Improving Comfort and Efficiency of WPI's Ailing Buildings

An Interactive Qualifying Project submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science

Submitted by:

Christopher Schuster
Michael Giles
Jordan Lopez

Submitted to:

Project Advisors:

Prof. Scott Jiusto
Prof. Fabio Carrera

Table of Contents

Table of Figures

Table of Tables

Chapter 1: Introduction

Many college campuses around the United States are taking steps to not only ensure the sustainability of their buildings, but also to reduce costs to both themselves and the environment. With university residencies housing thousands of students for the greater part of the year, savings through sustainability can add up to impressive numbers through the years, contributing significantly to the movement to a greener, more

Figure 1: An Overhead view of the WPI Campus (Source: http://www.wpi.edu)

environmentally conscious society. As students attend college and live in a more sustainable environment, they will carry the values of this movement with them and become the forefront of further environmental changes.

One would think that Worcester Polytechnic Institute, a university focusing on science and technology, would be at the forefront of such important changes. While certain strides have been made to improve energy efficiency on campus, specifically the LEED-certified Bartlett Center and upcoming residential dorm on Boynton Street, many old buildings are still lagging behind current technology in terms of energy efficiency and environmental friendliness. If WPI wishes to save money and protect the environment, they need to renovate their older buildings to compare with the new technology and sustainability of more recent additions to the campus.

One area where WPI can continue to work towards a greener, more efficient campus is in the Ellsworth, Fuller, and Stoddard residences. These particular buildings have been run on electric baseboard heat since their construction in the 1970’s. At the time, electric heating may have been a short term, economically sound option, but today this is not the case and unnecessary cost of the system both monetarily and environmentally is unacceptable. Not only is electric heat more expensive than Natural Gas and Fuel Oil, it releases greenhouse gasses which damage the atmosphere over twice as much than either of the aforementioned fuels.

The goal of this project is to fully analyze the electric heating systems of Ellsworth, Fuller, and specifically the Stoddard complex, and to find the most feasible path to making them as efficient as possible. This project will have a positive financial impact on WPI's energy costs and will also benefit the greater environment. Changing the envelope of the buildings by adding insulation and sealing the building against air leaks are cheap and effective ways to improve heating efficiency. Better thermostatic control and response times among other adjustments can lead to a more user friendly heating system. The most important change to make will be to change the current electric system to an alternative one which will greatly improve the energy efficiency and reduce the impact on the environment.

Figure 2: Fuller Apartments, One of WPI's Many Residence Halls (Source: http://www.wpi.edu)

Globally, there have been many initiatives to improve the environmental friendliness and efficiency of buildings. Many guides, like LEED, Energystar, and NESEA, as well as guides of a much more local scale have laid the groundwork for people less knowledgeable about green buildings to improve the quality of living in their buildings. In addition, contractors have expanded and begun to offer green alternatives, such as green roofs and environmentally safe insulation materials, to customers wishing to build or renovate their homes and buildings.

Currently, WPI is making strides to produce more energy efficient and green buildings by following the LEED certification guide in the construction of new buildings. As of 2007, the Bartlett Center has earned a LEED silver medal, while the new residence hall is on track for a silver medal as well. Despite these advances, however, WPI has many buildings that lag behind the current standard for efficiency. Many old buildings, particularly the Stoddard Complex, have required renovation for many years and their energy bills sap the university's funds annually. If WPI truly wishes to increase productivity of the campus, improving upon the antiquated buildings would be the logical next step.

In order to renovate WPI's older buildings, there needs to be a guide for how to accomplish such an undertaking. In order to facilitate its development, we outlined the cost for renovations on the energy efficiency of the Stoddard Complex's heating system. The first and foremost change to these buildings would be to improve the envelope of the building through different insulation techniques. By lowering the heat loss of each individual building, less energy will be expended heating residents. The new heat loss will then allow for a new heating system to be installed, preferably a natural gas or oil boiler that is both more cost-effective and also releases less greenhouse gases. Finally, by improving the user interface and allowing the residents more control of their own heating, we can maximize heating efficiency in the Stoddard Complex.

Furthermore, by creating a building renovation guide, more campuses and companies will be willing to pursue a green renovation with a blueprint already laid out to follow. These repercussions will only multiply as each new renovator adds their experience and advice to said guide, which will create a positive-feedback loop to urge others to renovate as well.

Our project team has calculated a heat loss for Ellsworth, Fuller, and Stoddard in order to determine both what kind of insulation is currently present as well as estimate the size of a boiler and its installation costs. In order to determine costs for both insulation and heating system, we contacted Mike Bafaro from the heating company J. J. Bafaro, who gave us an estimate as well as some suggestions regarding how to go about renovating the Stoddard Complex. Also, to make sure the heating system is comfortable as well as efficient, we surveyed the residents of Ellswoth, Fuller, and Stoddard to determine their general disposition regarding the current heating system, as well as any changes they would like to see in a new system. These results and suggestions were factored into our final judgment regarding the changes to make in the Stoddard Complex.

Chapter 2: Background

This project will show the extensive amount of work that was performed before we could begin making recommendations to the school. We needed to learn how the heating system in Ellsworth, Fuller, and Stoddard works, as well as the many different alternatives we could consider. We wanted to look at the entire envelope of the buildings, and research ways to fix the heating systems at every level, including windows, doors, and the heating system itself. We also did research into the user functionality portion of heating systems. We also looked at various green guides to find ideal remodeling solutions.

Green Guides

With builders and clients beginning to look at creating more sustainable facilities, more and more guides and systems are being created to help standardize this approach. The combination of increasing fuel costs and a growing environmental problem provides businesses with not only a monetary motivation but a great public relations motivation as well. Along with this increase in demand for sustainable building comes a responsibility to gauge just how "environmentally sound" a particular building really is. For example, if a company simply creates their own set of codes and makes a building according to them, it may be very lagging compared to a different standard. In order to be able to convey to the public the level of efficiency and environmental care that was taken in the building of a facility and to know exactly what about the building is efficient, a common, well know and readily available standard needs to be created. In the United States, the

U.S. Green Building Council has created the Leadership in Energy and Environmental Design Green Building Rating System (LEED) for this very reason.

LEED has become the standard for sustainable building for many federal, state, and local government buildings and is commonly used by the building community at large as a benchmark for creating energy efficient and environmentally sound buildings. Its primary function is to rate buildings based on a point system that is constantly refined and open to change based on overall consensus. LEED also has off-shoots that address various types of construction projects. There is LEED for New Construction which deals with primarily commercial and institutional areas and has a particularly good application to office style buildings. The LEED for Existing Buildings guidelines create a good framework to renovate an existing building and bring it up to LEED standards with respect to energy usage, water usage, indoor air quality, and lighting performance.

Figure 4: LEED Gold Symbol (Source: www.usbgc.org)

Figure 3: LEED Symbol (Source: www.usbgc.org)

The LEED rating system uses points to reward particular aspects of a building's performance and recognizes five particular areas to rate a building by. These areas are; sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality. For example, under the LEED for Existing Buildings (LEED-EB), an increase in ventilation will result in the project gaining one point. Points are added up for improvements to all aspects of the building and an over all rating for the project is given. To be a LEED certified building, a project must obtain 32-39 points, for a Silver rating, 40-47 points, for a Gold rating, 48-63 points, and for a Platinum rating, 64-85 points. In order to be approved by the Green Building Council and receive a LEED plaque with an official rating, builders must register their project with the Green Building Council in the initial stages of construction or renovation. A LEED Accredited Professional is usually utilized as a contact person for the project and official documentation chronicling the progress of the project must be provided. Once a project is finished, the points received from all the verified aspects of the building are added up and an official rating is given. If a building holds up to LEED standards, it reflects very well on the business or institution it represents.

In general, the standards and points rating system created by LEED have approved by the building community at large as well as institutions like Harvard University and the Massachusetts Institute of Technology. There is however some universities against a LEED like system for various reasons. Stanford University for example developed their own set of standards that is quite different than LEED. The committee that created the standards stated that some aspects of the point system are flawed. They sighted the fact that under the LEED system, points are awarded for having an efficient air conditioning system, but no points are awarding for not having an air conditioning system at all which obviously saves a huge amount of energy. Other areas have also developed their own guides for sustainability and green building design such as New York City, Minnesota, and San Mateo County in California.

The State of Minnesota Sustainable Building Guidelines were developed by the Center for Sustainable Building Research at the University of Minnesota. They are designed to work with other guidelines such as LEED but are developed further for more effectiveness in the climate Minnesota is set in. The guidelines are to be used for all new state buildings funded through bond money which are built after January of 2004. Instead of giving a point system for specific renovations such as LEED does, the Minnesota system provides more general suggestions to the approach of a green design. For example, a goal of the Minnesota guidelines states that new buildings should exceed the energy code of January 2004 by at least 30 percent. The guide then gives very specific systems and actions the builders can take to ensure that these more general goals are reached. The guide highlights the need of specific areas to take measures to adapt a system that may better apply to the local climate and landscape than nation guides and standards such as LEED.

Figure 5: Minnesota's attempt at increasing longevity of its buildings (Source msbg.umn.edu)

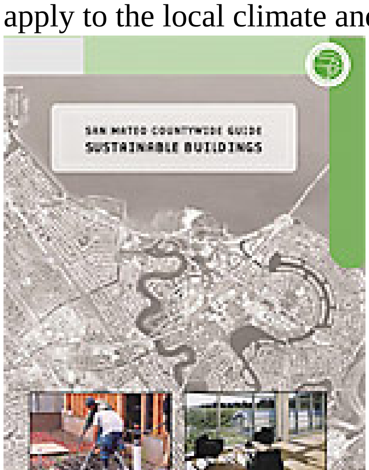

Figure 6: San Mateo County Energy Guide (Source: www.recycleworks.org/greenbuilding)

San Mateo County in California has also created their own set of standards outlined in the San Mateo Countywide Guide: Sustainable Buildings. The San Mateo area of California is home to a high concentration of green building expertise and many experts from the building community came together to create their own green building standards. The guide is a good starting point for a wide variety of new construction and renovation projects. The guide is made to be more user friendly and targets people who may not have a background in green building such as smaller project contractors and even homeowners who are looking to do a small scale renovation. Unlike the LEED and Minnesota guides, which are loaded with very technical language and are directed towards larger projects, the San Mateo guides are potentially useful to a wider range of people. San Mateo however, enjoys a climate that is naturally conducive to green building design. The weather provides temperature and humidity levels which are comfortable both in and outside year round. This obviously leads to greatly reduced heating and cooling costs that are present in the rest of the country. The guide helps to visualize useful concepts of green design, however the section on heating and cooling systems is understandably not as developed as the national LEED guide and the one from Minnesota.

When choosing a set of guidelines in the design of a sustainable building project, the parties involved should first decide why exactly they are seeking this type of building. If the real reason is to not only to build a high quality structure, but also to reap the public relations benefits, a guide such as LEED is probably the best choice. This will ensure that the project is set to a specific, widely know standard that will more easily be recognized by the public at large. When the notoriety aspect of things is less important and the true sustainability of the building is the real concern, than more relevant local guides to green building with some input from national standards may be the best route.

