarely	Microwave rarely	Stove/dishwasher frequently
Thermostat Use	Never	Rarely	Rarely
Wi-Fi thermostat	Interested	Very enthusiastic	Very enthusiastic
Rooms used	Library/3rd Floor	Library	Entire 1st Floor
Storage space	Poorly insulated closet	Basement	No storage
Other concerns	Not all floors need to be heated all day	Needs not high	Difficult to turn off thermostat when leaving

(Table 13) Interview Comparison Summary

Following the interviews, the needs of these organizations become clearer. The Wi-Fi thermostat would prove to be a critical part of the project. Due to the limited availability of the current thermostat and the organization's comfort level with technology this seemed like a perfect fit for the meetinghouse. Another goal was to provide the Center for Non-Violent Solutions with a detailed plan and cost analysis to improve the quality of their office space. The final aspect to determine was the different heating zones of the meetinghouse and identify what changes can be made to use the energy more efficiently.

7. Conclusion

This project's purpose was to evaluate the current heating system, window condition and insulation system in the meetinghouse and give recommendations for improving the current house conditions and reducing energy use. Before doing analysis, research was done on the heating system, insulation materials, window types and thermostats to understand the building mechanical system. Extensive researches helped to broad the project's scope and build the project's background on the building mechanical systems. The meetinghouse currently has many energy issues including that the heating system is not efficient, some of the windows are in bad conditions and the original thermostat was broken. Not only was the energy condition of the meetinghouse analyzed, but also some work was done to improve the efficiency of the building and reduce leakage.

- A new WIFI-programmable thermostat was set up to replace the broken one and the temperature was set up according to the weekly event schedule.
- A 3M Home Solutions Window Insulator kit was installed in one of the basement windows.
- Updated floor plans were drawn to facilitate the understanding of the layout of the house.
- Areas of leakage were identified by thermal camera.

After analyzing the house from the heating, insulating, window, and thermostat, it is recommended to split the meetinghouse into three heating zones, use the WIFI-programmable thermostat to schedule the temperature, replace the windows in bad conditions and keep tracking of the gas bills and electricity bills which regularly update the fuel and electricity use in the meetinghouse.

For the residential houses in the cold weather area, here are some general recommendations which will help people to understand their home heating system's performance and help them to improve their house's energy efficiency.

1. Install high-efficient heating system. The gas-fueled heating system generally has a higher AFUE rating. Boilers or furnaces are recommended for residential heating.
2. Split the house into several heating zones, which will reduce the gas and electricity used by the heating system.
3. Use programmable thermostat by setting a temperature schedule to save energy.
4. Keep the temperature in the basement not lower than 55F to make sure the heating system located on basement works well and the pipes that carry hot water and steam won't break due to low temperatures.
5. Make sure the roof, wall and floors are well insulated so the heat loss is minimized.
6. Keep tracking of the gas bills and electricity bills to get a better understanding of the current situation of energy use.
7. Use double-pane or triple-pane windows that have a higher R-value to reduce heat loss.

Following the completion of this project, a poster will be made to summarize all of the data, analysis and recommendations. The poster will be displayed near the entrance of the meetinghouse. This will accurately display the current condition of the meetinghouse to its users. This will also stress the need for retrofitting of the building's energy efficiency as well as offer a guided plan for future improvements.