Heat Loss

One of the core goals of our project is to try and understand the current heating system, how to best analyze it to find key areas to improve, and to learn about the various heating systems available today in order to make these improvements as effective as possible. One of the key elements of a heating system analysis and a building analysis as a whole is the calculation of heat loss. Once this value was found for the buildings on-campus, the various systems that could be implemented needed to be looked at and weighed against one another.

The most useful tool used to properly size a heating system to a particular building is heat loss. Heat loss is the measure of how much heat a building will lose based on normal use and a given inside/outside temperature difference. This temperature difference varies with the climate of the given region where the building is being constructed. In the Massachusetts area for example, a temperature difference of 70 degrees Fahrenheit is the standard. This value, along with information about the building's envelope and type of usage can be used to calculate the amount of heat energy required by the heating system in order to maintain a temperature difference of 70 degrees between the inside and outside of the building.

Figure 7: A visual explanation of the ways heat can escape a building (Source: www.energystar.gov)

Often a standard inside temperature is set in order to scale the temperature difference to the climate of the region. This temperature is typically 65 degrees Fahrenheit. This means that a properly sized system in the Massachusetts area will be able to maintain an inside temperature of 65 degrees while the outside temperature is -5 degrees. Looking at the climate information for the area, this checks out because the temperature rarely goes below -5 degrees and the system will be able to handle the required load for the vast majority of the time. Of course the temperature has certainly gone below -5 degrees in the past and any rare time that this happens, the heating system may not be able to reach the 65 degree indoor goal. This is carefully weighed against the consequences of over sizing the system for normal use, which would decrease the efficiency of the system and lead to higher energy costs in the long run.

Another building characteristic that can dramatically affect the heat loss is the envelope of the building. Any change in the insulating factor (R-value) of building materials involved in construction will change the heat load of the building. In the United States, the standard measure of R-value is in units of ft^2*degrees F*Hr/Btu. Where the surface area of the material in question is in square feet, the difference in temperature between one side of the material and the other is in degrees Fahrenheit, and the amount of heat conducted through the material is in British thermal units (Btu) per hour. In order to calculate the heat flow through a material, the inverse of the R-value needs to be taken and the result is called the U-factor. For example, a material with an R-value of 10 would also have a U-factor of 0.10. Then to calculate the total heat flow through a given material with a given difference in temperature, the U-factor is multiplied by the total surface area of the material and then multiplied by the difference in temperature between the two surfaces (delta T).

Type of Insulation	R-value (F*sqft*Hr/Btu)	U-factor (Btu/F*sqft*Hr)	Delta T (degrees F)	Area (sq. ft.)	Heat Loss (Btus/Hr)
Fiberglass Batt	3.14	0.318	10	15	47.7
4 inch Brick	0.80	1.25	10	15	187.5

Table 1: Heat Loss Values for Wall Insulation

As can be seen from the above sample calculation, the R-value of a material can have a dramatic impact on the amount of heat lost through the material. Refer to Appendix A for R-values of typical building materials.

The walls, roofs, and floors of a building are of course usually not composed of only one material. Walls commonly have as many as six or seven components to them, each with their own respective R-values. Fortunately all of these individual R-values can simply be added together to yield the overall R-value of the wall, roof, or floor in question.

The building surfaces needed in order to calculate a building's heat loss are only those which will result in a net loss of heat from the building. For example, any inside walls or floors between heated areas of the building are not factored into the heat loss calculations. Any surface that is exposed to the outside or an unheated area of the building is considered into the heat loss. For each

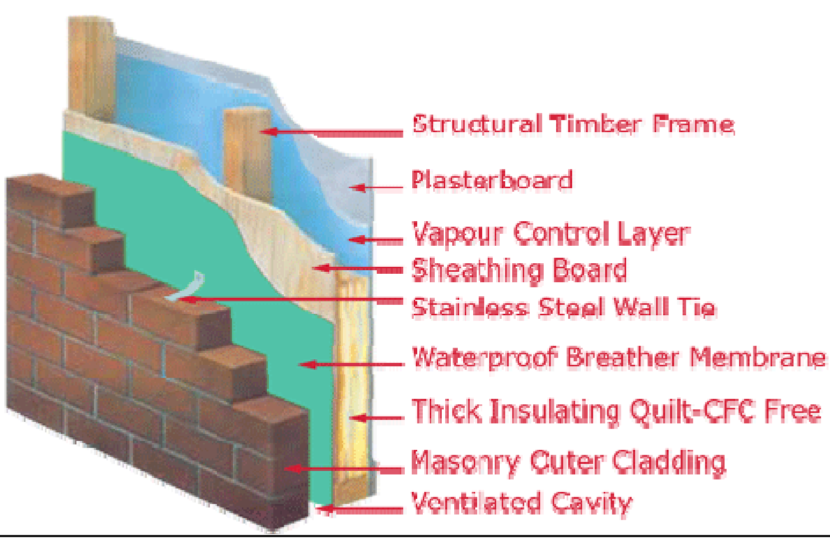

Figure 8: Breakdown of a Standard Wall (Source: www.energystar.gov)

window, door, outside wall, floor, and roof the heat loss is calculated and totaled to give the amount of energy lost due to the building materials used.

Another important factor in the heat loss of a building is how the building is used. This property of the building will greatly contribute to the rate of air exchange (infiltration factor) of the building. For example a factory building that has loading bays open much of the time will allow the air inside to escape at a fast rate and will therefore have a larger infiltration factor than a small home where doors and windows are closed for the majority of the time. The number of inhabitants of a particular building thus becomes an important component of the heat loss because it is directly linked to how often the doors of the building are opened and closed. The infiltration factor is the volume of air that exchanges in one hour divided by the total volume of the building. Once this volume of exchange is determined, it is multiplied by the constant 0.018 (the amount of energy in Btu it takes to raise the temperature of one cubic foot of air one degree Fahrenheit) and delta T. This value is the energy loss due to air exchange and is added to the loss due to building materials to yield the total heat loss of the building.

Once the total heat loss is calculated, it can be coupled with climate information such as the average mean temperature of an area to give an annual fuel requirement. Prices of these fuels can be assigned along with an efficiency of a proposed system to yield estimated annual heating costs for a particular building.

Heating Systems

As energy costs rise there is always a need to create and implement more efficient sources for heating. According to Plant Services Director John Miller, just last year, WPI's energy costs have increased 30 – 40%. This places an importance on creating the most efficient heating system for all buildings on the WPI campus. The newly renovated central heating system is already up to an 86% average efficiency rating. However, problems lie in buildings that are not connected to the campus' main heating system. Some of these buildings use electrical heat, which is considerably more expensive. Electrical heating is considered to be the most expensive form of heating currently on the market. According to the Metropolitan Utilities District of Omaha, Nebraska operating an electric water heater costs 75% more than a gas water heater. Even during off peak times, electrical heating systems cost considerably more than conventional gas or oil boiler systems. Modern, efficient boilers have efficiency ratings of up to 98%. Although they have a high initial cost, the annual savings on energy expenses would make the change beneficial in the near future.

Electric Heating

There are many different forms of electric heating available, but every version works essentially the same way. All electric heating is based off the idea that when electricity is passed through a resistor, electric energy is released and converted into heat energy. The benefits of electric heating systems are their relatively cheap installation costs, as well as the ease of installation. They also offer the most direct control over heating—each individual heat element can be turned on or off with just the flip of a switch. However, electric heating has been proven to be the least environmentally friendly of the three major sources of heating. This is because of how electricity is generated—generally, fossil fuels are burned to create electricity, and up to half of that electricity generated can be lost in transmission and through other means. On average, the greenhouse gasses emitted by electric heat is one-and-a-half times that of Natural Gas. In addition, the cost of heating a building with electric heat is on average over twice as expensive as heating the same building with Natural Gas or fuel oil. The various types of electric heating are radiative heaters, convection heaters, storage heaters, and radiant heating.

Convection heaters operate on the principle that hot air rises, while cool air descends. The principle of conduction is used to heat particles of air, which are then released into a space and eventually rise. This allows the cool air to enter the heating area and undergo the same process. Convection heaters set up a perpetual current of hot and cool air through the room, and are best used in isolated areas.

A refinement on the traditional convection heater is the fan heater, sometimes coined a "forced convection heater." These operate similarly to regular convection heaters, but also include a fan that helps expel the hot air and draw in the cool air to be heated at a faster rate. These forced convection heaters also more evenly heat an area due to the faster exchange rate and air distribution of the fan. Even with the addition of a fan, convection heaters are still the most inefficient form of heating available in the United States.

Natural Gas

While many boilers simply create steam and spread it through piping, hydronic boilers do not necessarily boil water into steam, though that option is still available to them. Hydronic boilers heat water to a preset temperature and circulate the heated water throughout a building using a motorized pump. The water can be passed through the radiators, baseboard heaters, or floors to heat the building. Hydronic boilers are often used in Europe, but are gaining support in North America because of their increased efficiency over regular forced-air boilers and they are smaller than the standard boiler. In addition, hydronic boilers provide a more even heating than regular boilers, do not introduce any airborne allergens or mold, and do not sap moisture from the air.

Of all the available heating systems, a hydronic boiler powered with natural gas is currently the most efficient and overall best of the heating options. The benefits a hydronic boiler provides in terms of cost and greenhouse gas emissions are augmented by the comfort and satisfaction they generally offer. For a sustainable, cost-effective heating system that provides the most satisfaction possible, a hydronic boiler would be ideal.

Envelope

In order to build a sustainable building, it is imperative for the windows, walls, doors, and roof to be taken into consideration. Every state in the United States has minimum requirements for new buildings under construction in regards to its envelope, and there are many organizations, such as Energy Star, which provide homeowners attractive, energy efficient alternatives to basic, low-end insulation.

Roof

The roof is a very important part of a building's envelope regarding insulation due to the nature of heated air and its tendency to rise and escape through the ceiling of a room. As such, many buildings have several inches of polystyrene insulation directly below the roof to keep heat loss to a minimum. The United States Department of Energy has created a building energy code program that outlines the minimum R-value of insulation needed in various sections of a building's envelope before the building is deemed acceptable to begin construction on. In the case of roof insulation, an R-value of 38 is "good," whereas insulation equal to or higher than R45 is considered "great!" In perspective, the R-value of Stoddard's roof is around 16, much below the Department of Energy's new standard.

Green Roofs

The concept of a green roof is to simply replace the land taken by a building by growing plants on the roof of said building. Though initially expensive, green roofs are lauded for their environmentally friendly nature and superb insulation and efficiency. The movement towards green roofing buildings began in the 1980's in Europe, when country governments began supporting both companies creating green roof technology as well as companies that opted for green roof building construction.