8. Acknowledgements

Clarence Burley -- Corresponding Clerk, Worcester Monthly Meeting

David Legg -- Energy Specialist

Jeffrey Adams – Contractor/Consultant

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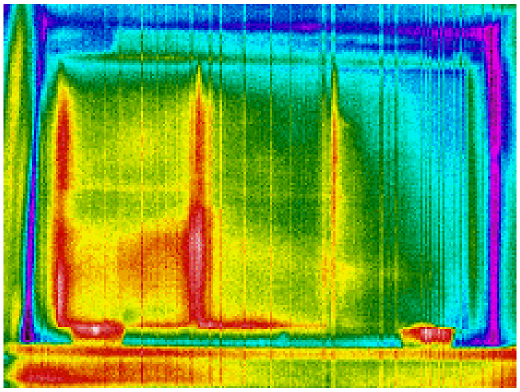
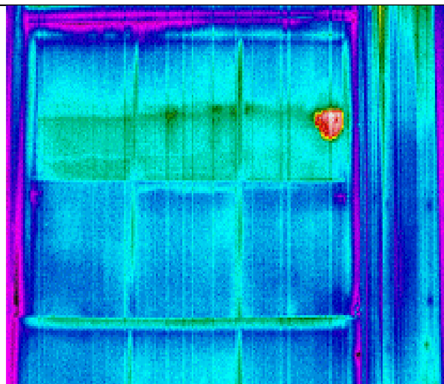
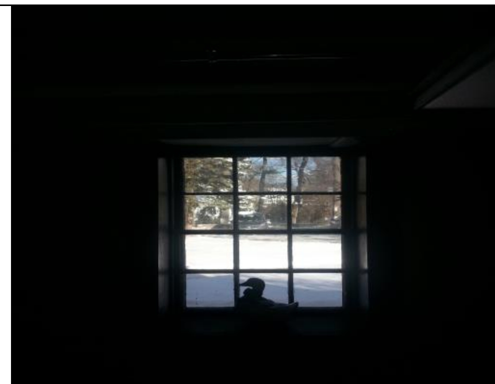
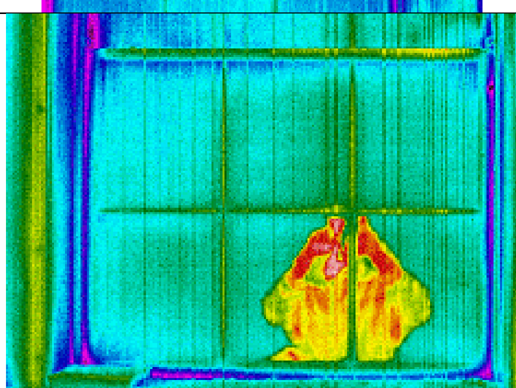
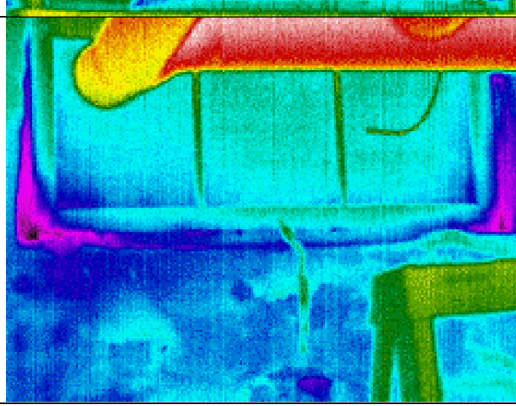