Figure 9: Chicago's City Hall is one of the few green roofs currently in the United States (Source: www.greenroofs.org)

The advantages of green roofs include all the advantages that plants would provide to the greater environment while allowing the space for construction of a building, a commodity in many of America's cities. These benefits include the replacement of a yard or garden, the filtration of carbon dioxide in the atmosphere by the cultivated plants, as well as the ability to attract wildlife and allow room for habitats of both humans and other animals. In addition, the advent of a green roof can lower heating costs and heat loss significantly, lengthen the lifespan of the roof, and reduce runoff during heavy rains.

Despite the multitude of advantages of a green roof, there are some unconventional drawbacks not usually associated with roof installation and maintenance. Due to the extra weight caused by soil and vegetation, buildings that are in line for green roof fitting or retrofitting require more support than a standard roof. As a result, it is sometimes impossible to retrofit a green roof on an old building if it cannot achieve the support necessary for this change. Any repairs that are required for a green roof often come with a much higher cost of repair due to the extra labor required to keep the green roof intact. Furthermore, green roof designs are often imported from Europe due to their expertise in the matter, and any vegetation considered for a green roof requires adapting to exist in the United States climate.

Walls

Walls are a crucial part of a building's envelope in that they often compose the majority of the building's surface area, which increases as more floors are added to the building. Heat loss is generally very high through walls, and as a result many different forms of insulation have been created to combat this heat loss. As a rule, the heating coefficient of insulation increases with its thickness, and most insulation is calculated for a simple 2X6 wall for convenience. This allows 5.5 inches of insulation, as the remaining thickness is reserved for wall covering.

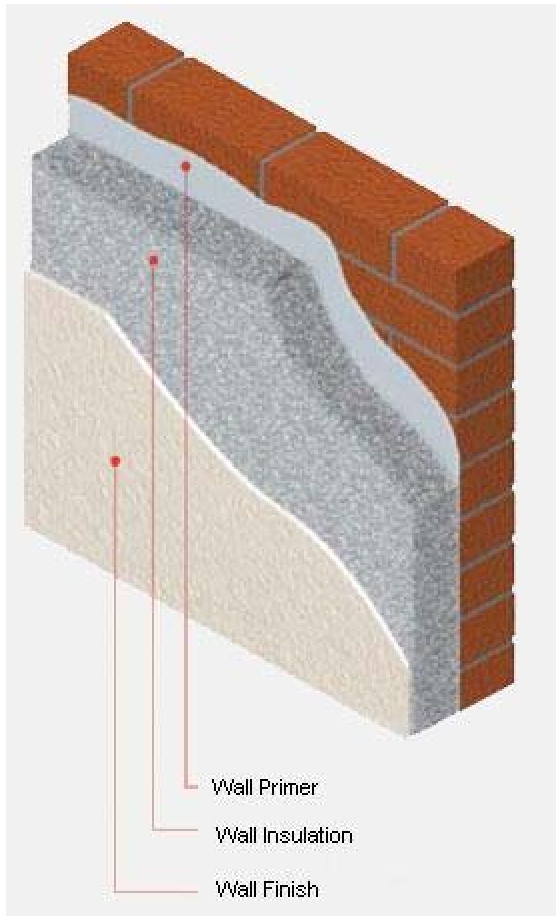

Figure 10: A Cross-Section of a Standard Wall (Source: www.thermalindustries.com)

Fiberglass

Most commonly found as rolls/blankets, fiberglass is available in low-, medium-, and high-density varieties, and is one of the most commonly used forms of wall insulation. Fiberglass blankets are applied to unfinished walls and can be easily installed by almost anyone provided the wall is not yet complete. In a standard 2X6 wall, high-density fiberglass blankets provide an R-value of 21, midway between "good" and "great" insulation values for northern United States regions according to the Department of Energy. The insulation coefficient jumps to 38 if the insulation thickness is doubled to a foot.

Polystyrene

Polystyrene is a very common form of insulation due to its cheapness. It is often supplied in the form of foam boards, and is applied to unfinished walls, ceilings, and floors. However, despite its benefits, polystyrene requires a thin layer of a fireproof material before it can be used as insulation. Common polystyrene is also somewhat inefficient, providing insulation of about R3.8/inch. The high-density version of polystyrene can achieve R-values of up to 5.0/inch, translating into R19 and R25 for a normal 2X6 wall (factoring in the fireproofing), respectively.

Cellulose

Figure 11: Cellulose is Packed Tightly in Wall Cavities For Insulation (Source: www.inhabitat.com)

The same material found in plant cell walls, cellulose is a loose-fill insulation used in wall cavities that takes the form of shredded newspaper or recycled wood fiber. The insulation can be added even after the wall is constructed and is packed tightly, inhibiting airflow and lowering heat loss through infiltration, as well as providing a low value of R3.6-R3.8 per inch, or an average of R20 for a 2X6 wall. Unfortunately, should a water leak appear in the wall, the cellulose absorbs water faster than any other insulation, which could lead to large sections of walls being damaged.

Polyurethane

As the most efficient wall insulation, polyurethane is a spray-in insulation that contains a low-conductivity gas within its composition that prevents heat from passing through the material. Aside from the convenience of being able to apply spray-in polyurethane at any time during or after wall construction, it has nearly double the R-value of the second most efficient wall insulation with an R-value of 7 to 9 per inch. This translates to R39 or R50 for a 2X6 wall. The only downside to polyurethane insulation is that it is subject to depreciation in the form of thermal drift. Thermal drift is a phenomenon similar in principle to infiltration: the low-conductivity gasses trapped in the polyurethane slowly exchange over time with the gasses in the atmosphere, lowering the R-value somewhat, though old polyurethane still remains a more efficient insulation than any of its competitors.

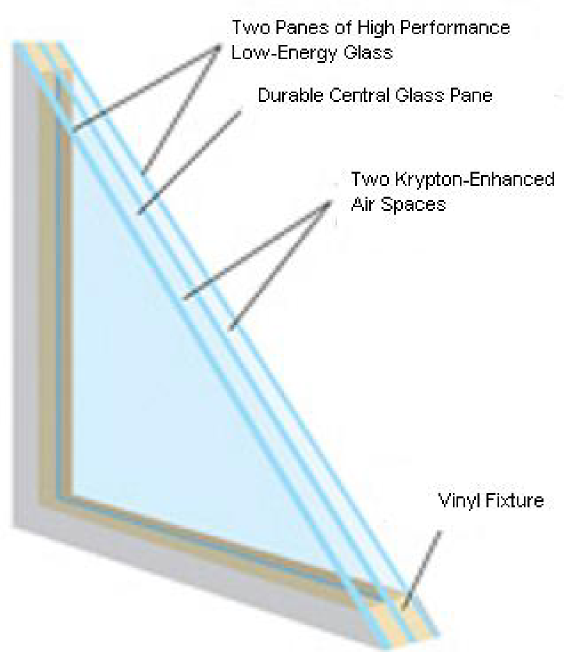

Figure 12: Diagram of a High-Efficiency Window (Source: www.thermalindustries.com)

Windows

Windows are often overlooked when considering the envelope because they are not usually permanently sealed sections of a building, but older windows are a prime target for renovation due to the huge advances made in window technology in recent times. Many old windows have low R-values due to not only outdated technology, but also dilapidation in the seals around the window. Finding a sustainable window can go a long way in lowering the heat loss of a building.

The most common guideline for efficient windows is that provided by Energy Star's rating system, which suggests a window to have an R-value of around 3 as a bare minimum. This can be achieved through double-paned windows with a low-energy coating. However, for truly efficient and sustainable windows that can prevent heat exchange with outside air, a few improvements can be made. First, adding a third pane can raise the R-value by presenting another solid material for air to pass through to exchange heat. To fully maximize the effective use of the gas layers in between the panes of glass, a heavy, inert gas such as Krypton can be pumped in, which further hinders lighter molecules in the air to pass through the window. For sustainability, vinyl would be the preferred choice over wood and aluminum for window fixtures. With these changes, an R-value of 9 can be achieved, roughly tripling the insulation coefficient of Energy Star minimum requirements.

User Functionality

The way a user interacts with his or her heating system can affect many things, including heat loss, user satisfaction, and energy costs. This section will explore several different aspects of user functionality in heating systems.

Thermostats

A thermostat is a device used to set the temperature for a room or rooms. It controls the flow of heating and/or cooling elements to match a temperature set by the user. There are two basic types of thermostats used in residential buildings, electromechanical and electric.

Electromechanical Thermostats

The Stoddard complex currently utilizes bi-metallic, electromechanical thermostats. A bi-metallic, electromechanical thermostat from Honeywell (as shown in Figure 10) works in the

Figure 13: A Thermostat in Stoddard

following way. Inside the thermostat is a bi-metallic strip. This consists of two strips of different metals that react differently to heat. The two strips of metal are connected, generally by rivets or welding. When affected by heat one strip will expand more than the other, causing the two strips to curve. These sensors are then attached to a small glass vial containing mercury. Heat causes the bi-metallic strip to curve, and tilt the glass vial one way or the other. The mercury contained in the vial is conductive, so when it is tilted to a certain point, it completes an electrical circuit that is connected to the heating system. Other companies, such as General Electric, also make these types of thermostats. They work similarly to those from Honeywell, except they use a magnetic snap reed switch, rather than mercury.

Electronic Thermostats

Growing more and more common in residential applications are electronic thermostats. These are also known as digital or programmable thermostats. These types of thermostats utilize no moving parts to detect temperature, but use thermistors. This is a special type of resistor whose resistance value changes based on the temperature. This allows the circuit to be open or closed based on temperature without having to rely on moving parts, which can wear down as time goes on. Electronic thermostats generally have an LCD display, as well as a keypad that allows users to program the system. This allows for greater efficiency, as users can program the system to turn off automatically when they will not need heat, such as when they are sleeping or at work. The LCD screen generally contains clock, date, and current setting displays.

Location

Placement of thermostats is very important. Thermostats read the room temperature as part of their functionality, so it’s important that they be away from heating elements. It is also necessary that the thermostat be out in the open, in a place where it is near an area of free air flow, to ensure that it gets a good reading of the general temperature of the room.

WPI System Status Quo

Figure 14: The Bartlett Center

Another aspect of our project looked at what the current trend in WPI buildings is and what has been the status quo in the past. This information is valuable in proposing a change in one or more buildings in order to make the proposal both realistic and a step in the right direction. The area of campus bordered by Institute Road on the south, Park Avenue on the west, Salisbury Street on the north, and Boynton Street on the east (the central campus) is heated by the WPI powerhouse. The main boilers at the powerhouse burn a combination of natural gas and fuel oil. In the past the powerhouse burned fuel oil #6 which was inexpensive; however it burns fairly inefficiently and created harmful emissions. Now the powerhouse only burns ultra-low sulfur fuel oil #2 which is less harmful than its predecessor. The powerhouse was also renovated in 2005 and currently operates at around 84% efficiency. This means that all heat provided to the central campus comes from an efficient source. WPI has also continued a movement towards energy efficiency with the construction of the first LEED certified building on campus, the Bartlett Center finished in 2006. The Bartlett Center now functions as the new admissions building and showcases WPI's commitment to creating energy efficient and high performance structures. Also planned for completion in the fall of 2008, is a new upperclassmen dorm on Boynton Street next to Founders Hall. The new building will house 232 residents and will implement an innovative green roof design. With this commitment to establishing new, efficient buildings on the WPI campus needs to come the renewed effort to update some of WPI's older buildings as well.

Figure 15: WPI's Power House

As for other WPI buildings off of the central campus, various systems provide the heat. Founders Hall and Institute Hall are both run on an efficient gas boiler system that uses a hydronic heating system to deliver the heat. Various other buildings are heated in a similar fashion. Three exceptions to this are the Fuller Apartments, the Ellsworth Apartments, and the Stoddard Complex. These buildings were built in the 1970's with an electric based heating system, and today this system is still in place.

In 1973, the Yom Kippur War against Israel prompted the Organization of Arab Petroleum Exporting Countries (OAPEC) to declare that no more oil could be exported to countries that supported Israel in the conflict. This included many countries in the West including many in Europe and of course the United States. The effects were almost immediately felt throughout the country. Gasoline prices in particular rose through the roof. The price of oil quadrupled by 1974 and the US suffered the first energy shortage since World War II. This prompted many people to begin conserving the energy they used. Conservation and rationing of fuel spread throughout the country and many large companies also took part. Fuel consumption in the US decreased by seven percent by the end of 1974 and this had a very lasting effect on the United States.

As people conserved and general energy usage

Figure 16: An artist's rendering of the new residence hall (Source wpi.edu)

in the United States fell or leveled off for several years, electric power companies began to encounter problems as well. The electric companies grew in this period to meet the new demand for electric power, causing a surplus of power to form. This caused companies to lower prices and create incentives for homeowners and business owners to switch to electric heat. It was in this setting that the Ellsworth and Fuller Apartments and the Stoddard Complex were created. Electric heat was implemented because the initial cost of installing the system was low when compared to gas or oil heat and the price of electricity was relatively low at the time. Measures such as solar cells, for domestic hot water, were at one time placed on the roofs of Stoddard to make the system more environmentally sound. These however, were taken down at one point and were never replaced. Now in the time of increased electric prices and a movement to curb global climate change with environmental awareness, buildings that are electrically heated become an economic and environmental eyesore.

These buildings are still electrically heated and are beginning to experience many maintenance problems. In the Ellsworth and Fuller Apartments, residents live in a combination of double and single rooms in two, three, five and seven person apartments. These apartments are only available to upperclassmen and are seen as some of the best places to live on campus. Each apartment has its own living room area, kitchen area, and private bathroom. Each bedroom, living room, kitchen, and bathroom has a thermostat which the students are free to control. The thermostats control electric heating elements which are placed along the outside walls of the apartments, generally below window areas.

In the Stoddard Complex, there is a similar system in place. Instead of having apartments, the residents of Stoddard live in either single or double rooms in a dorm-style setting. Each floor has their own lounge with a television and several chairs and couches. The complex consists of three buildings arranged in a U shape with a central quad-style area in the center often referred to as the Stodd-Quad. The buildings of Stoddard are labeled A, B, and C, with A and B making up the sides of the U shape and C linking them at the bottom. Stoddard A and B are identical buildings and are arranged in a mirror image configuration in the complex. Each has three floors with a lounge and set of bathrooms on each floor. The floors are separated by gender with all but the second floor of Stoddard A being male. Stoddard C is unlike A and B in that there are four floors, the lowest of which contains WPI's Health

Figure 17: Stoddard A

Services. The Stoddard Complex houses only freshmen and holds a total of 154 residences. This makes Stoddard the first place many students see when they come to WPI. Each room in Stoddard, including the lounges has its own thermostat which controls the main heating element in the room under the windows. In both the Stoddard Complex and the Ellsworth and Fuller Apartments, hot water is currently provided by natural gas water heaters. The system currently operates in an acceptable manner but is one of the least efficient ways to provide heat to the buildings in both an economic sense and an environmental sense.

Envelope for Ellsworth, Fuller, and Stoddard

Currently, the Ellsworth and Fuller Apartments consist of a combination of various types of walls. The gable-end of each building is made of an eight inch thick brick wall with little insulation inside the wall. Each apartment building is also separated by a similar brick-style wall which serves as both a structural component of the building and a noise barrier between each apartment. None of the buildings have a basement and are built on a concrete slab at grade level. Some of the buildings in the Fuller apartments are built into the side of a hill and provide a third level below the first two which contains studio style apartments. These walls which are built below grade are made of poured concrete and are around eleven to twelve inches thick. Besides masonry based walls, there are more conventional framed walls and roofs creating the fronts and rears of the individual apartments. These walls are made of either wood or metal based framing with around eight inches of fiberglass insulation. The floors in between the first and second stories of the apartments are made of concrete with a metal frame for support. This provides for not only strong construction, but also reduced noise inside each apartment.

The windows in the Ellsworth and Fuller apartments appear to be from the original construction of the building. Most of the windows are casement-type and provide a good amount of fresh air to the apartments when opened. The windows are double-pane glass and most have fairly good weather stripping on them that still functions to reduce infiltration. Large windows are present in both the kitchens and the living rooms of each apartment, while smaller windows are utilized in the bedrooms.

The current envelope in the Stoddard complex however, is not as sealed as the ones in the Ellsworth and Fuller Apartments. The Stoddard Complex's three buildings also have various types of walls in them. The buildings are primarily masonry based and contain walls that are faced on the outside by brick and on the inside by painted concrete block. In these walls are two inches of ridged insulation contributing an R value of seven. The structural components of the buildings consist of one foot square pillars running from the slab of the building to the roof to support the weight of the building. Concrete floors with a supporting metal frame separate each floor. The roof consists of a concrete ceiling on the third floor with four inches of polystyrene insulation in between the ceiling and the asphalt sheeted roof with stone gravel on the very top. Windows set in a metal frame make up the rest of the outside walls and are not structural in function. Each room contains a large double pane glass window with two smaller windows directly underneath them that can be tilted open. These windows do not provide nearly as much window area that can be opened as the window in Ellsworth and Fuller. They are also not as well sealed which is a possible contributor to the overall infiltration of the building. The metal frame that contains the windows separates each window with a section of wall that consists of an outside metal layer with a two inch thick insulating board behind that is exposed in the inside of the rooms. This is referred to as the metal wall in the rest of this report.

Chapter 3: Methodology

Our project consisted of three main goals: analyze the possibility of renovating the heating system of the Stoddard Complex, consider the feasibility of remodeling of the envelope of the buildings, and a user satisfaction questionnaire to determine what, if any, aspects of the building should be changed in order to improve comfort. It was important, therefore, for us to find a way of continuing our work in each aspect, without losing sight of the other two. We ended up settling on a system in which we focused on one main goal at a time, while still working on the other goals as well. For instance, when we were mainly working on our survey, we also made sure to stay in contact with contractors. This method allowed us to focus on what needed to be done, without losing sight of the bigger picture. In order to manage all our goals effectively, the renovation plans for Ellsworth and Fuller were dropped. According to John Miller, these buildings have tentative plans for demolition, which reduces the likelihood that WPI would consider any renovations suggested for Ellsworth and Fuller.

System Analysis

A heat loss was performed on the Stoddard Complex in order to both isolate problem areas of the current envelope and to generate estimated annual heating costs for the three buildings. The known insulation content of the building was obtained from Plant Services and a visual assessment of the building. These factors were then converted to R values using building material information. Once the R values were known, than the area of each component of the Complex's envelope could be calculated using prints of the buildings obtained from Plant Services and from measurements of the actual building. With the insulation factor and area of each component now known, the heat loss through each can be calculated with a base of 70 degrees Fahrenheit (Massachusetts Standard) in temperature difference with the exception of the floor. The floors of the buildings sit on ground which maintains a temperature of around 50 degrees Fahrenheit throughout the year. Due to this, the delta T used in the calculation of the base heat loss through the floor will be 20 degrees Fahrenheit instead of 70.

Once a heat loss through each component of the envelope of the building was calculated, a heat loss due to infiltration also needed to be obtained. This value was much harder to obtain than the heat loss through the materials of the building without it being measure with sophisticated techniques implemented by professionals. Through calculators and an assessment of the building's envelope and use, we arrived at an air exchange factor of roughly 0.8 (inverse hours), which is higher than normal due to several reasons. Each building in the Stoddard Complex contains around 52 students who open doors at least twice a day each. This high traffic condition results in the doors of the buildings being open a good amount of time and adds significantly to the air exchange rate. The windows also play a large role in the infiltration of a building and there are many large ones in the Stoddard Complex. With a few reports of draftiness from the residents of the buildings and in some cases the appearance of light through cracks in the metal window frames in the building, we believe this also contributes greatly to the overall infiltration of the building. Also, visual evidence of students opening windows in the middle of winter because the room is too hot contributes to our assessment of a higher than average infiltration for Stoddard.

With this air exchange rate finally settled upon, it is important to note that this is an estimated heat loss of the building and the infiltration aspect of the heat loss performed for the purposes of this report is only an estimate to the best of our knowledge. With the time allotted to our project, we feel that our values are of a quality that is useful as a starting point for similar projects that may take our ideas further in the future. However, for an actual renovation of the Stoddard Complex, a professional reading would need to be taken.

Once the heat loss for the entire complex was calculated, this value was coupled with climate information for the Worcester area from NOAA and an annual heating cost for the Complex was estimated.