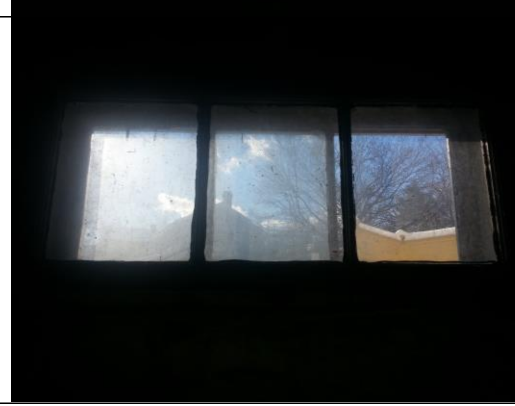
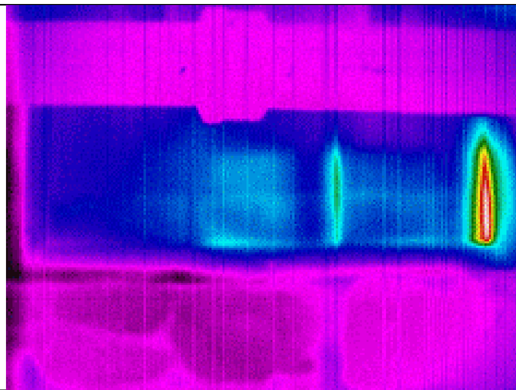
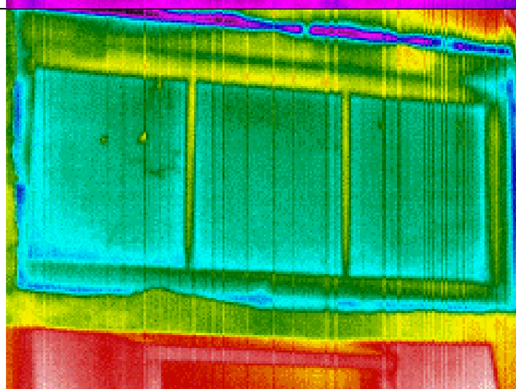
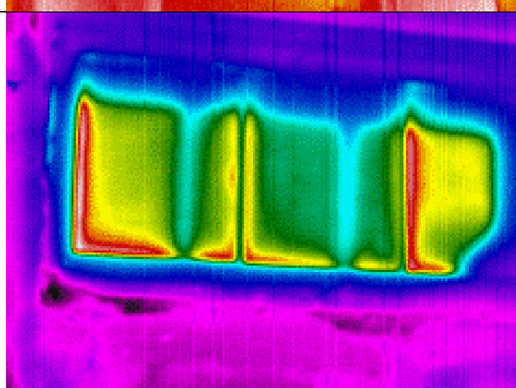
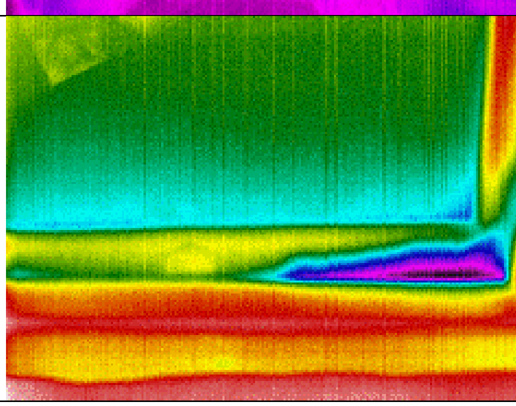
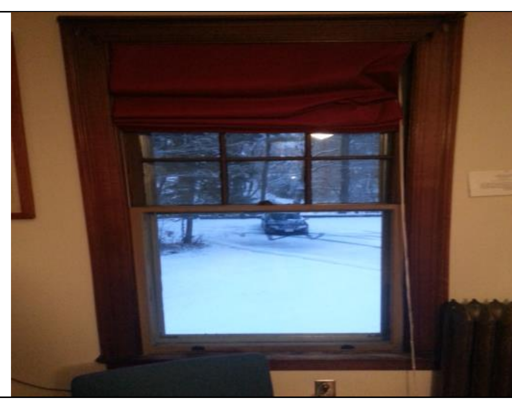
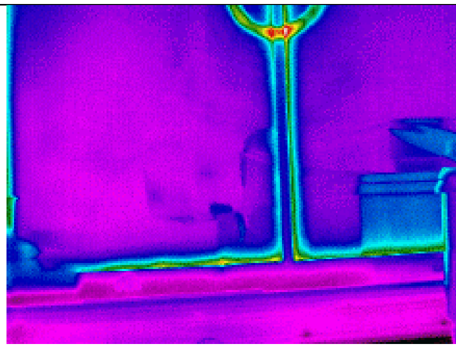
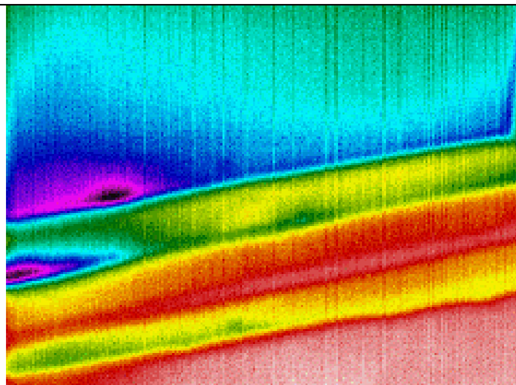
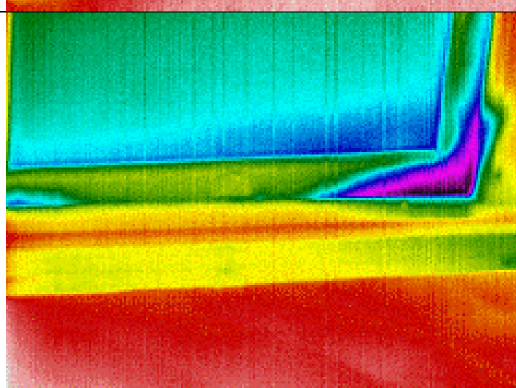
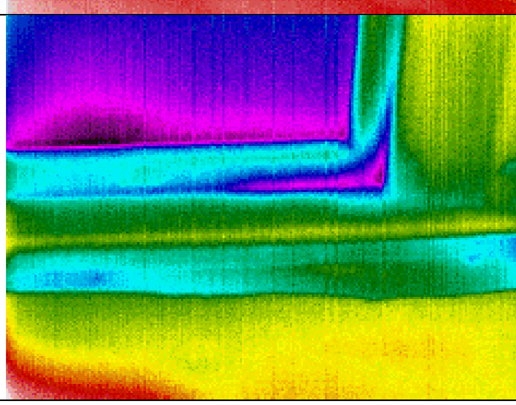
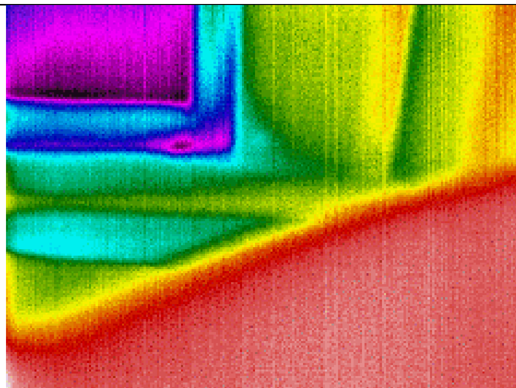