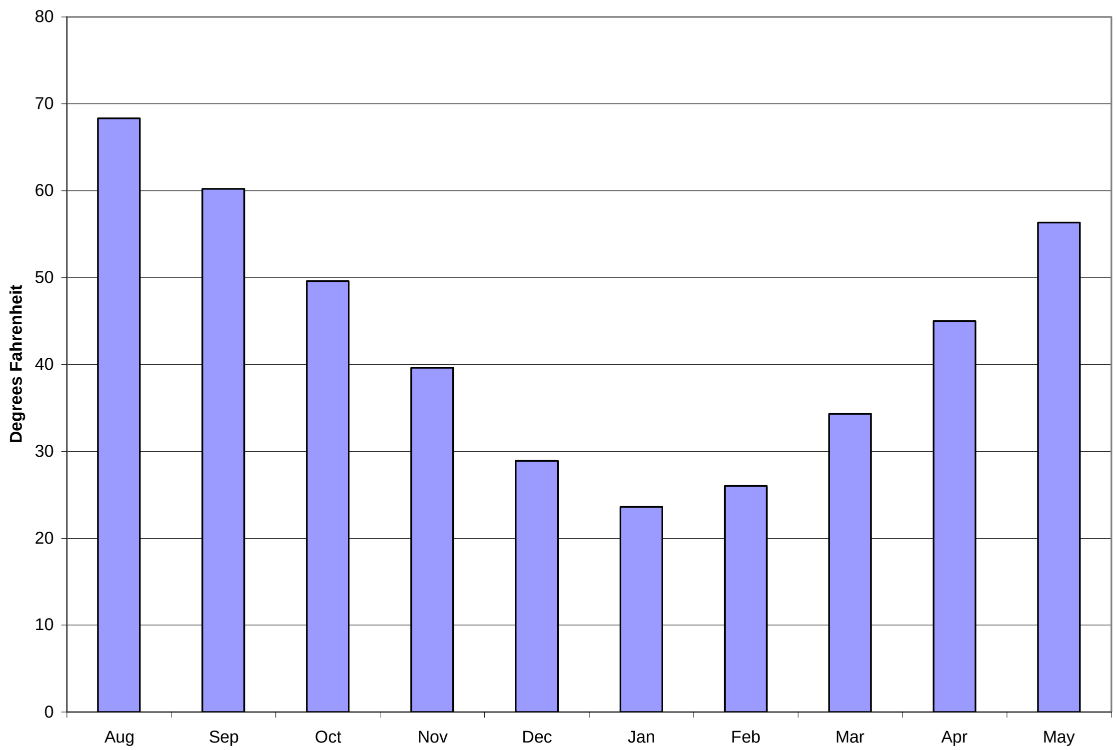

Figure 18: Average Temperature for the Worcester Area by Month

The months used in the calculation were August through May and the summer was ignored due to the buildings being shut down during this time. Using this climate information, the mean temperature for each month was obtained and subtracted from 65 degrees. This difference was then multiplied by the number of hours in the month to obtain the total amount of Btus needed to heat the building for a typical year. This energy value was then converted into an equivalent amount of electricity, fuel oil #2 and natural gas. Once these values were obtained an efficiency of a theoretical system along with prices from WPI's current heating bills was assigned to each type of fuel. For electricity an efficiency of 98% and a price of $0.1315 per kilowatt hour were used, 85% and $2.21 per gallon for fuel oil #2, and 85% and $14.81 per decatherm. The three fuels analyzed were chosen in order to compare and contrast the annual cost of each system and see which would be the most feasible economically.

An analysis for the greenhouse gas emissions of each system were also performed in a similar fashion with data obtained from the Environmental Protection Agency. This provided us with a good comparison as to which system would emit the least amount of greenhouse gases and hence which one would be the most environmentally friendly system.

Survey

A university is, at its core, a service industry. Therefore, when a change is to be made that affects the customer, it is advised that they be sure the customer will appreciate the change. Some of the changes that this project suggests, such as converting from electric to gas heat, will not be very noticeable. Other changes, however, such as changing the windows in the Stoddard Complex, are very different and easily noticeable. It is also important to see whether or not these changes would matter to the students. It is pointless to try to improve user satisfaction of a system whose users are already satisfied. Interviewing residents who work with this system every day would also help us uncover any other problems we may have missed. We decided that in order to gauge the students reactions to our proposed changes, our best choice was to conduct a survey based on their satisfaction with the current system, as well as their opinions on our ideas. The Ellsworth/Fuller Apartments and Stoddard complex vary greatly in terms of how they’re set up, so we wrote two separate surveys to better accommodate the students.

Surveying WPI Residents

The Ellsworth and Fuller Apartments contain 2, 3, 5, and 7 person apartments that are broken into singles and doubles. Each of these apartments contains a bathroom, kitchen, and living room area. The apartments have one thermostat per bedroom, living room, kitchen, and bathroom.

A major aspect of our survey was centered around seeing how the students use the heating system. Through our own experiences in the WPI residence halls, we decided to start the survey with a simple yes or no question asking whether or not the thermostat works in the first place. Our next questions focused on how often the students used their thermostats. We chose to ask how often the residents used the thermostats in their bedrooms and in the living room, which we assumed to be the most often used thermostats of the apartment. In order to get more of a response on student use, we also asked how the students reacted when the room got too hot, as well as how they reacted to the room being too cool. We also had to ask a few questions that are harder to measure, that we had to take the residents’ word on. We asked them if the room heated evenly and about how long it took them to notice a change in the room temperature after they adjusted the thermostat setting. An advantage of performing these surveys in person over an internet based survey is that we were able to directly measure certain information. We made it a point to measure the temperature in each room we surveyed using a handheld digital thermometer. We also asked each resident if we could measure their thermostat so that we could see exactly what temperature it was set to. We wrapped the survey up with a few opinion questions. Our first opinion question asked the students what, if anything, they would choose to change about the current heating system. Clearly, if these matched the changes we hope to see, then we are on the right track. We also asked students if they would favor an automated monitoring system that would credit those whose energy usage was well below the average. Our final question asked students if they would be interested in seeing their energy usage, to give them an idea of how much they use. We hoped that this survey would validate our work and give us another tool to show the administration what a necessary change this is.

We used the same basic methodology for constructing our survey for the residents of Ellsworth and Fuller Apartments as we did for the residents of the Stoddard Complex. The only change that we made to the survey was to adapt to the fact that the rooms in Stoddard have only one thermostat.

Renovations

Cost estimating guides, specifically the State of Minnesota Sustainable Building Guidelines and the San Mateo County Green Guide, were used to estimate for various renovation scenarios on the Stoddard Complex. The proposed renovation, involving a 2X6 wall, for example, involved using the guide to obtain per-square-foot prices for all aspects of the wall. These prices take into account both the material and the labor costs associated with the construction. This value was then multiplied by a cost-indexing value to adjust for geographical location. The Worcester area is slightly higher than the average and all dollar values were multiplied by a factor of 1.08 to compensate for this.

For the windows in the planned renovation, prices were obtained from a local home depot for standard double-hung windows. A labor cost for hanging each window, and an additional value to account for the needed changes to the framing were then added to the Home Depot value and an overall cost estimate for the windows was obtained.

To obtain return-on-investment values for the renovation aspects of the project, the new insulation factors were entered into the data sheet used to calculate the initial heating costs. The annual heating costs were reduced and the total cost was divided by these values to yield a payback period for the proposed renovations.

Estimates for the heating system were far too complex for our group to calculate and were obtained through contact with J.J. Bafaro, a local heating and building contractor who has worked with WPI in the past on buildings such as the Bartlett Center. After a tour of the Stoddard Complex and inquiries into space for a new installed heating system Bafaro returned an estimate of $1.2 million. To calculate the overall return-on-investment, this value was combined with the renovation estimate and divided by the annual savings.

Analysis of Results

With the data collected, our next job was to properly analyze it to give us a good idea of how the students felt about or proposed changes. We put the raw data that we obtained into an excel spreadsheet using a simple value-based system. Each response that we got for each question was given a reference number. Using numbers instead of words allowed us to concisely report the information that we gathered. This made it easier for us to analyze the data at a glance. We added up the point values for each questions to make charts of responses in order to make the information even more visibly appealing. The actual analysis of the survey results will be covered in the Results and Analysis portion of the report.

Chapter 4: Results and Analysis

Our work involved collecting data that included information on costs and types of building materials, labor costs from contractors, survey result data, and more. In order for this to be of use for us to create a solid, concise, and understandable presentation to the decision makers in the WPI community, we needed to be sure that we properly analyzed the data we had collected, and use it to come to strong, useful conclusions.

Current System

An analysis of the current heating system was performed using the heat loss results and pricing information of Natural Gas and Electricity from WPI and market prices. The results highlight many areas of the current system that need to be addressed and with the addition of an emissions analysis emphasize a move away from the current system. This analysis was performed for the base heat loss of the entire Stoddard Complex under conditions where there is a delta T of 70 degrees Fahrenheit. The results of the heat loss analysis reveal the major problem areas of the Stoddard Complex.

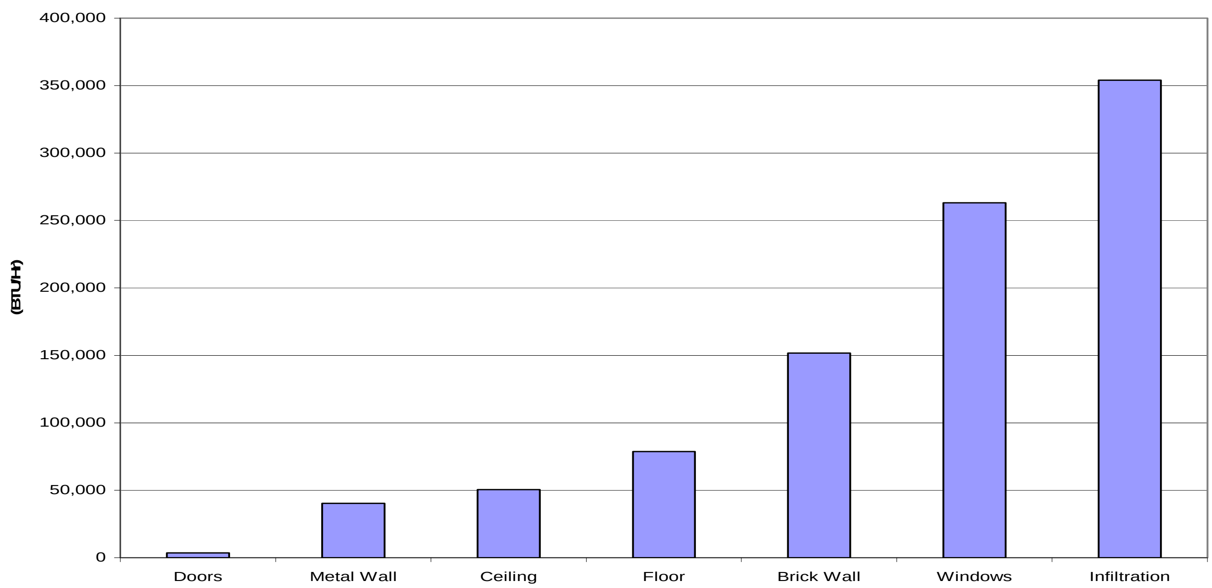

Figure 19: Breakdown of Heat Loss in the Stoddard Complex

As seen in the above graph, the two largest factors of the heat loss are the windows and infiltration, accounting for 28% and 37.5% of the total heat loss, respectively. They dwarf the next largest source of heat loss, the brick walls of the complex, by over 100,000 Btu's per hour. It may seem inaccurate for the doors to lose such a small amount as can be seen because they are opened and closed often. This air exchange experienced when the doors are opened and closed is accounted for in the infiltration component. Also in the infiltration value is any air exchanged due to cracks in the envelope of the building. These values for the heat loss are then added together to give the overall heat loss for the complex; 942,000 Btu's per hour. In relation to the average home, which has a heat loss of around 75,000 Btu's, this is a relatively large number. After taking the overall heat loss of

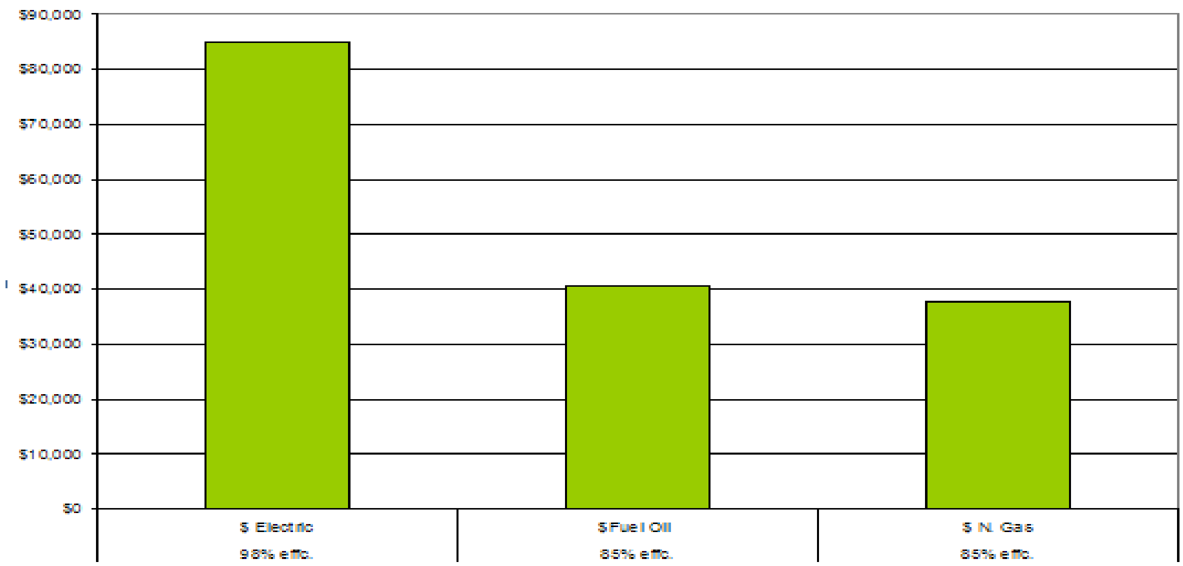

Figure 20: Annual Cost of Heating the Existing Stoddard Complex with Different Fuel Types

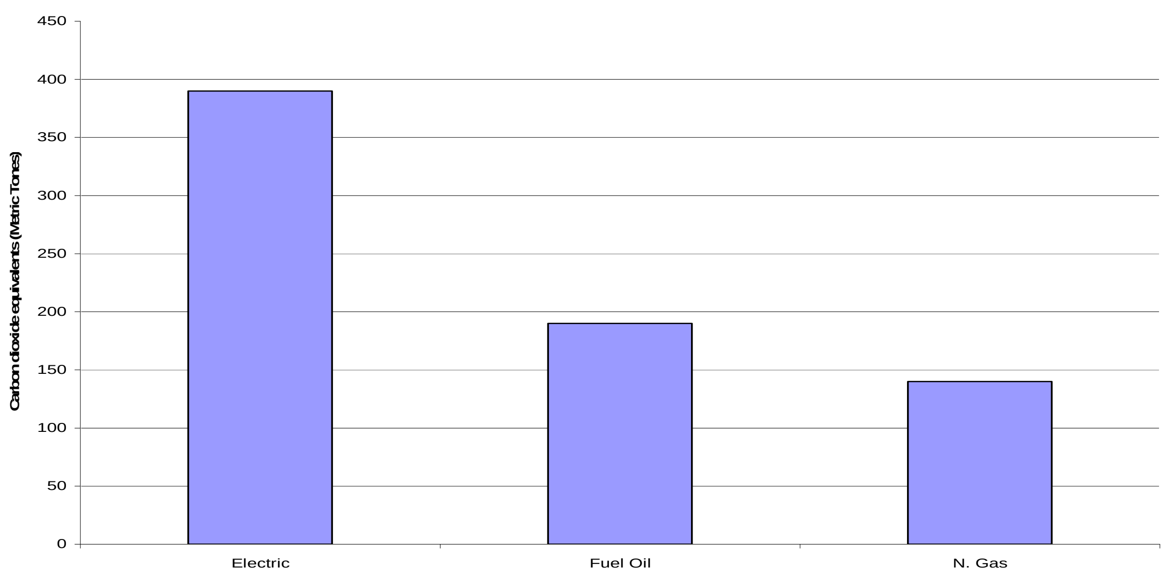

Figure 21: Annual Greenhouse Gas Emissions for Heating the Existing Stoddard Complex

the Stoddard Complex and using both climate and billing information, the annual cost of heating the Complex was estimated.

As seen in Figure 20, the cost of heating the Complex with electricity is more than twice as expensive as heating it with either fuel oil or natural gas. In fact the total annual saving if the system was made to use an 85% efficient oil system would be $45,000, and if the system was made to use an 85% efficient natural gas system would be $47,000 per year. The heat loss analysis was then used to calculate the total amount of greenhouse gas emissions of each system.

As is seen in Figure 21, both fuel oil and natural gas systems emit less than half of the greenhouse gases of the electric heating system. If either the cost or greenhouse gas emissions were higher for one system in particular and not the other, than it would have to be weighed which aspect is more important. However, as is shown in the above analysis, both the greenhouse gas emissions and the cost of the natural gas heating system are the lowest. This leads our group to conclude that if the heating system were to be changed from the current electric one, it should undoubtedly be changed to a natural gas one. This change alone without any further renovations to the envelope of the Stoddard Complex would reduce heating costs by over 55%, saving over an estimated $47,000 annually. The change to natural gas would also reduce the overall emissions emitted from the system by over 65%, preventing nearly 260 metric tons of carbon dioxide equivalents from being released into the atmosphere.

Survey Results

After spending a few days worth of knocking on doors in the Stoddard Complex, we had managed to poll students from 38 rooms, comprising of singles, doubles, and Resident Advisors from all three of the Stoddard buildings. (See Appendices for full lists of questions and survey results.)

Figure 22: Windows Covered in Stoddard C

Our results showed that more than half of the students surveyed would not mind replacing the large windows in their rooms with smaller ones. Several students commented that the large amount of sunlight entering the room made it difficult to cool off in the warmer months. We also learned that slightly under a quarter of the students (about twenty-two percent) never change their thermostats, while about forty percent (the majority in this case) only change theirs about once a week. This confirmed our suspicions that the amount of control over the temperature in these rooms is very limited. When asked what students do to deal with heat, the majority said that they simply open or close the doors and windows. This is not the best solution in terms of cost and energy conservation. Simply walking around the complex gave us information that

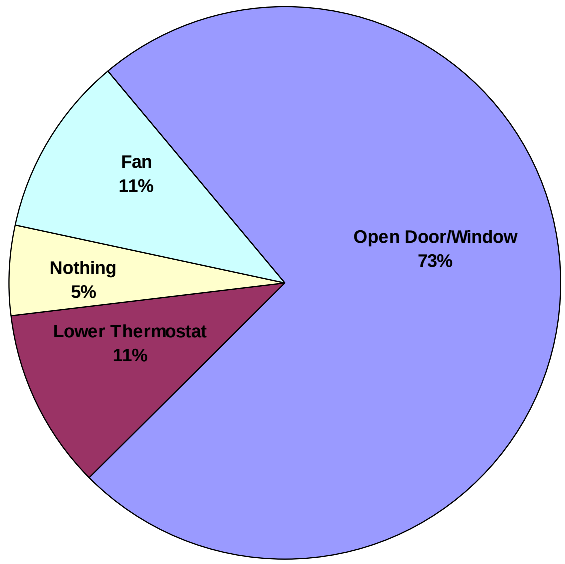

Figure 23: Responses to "What do you do when the room is too hot?" from questionnaire

we didn't get from talking to the students. We saw that many of the windows were covered in curtains, even during the middle of the day. With smaller, more efficient windows, students would feel less obligated to take such drastic measures to reduce the heat in their room.

These results helped cement the fact that a change would benefit the students that live in these buildings for years to come.

Insulation Possibilities

In order to renovate the Stoddard Complex, the envelope needs to be improved to reduce heat loss. Since the major contributors to heat loss are the windows and infiltration, improving both would be ideal. Unfortunately, infiltration is hard to effectively focus on, and is usually changed as a result of improving the envelope in other

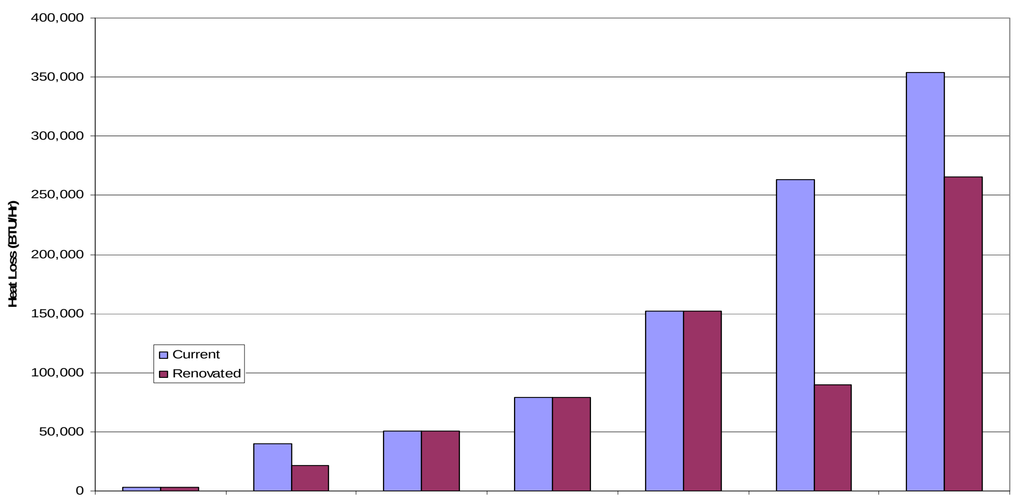

Figure 24: Current and Renovated Envelope Heat Loss for the Stoddard Complex

ways. Since the windows are the most obvious targets for renovation, those can be replaced with more efficient windows with a higher R-value. As the majority of Stoddard residents surveyed did not mind the possibility of smaller windows, the large, double-paned windows present can be replaced with smaller, double-hung windows. To save money on installation, the windows will only be double paned, low-energy coated, just within Energy Star's standards with an R-value of about 3. It is worth noting that with advances in window manufacturing, more efficient windows are now available. Windows with R values exceeding 9 could potentially be used in any renovation. In addition, as the windows are a major part of the metal wall faces on the Stoddard building that do not provide support for the building, the windows and metal walls can be removed from Stoddard and replaced with more conventional windows and walls. By replacing the metal wall with a standard 2X6 wall, a more efficient spray-in insulation like polyurethane can be used to lower heat loss drastically, and the lost surface area of the windows will be replaced with this insulation, lowering heat loss estimates more than if the windows were replaced inch for inch. The spray-in insulation will also seal the walls much more efficiently than the metal walls did, and the newer windows will be more sealed than the 30-year-old windows currently in place, reducing infiltration by an estimated 25%. This estimate could be higher depending on the current state of the windows, but as they age further, their sealing will decrease and infiltration will rise, making them an excellent choice for renovation as well as lowering heat loss.