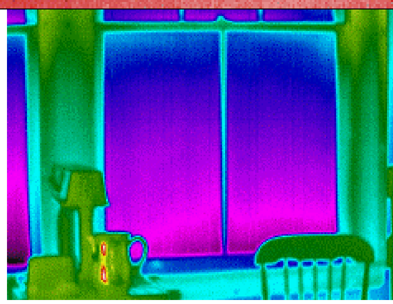
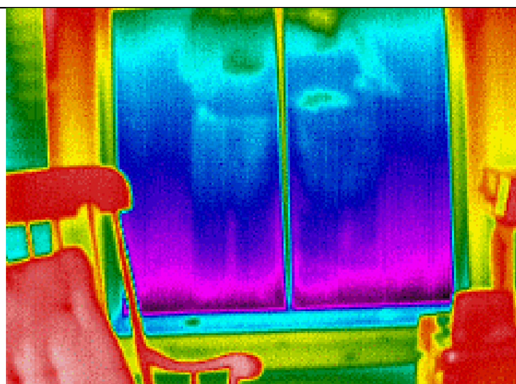
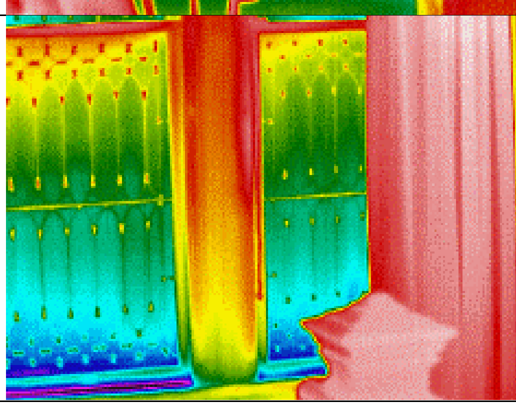
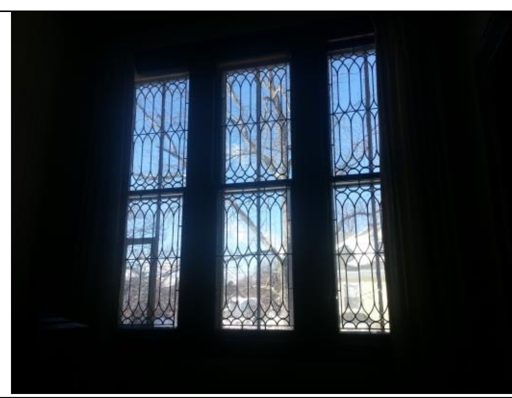
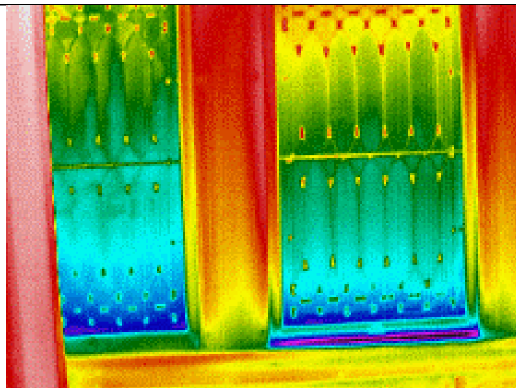
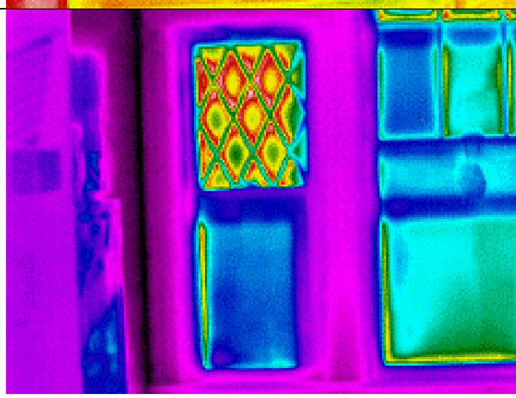
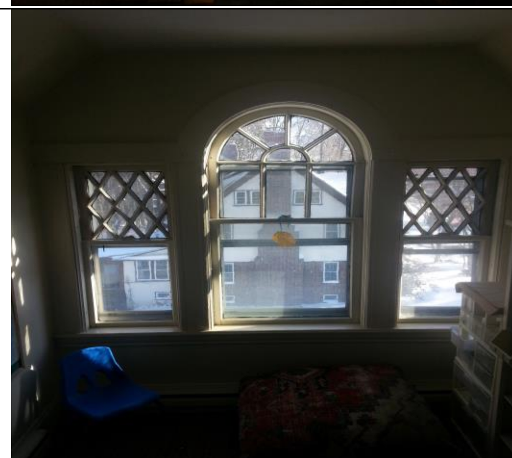
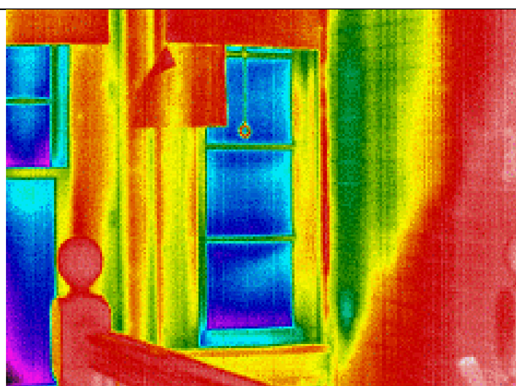
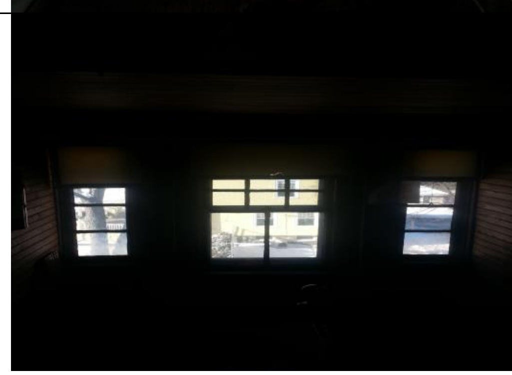
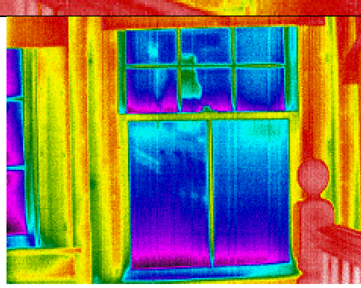
10. Appendix