The new calculated heat loss for the Stoddard complex with the window and wall replacement lowers heat loss from 942,000 BTUs/Hr to 661,000 BTUs/Hr, a decrease of about 30%. The changes will lower heat loss through the metal walls by roughly 50%, the windows by about 60%, and infiltration an estimated 25%. These numbers are by no means exact, but window and wall insulation information is fairly reliable. Infiltration, however, is an estimate in the first place, and any changes affect it secondarily, meaning it is hard to find a direct correlation between spray-in insulation and infiltration. Lowering the infiltration coefficient from 0.8 to 0.6 is a conservative estimate, and in practice, these changes could very easily lower infiltration even more. Use of super-efficient windows and carefully sealed walls could greatly reduce the infiltration factor.

Table 2: Renovation Cost Estimates

Renovation	**Estimated Cost**
Removal of Windows	$21,000
New Windows	$137,000
New Wall Construction	$193,000
Total	$351,000

The renovation to the envelope of the building would cost an estimated $351,000 according to data obtained from both The Home Depot and renovation cost estimation manuals for 2007 and adjusted for the Worcester area. A break-down of the components of the estimate can be seen in the below table.

For the heating system renovation, the J.J. Bafaro Company out of Worcester was contacted to obtain an estimate. The initial estimate proposed by Bafaro was $1,200,000. The proposed new heating system for the Stoddard Complex would consist of a natural gas fired boiler placed in the basement of Stoddard C and would produce hot water which would be piped via two, two inch insulated lines to Stoddards A and B. This hot water would then be supplied to each floor of the buildings in a circular loop with baseboard radiators pulling heat out of the pipes and into the rooms of the buildings. According to Bafaro, the system could be piped to provide each room with its own thermostat; however it is not clear if this initial estimation includes such items. Combined with our proposed renovation to the envelope of the buildings, the total renovation would come to an estimated $1,551,000. With a yearly savings of $47,000, the return on investment for the total renovation is estimated at 33 years.

Chapter 5: Conclusions and Recommendations

After accumulating and analyzing all our information and data from this project, we had to decide on what options would be best for the WPI campus, in terms of heating efficiency, cost efficiency, user satisfaction, environmental friendliness, and building sustainability. Ideally, we would improve efficiency, satisfaction, sustainability, and eco-friendliness to whatever the current maximum is in each field, but unfortunately that option is both too time-consuming for residents, as well as too costly for the WPI administration. In order to find a comfortable middle ground, we weighed the importance of each category and focused on the most improvable areas while keeping in mind WPI's conservative renovation policy and tendency to overlook renovations in lieu of constructing old buildings.

Savings to WPI

For maximum efficiency, it would be ideal to replace the roof of Stoddard with a green roof, insulate the brick walls with spray-in polyurethane, replace the metal walls with a 2X6 wall similarly insulated with polyurethane, and replace the windows with triple paned Krypton-filled windows, the cost of doing so is so high that it would be more economical to replace the Stoddard Complex as a whole. Due to housing limitations and costs, it would be difficult to convince WPI to commit to either of these solutions. In order to see any improvement to the woefully inefficient Stoddard Complex, compromises must be made.

By only replacing the existing, outdated windows with smaller windows that comply with the Energy Star minimum insulation coefficient and replacing the metal walls with polyurethane-insulated 2X6 walls, WPI can get the most out of a minimal envelope renovation. By targeting the areas of greatest heat loss and simplest and easiest sections to replace, an annual savings of 30% on heating bills can be achieved. Though a greater annual savings could be reached, the initial costs are too high for WPI to allow the go-ahead on, meaning only the most efficient renovation would even be considered.

However, the electric baseboard heating system currently present in the Stoddard Complex costs the campus unnecessary money, and replacing it with a standard natural gas or even oil boiler will save the university money on its heating bills in the future, and could spur the campus to renovating some of its other electric heating systems once the impact has been made clear to them. According to our investigations, on top of financial savings, WPI will save hundreds of metric tons of greenhouse gas emissions per year instantly after a heating system renovation, which will not only help protect the environment, but will also help WPI tout its movements toward a greener and more environmentally friendly campus instead of forcing them to hide the inefficiencies of their older buildings, such as Stoddard.

Environmental Impact

The conversion to natural gas heating in the Stoddard Complex would reduce greenhouse gas emissions by more than 200 metric tons of carbon dioxide equivalents a year. If WPI were to reduce its campus emissions by that much, the university would save thousands of metric tons in carbon dioxide emissions before the Stoddard Complex is removed. Furthermore, the electricity saved in heating the complex could be better spent on appliances that cannot use natural gas, vastly increasing the efficiency of our fossil fuel consumption.

However, 200 metric tons of carbon dioxide equivalents is a miniscule amount for a campus like Worcester Polytechnic Institute. Hidden costs are all around the campus, and small changes could improve the campus’s efficiency to truly make an impact on the world and save the planet for just a little while longer. The renovation of the Stoddard Complex is a big step, but it is only one of many on a staircase WPI should climb to help the greater environment.

References

Balboni, Barbara. (Ed.). (2006).
Interior Cost Data. Kingston, MA:
Reed Construction Data

Energy Star
http://www.energystar.gov
Date Viewed: March 20th, 2007

Greenroofs.com
http://www.greenroofs.com
Date Viewed: February 28th, 2007

Green Roofs for Healthy Cities
http://www.greenroofs.org
Date Viewed: March 3rd, 2007

Inhabitat
http://www.inhabitat.com
Date Viewed: April 7th, 2007

National Oceanic and Atmospheric Administration
www.noaa.gov
Date Viewed: February 2nd, 2007

San Mateo Countywide Sustainable Buildings Guide
www.recycleworks.org/greenbuilding/
Date Viewed: March 22nd, 2007

Students for a Sustainable Stanford - Green Buildings
www.sustainability.stanford.edu/projects/greenbldng
Date Viewed: March 22nd, 2007

Thermal Industries, Inc.
http://www.thermalindustries.com
Date Viewed: April 8th, 2007

The State of Minnesota Sustainable Building Guidelines version 2.0
www.msbg.umn.edu
Date Viewed: March 22nd, 2007

United States Green Building Council
www.usgbc.org
Date Viewed: March 14th, 2007

Urban Agriculture Online
http://www.urbanag.org.au
Date Viewed: March 25th, 2007

US Dept. of Energy: Energy Efficiency and Renewable Energy—Building Energy Codes Program
http://www.energycodes.gov
Date Viewed: February 12th, 2007

Waier, Phillip R. (Ed.). (2006).
Building Construction Cost Data. Kingston, MA:
Reed Construction Data

Worcester Polytechnic Institute
www.wpi.edu
Date Viewed: January 2007

Appendices

Appendix A: Tables of R-Values

Wall Assembly R-Value

Component	R-value
Wall - Outside Air Film	0.17
Siding - Wood Bevel	0.80
Plywood Sheathing - 1/2"	0.63
3 1/2" Fiberglass Batt	11.00
1/2" Drywall	0.45
Inside Air Film	0.68
Total Wall Assembly R-Value	**13.73**

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	
Autoclaved Aerated 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	
Sheathing Materials		
Plywood	1.25	
1/4"		0.31
3/8"		0.47
1/2"		0.63
5/8"		0.77
3/4"		0.94
Fiberboard	2.64	
1/2"		1.32
25/32"		2.06
Fiberglass (3/4")		3.00
(1")		4.00
(1 1/2")		6.00
Extruded Polystyrene (3/4")		3.75
(1")		5.00
(1 1/2")		7.50
Foil-faced Polyisocyanurate (3/4")		5.40
(1")		7.20
(1 1/2")		10.80
Siding Materials		
Hardboard (1/2")		0.34
Plywood (5/8")		0.77
(3/4")		0.93
Wood Bevel Lapped		0.80
Aluminum, Steel, Vinyl (hollow backed)		0.61
(w/ 1/2" Insulating board)		1.80
Brick 4"		0.44
Interior Finish Materials		
Gypsum Board (drywall 1/2")		0.45
(5/8")		0.56
Paneling (3/8")		0.47
Flooring Materials		
Plywood	1.25	
(3/4")		0.93
Particle Board (underlayment)	1.31	
(5/8")		0.82
Hardwood Flooring	0.91	
(3/4")		0.68

Tile, Linoleum		0.05
Carpet (fibrous pad)		2.08
(rubber pad)		1.23
Roofing Materials		
Asphalt Shingles		0.44
Wood Shingles		0.97
Windows		
Single Glass		0.91
w/storm		2.00
Double insulating glass (3/16") air space		1.61
(1/4" air space)		1.69
(1/2" air space)		2.04
(3/4" air space)		2.38
(1/2" w/ Low-E 0.20)		3.13
(w/ suspended film)		2.77
(w/ 2 suspended films)		3.85
(w/ suspended film and low-E)		4.05
Triple insulating glass (1/4" air spaces)		2.56
(1/2" air spaces)		3.23
Addition for tight fitting drapes or shades, or closed blinds		0.29
Doors		
Wood Hollow Core Flush (1 3/4")		2.17
Solid Core Flush (1 3/4")		3.03
Solid Core Flush (2 1/4")		3.70
Panel Door w/ 7/16" Panels (1 3/4")		1.85
Storm Door (wood 50% glass)		1.25
(metal)		1.00
Metal Insulating (2" w/ urethane)		15.00
Air Films		
Interior Ceiling		0.61
Interior Wall		0.68
Exterior		0.17
Air Spaces		
1/2" to 4" approximately		1.00

Appendix B: Interview Questions

Questions for Bill Grudzinski

1. Were Ellsworth/Fuller/Stoddard meant to be temporary housing?
2. Is there any insulation in the walls for Ellsworth/Fuller/Stoddard?
3. Is there space for one or multiple boilers in E/F/S?
4. Can the campus heating system cross Institute Road?
5. Would the central system be able to handle any additional work?
6. Are there any plans in progress to change E/F/S?
7. Could any insulation be added to E/F/S?
8. Would WPI be open to changing the current thermostat system in E/F/S?
9. Are there specific companies that WPI would look for a boiler from?
10. How would we go about getting an estimate from a contractor for a possible renovation?
11. Is WPI currently trying to be more efficient with its heating plan?

Appendix C: Heating Systems (Unabridged)

Natural Gas

Natural gas is a fossil fuel often found in oil fields, natural gas fields, and sometimes in coal beds. Natural gas can also be produced from the decay of organic materials, specifically plants and dead animals, where it is known as biogas. Biogas is often found in swamps, marshes, and landfills. It can also be produced by bacteria that digest organic material anaerobically, also known as fermentation.

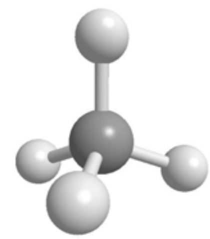

Figure 25: CH_4 (Methane), the major component of Natural Gas (Source: worldofmolecules.com

Crude natural gas is composed of methane, ethane, butane, propane, carbon dioxide, nitrogen, helium, and hydrogen sulfide. Natural gas cannot be used as fuel in its raw form. It must be processed to remove the most of the molecules that are not methane. Refined natural gas is mostly methane, but it also contains small amounts of ethane, propane, butane, and gases classified as mercaptans (sulphur-containing compounds) in order to provide the distinctive smell associated with natural gas. Trace amounts of nitrogen, helium, and carbon dioxide are also present in the refined form of natural gas. Due to natural gas' smaller molecule size, it combusts more cleanly than other fossil fuels, resulting in less greenhouse gas emissions than usual.

Component	wt. %
Methane (CH_4)	70-90
Ethane (C_2H_6)	5-15
Propane (C_3H_8) and Butane (C_4H_{10})	< 5
CO_2, N_2, H_2S, etc.	balance

Table 3: Composition of Refined Natural Gas (Source: www.gaschem.com)

Natural gas is quantified in standard cubic feet (CCF), which produces roughly 1,000 BTUs per CCF. Natural gas is traded and sold in units of therms, which is the amount of natural gas required to produce 100,000 BTUs of heat. Purchases of natural gas can escalate to decatherms, thousand decatherms, or even million decatherms for greater needs.

The largest problem with natural gas is transportation. Natural gas is a low-density gas, so containment can be hard if any leaks are found in its container. It is often transported across pipelines on land and as liquefied natural gas across oceans. Excessive transportation can occasionally result in inflated prices due to the time and effort spent ensuring the natural gas reaches its destination safely.

Natural Gas and heating oil typically can be used in all the same boilers. Natural Gas is often preferred in hydronic boilers due to its clean burning and environmental friendliness, which complements the efficiency of hydronic boiler systems nicely. Despite its low supply, natural gas usage in residential heating systems has been on the rise due to recent concerns regarding global warming and increased greenhouse gas emissions.

Fire-Tube Boilers

Fire-tube boilers are used in locomotives as well as in housing. The heating source is contained in thin pipes, which are submerged in water. The hot pipes boil the water and release water vapor, or steam, which escapes into a pipe that leads to the room to be heated. There is a chimney attached to the pipes that allows the products of combustion to escape the building, as Fire-tube boilers are often heated by wood or coal.

For a cheap, effective heating source, a fire-tube boiler would be a welcome change to the Stoddard heating system. The fire-tube boiler is a lower-technology boiler that would cost less than other forms of boilers should cost be an issue in installation.

Water-Tube Boilers

Water-tube boilers are essentially the reverse of fire-tube boilers: there are many thin pipes containing water surrounding a central heat source. These pipes are usually thin and can have many bends and fins to increase surface area and increase heating efficiency. The high-pressure water and steam contained within the pipes is then fed into a room for heating.

Water-tube boilers are similarly priced to fire-tube boilers, and they can be interchanged in terms of efficiency and comfort. The only difference would be safety of the boiler maintenance, which is slightly lower with a water-tube boiler.

Superheated Steam Boilers

Unlike regular boilers, superheated steam boilers do not release the produced steam directly into the necessary room. Instead, the steam is superheated past water's boiling point through convection, radiation, or a combination of the two. While efficiency is lost through superheating, the extra thermodynamic barrier required to condense the steam does less damage over time to the piping. Unlike other heating systems, superheated steam boilers can prove to be dangerous should any cracks or leaks be present in the piping, as the steam will cause serious harm to anyone exposed to it.

Though damage to piping and the overall system is usually minimal for a superheated steam boiler, the inefficiency is too great for commercial use and is best confined to specific tasks where a boiler's maintenance is imperative. In addition, the health risks a superheated steam boiler poses are too great for dormitory use.

Hydronic Boilers

While many boilers simply create steam and spread it through piping, hydronic boilers do not necessarily boil water into steam, though that option is still available to them. Hydronic boilers heat water to a preset temperature and circulate the heated water throughout a building using a motorized pump. The water can be passed through the radiators, baseboard heaters, or floors to heat the building. Hydronic boilers are often used in Europe, but are gaining support in North America because of their increased efficiency over regular forced-air boilers and they are smaller than the standard boiler. In addition, hydronic boilers provide a more even heating than regular boilers, do not introduce any airborne allergens or mold, and do not sap moisture from the air.

Of all the available heating systems, a hydronic boiler powered with natural gas is currently the most efficient and overall best of the heating options. The benefits a hydronic boiler provides in terms of cost and greenhouse gas emissions are augmented by the comfort and satisfaction they generally offer. For a sustainable, cost-effective heating system that provides the most satisfaction possible, a hydronic boiler would be ideal.

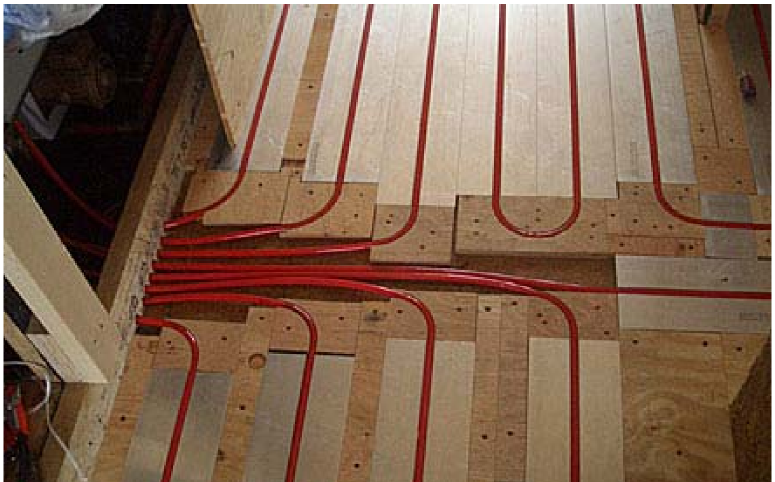

Figure 26: The Groundwork for Radiant Heat in a Floor

(Source www.torontowarmfloors.com)

Radiant Heaters

Radiant heat is the most uniform form of heating available. Within the floor and sometimes walls of a room are placed either pipes filled with heated water orhigh heat-conductive materials, which draw in the heat of a natural gas heating system or an electric heating system, respectively. The heat is transferred into the floor of the room through convection, and then from the floor to the air in the room through the same principle. A thermostat within the floor regulates the heat transferred, keeping the room at a consistent temperature until the system is turned off.

Radiant heat is the most efficient form of electric heat and one of the most efficient forms of natural gas heat. This system is ideal for a new building, as the installation is very involved and requires piping or wires to be laid throughout the floors. Renovating a building with radiant heat would unfortunately be very expensive and time-consuming, leaving it a better option for a new building in the future than a renovation for Stoddard.

Fuel Oil Heating

Fuel oil is obtained from fractional distillation of petroleum obtained from the Earth. Fractional distillation is the separation of the base product, in this case, crude oil, into more refined groups that based on molecular weight and, to a lesser degree, size. Fuel oil is separated into six different groups based mostly on the length of the hydrocarbon, ranging from No. 1 fuel oil with a 9-16 carbon chain to No. 6 fuel oil with a 20-70 carbon chain.

The lower-number fuel oils are generally more pure than the higher-number fuel oils, which are residually obtained from the distillation of crude oil into lower-number oils. The benefit to burning lower-number fuel oils is that they burn more thoroughly and cleanly, leaving less waste and greenhouse gas emissions upon combustion. No. 5 and 6 fuel oils, being residual products, are also prone to having other impurities in their composition, raising the probability of a dirtier combustion and higher greenhouse gas emissions.

Table of fuel oils				
Name	**Alias**	**Alias**	**Type**	**Chain Length**
No. 1 fuel oil	No. 1 distillate	No. 1 diesel fuel	Distillate	9-16
No. 2 fuel oil	No. 2 distillate	No. 2 diesel fuel	Distillate	10-20
No. 3 fuel oil	No. 3 distillate	No. 3 diesel fuel	Distillate	
No. 4 fuel oil	No. 4 distillate	No. 4 residual fuel oil	Distillate/Residual	12-70
No. 5 fuel oil	No. 5 residual fuel oil	Heavy fuel oil	Residual	12-70
No. 6 fuel oil	No. 6 residual fuel oil	Heavy fuel oil	Residual	20-70

Table 4: Breakdown of Fuel Oils (Source www.gaschem.com)

Fuel oil is often used to heat residential buildings in a furnace, or boiler. The most common oil is No. 2 fuel oil, a low viscosity liquid that is often dyed red to distinguish it from diesel fuel used in cars and is commonly 14-20 carbons long. No. 2 fuel oil is often kept in storage tanks until deemed necessary to use, when it is transported to the boiler for burning.

To efficiently burn fuel oil, it is first pressurized in a container. The oil then travels through a calibrated orifice as atomized droplets of oil, which are ignited with a high-voltage spark contained within the boiler. No. 2 fuel oil produces 19,500 BTU/lb, similar to the heat generation of diesel fuels.

The boilers used to heat buildings can vary between several models. They are universally made from copper, some form of steel, and/or cast iron. The source of combustion used to power boilers can be either oil or natural gas (the same boilers can be used for both oil and natural gas). Boilers can also be powered by electricity by the same principles as heating a room. Many boilers have the option of adding heat system recovery generators to them, most commonly used in combined heat and power generators.

Electric Heating

There are many different forms of electric heating available, but every version works essentially the same way. All electric heating is based off the idea that when electricity is passed through a resistor, electric energy is released and converted into heat energy. The benefits of electric heating systems are their relatively cheap installation costs, as well as the ease of installation. They also offer the most direct control over heating—each individual heat element can be turned on or off with just the flip of a switch. However, electric heating has been proven to be the least environmentally friendly of the three major sources of heating. This is because of how electricity is generated—generally, fossil fuels are burned to create electricity, and up to half of that electricity generated can be lost in transmission and through other means. On average, the greenhouse gasses emitted by electric heat is one-and-a-half times that of Natural Gas. In addition, the cost of heating a building with electric heat is on average over twice as expensive as heating the same building with Natural Gas or fuel oil. The various types of electric heating are radiative heaters, convection heaters, storage heaters, and radiant heating.

Radiative Heaters

Figure 27: A Standard Portable Convection Heater (Source: www.masterheaters.com)

Radiative heaters are most commonly known as the small, portable heaters that can be bought at many department stores. They contain a heating element that reflects off a highly polished sheet of metal or similar reflective material and emits infrared light that travels through the air until it makes contact with any object that will absorb the light. Once it is absorbed, the infrared light is mostly converted into heat; some of the heat is reflected back into the air. These heaters are most effective when only a small area needs to be heated, as they lose effectiveness the further the light travels in the air.

Convection Heaters

Convection heaters operate on the principle that hot air rises, while cool air descends. The principle of conduction is used to heat particles of air, which are then released into a space and eventually rise. This allows the cool air to enter the heating area and undergo the same process. Convection heaters set up a perpetual current of hot and cool air through the room, and are best used in isolated areas.

A refinement on the traditional convection heater is the fan heater, sometimes coined a “forced convection heater.” These operate similarly to regular convection heaters, but also include a fan that helps expel the hot air and draw in the cool air to be heated at a faster rate. These forced convection heaters also more evenly heat an area due to the faster exchange rate and air distribution of the fan. Even with the addition of a fan, convection heaters are still the most inefficient form of heating available in the United States.