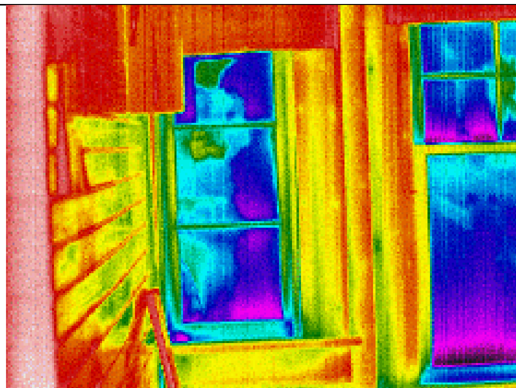
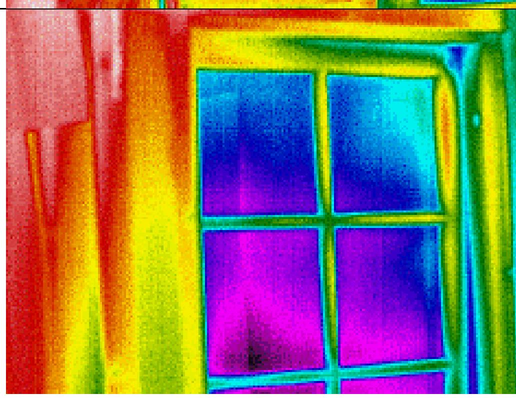
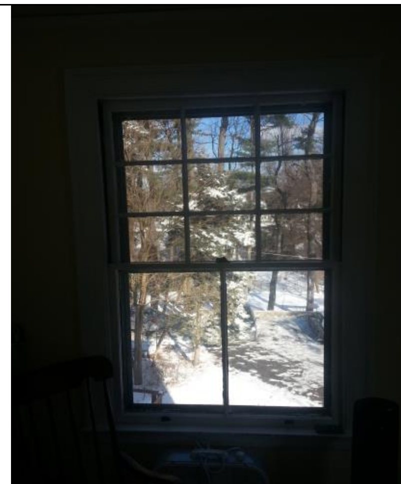
B1		
B2		
B3		
B7		

B9		
B10		
B11		
F2		

F3		
F6		
F14		
F15		

F16		
S4		
S5		
S10&S11		

S11&S12		
T4		
T5		
T6		

T7		
T8		
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