Advancement of Renewable Thermal Energy Programs in MA through the Production of Case Studies

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ABSTRACT

The Massachusetts Department of Energy Resources has created programs to promote the installation of renewable thermal systems in buildings in order to decrease the Commonwealths dependence on nonrenewable resources, which are unsustainable and harmful to the environment and public health. The goal of this project was to support the DOER by evaluating three renewable thermal projects to improve and promote the installation of renewable thermal systems. We gathered information on the project processes and compiled it into informational case studies for each site. It is our hope that these case studies will lead to the implementation of more renewable thermal projects, each with more efficient implementations.

ACKNOWLEDGEMENTS

We would like to thank project advisors Seth Tuler and Paul Mathisen for providing us guidance throughout the entirety of our project process and pushing us to produce our very best work. We would also like to thank the Massachusetts Department of Energy Resources, and specifically our sponsor, Elise Anderson, for providing us with such an interesting and relevant project opportunity as well as providing feedback and support throughout our time working with the DOER. Additionally, we would like to thank Rob Rizzo for accompanying us on site visits and being a great resource for us and Betsy Harper for working with us on the Sudbury site analysis.

Table 1: Authorship

Section	Primary Author	Primary Editor
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Executive Summary	—	—
Introduction	All	All
Background	All	Jonas, Carolina, and Luis
Methodology	Keirstan and Luis	Keirstan
Results	Jonas and Keirstan	Keirstan and Carolina
Recommendations	Carolina and Keirstan	All
Bibliography	All	Luis
Appendices	Carolina	Jonas and Luis

EXECUTIVE SUMMARY

The use of fossil fuels is both harmful to the environment and unsustainable. It is linked to many problems worldwide such as greenhouse gas emissions, which cause climate change, and health issues such as cancer and respiratory problems. Furthermore, the earth's fossil fuel resources may be depleted by the end of the century.

In a legislative effort to reduce the use of fossil fuels in the Commonwealth of Massachusetts, the Global Warming Solutions Act (GWSA) was enacted in August of 2008. The GWSA created a framework for reducing heat-trapping emissions to levels that scientists believe gives humanity a chance of avoiding the worst effects of global warming. Pursuant to the GWSA, all sectors of the economy must reach a target of a 25% reduction of Greenhouse Gas (GHG) emissions by 2020 and an 80% reduction by 2050. As a result of the GWSA, many programs exist regarding energy efficiency and the use of renewable resources.

For our project we worked with the Department of Energy Resources (DOER) and their SAPHIRE and Renewable Thermal Programs that focus on reducing the fossil fuel dependence and greenhouse gas emissions in buildings. These programs had made an effort toward reducing fossil fuel use in the Commonwealth, but were lacking an evaluation and explanation of existing project processes. Evaluations and explanations of renewable thermal project processes would allow for future improvement while also providing information necessary to promote the DOERs programs.

GOAL, OBJECTIVES AND METHODS

The goal of our project was to support the DOER's commitment to reducing greenhouse gas emissions in the Commonwealth of Massachusetts by evaluating three renewable thermal pilot projects to investigate ways to improve and promote the installation of renewable thermal heating and cooling systems. In order to achieve this goal, we completed the following three research objectives to produce case studies to evaluate pilot renewable thermal programs:

Our first objective was to *identify the questions and concerns past project site leaders have had when considering implementing a renewable thermal project.* We utilized metrics formed from an interview with our sponsor to produce interview questions that we used when interviewing stakeholders at each project site. In order to identify questions and concerns past project site leaders have had we interviewed the on site project leaders and stakeholders including but not limited to: school superintendents, housing development directors, department of housing representatives, school facilities managers, and grant coordinators at the three case study sites.

Our second objective was to *determine project implementation processes and challenges of renewable thermal projects.* The application of renewable resources in buildings such as schools and public housing initiatives is relatively new in Massachusetts. Consequently, we found it important to produce an explanation of the entirety of the project process including decisions and how they were made, incentives and assistance that were provided, and any barriers encountered and how they were overcome. We interviewed those who were/are in charge of each site in regards to the implementation process of the DOER renewable thermal project at each project site.

Our third objective was to *determine how these renewable thermal projects are performing in regards to cost and energy usage.* When producing these case studies, we desired quantitative data to illustrate the effectiveness of the project. In an effort to achieve this goal, we attempted to gather information from utility bills and projected values from feasibility studies as well as utilized existing energy auditing tools to collect and categorize numerical data from each project site.

Using the information obtained through the previous tasks, we produced case studies on the three renewable thermal projects to promote future renewable thermal energy projects. We then compiled this information for each of our three sites using the data we collected and organized from the interviews and qualitative data analysis we conducted.

The three projects we focused on when completing these objectives and producing our deliverables were:

- *Amherst College Bunker Building:* Installed biomass pellet boilers. Funded partially by the Mass CEC Pilot. Operational as of April 2015.

- *Southern Berkshire Regional School:* Installed biomass pellet boilers. Funded partially by SAPHIRE and the MSBA. Nearing completion as of October 2015.
- *Sudbury Public Housing Development:* Installed Air source heat pumps. Funded entirely by the SAPHIRE program. Operational as of January 2015.

RESULTS

The findings from our fieldwork and data analysis are presented in this chapter. We first discuss the metrics used when collecting data, and then present the most relevant aspects of each of the following DOER-sponsored renewable thermal project sites we investigated: the Amherst College bunker building, the Southern Berkshire Regional School, and the Sudbury Public Housing Development. We then provide the list of findings we compiled from our data collection at each of the three project sites.

Determination of Metrics

- Cost is a Metric for Assessing Renewable Thermal Projects
- Community Acceptance is a Metric for Assessing Renewable Thermal Projects
- Operational Logistics and Aesthetics are Metrics for Assessing Renewable Thermal Projects

Site Findings

- Commissioning a feasibility study prior to beginning a renewable thermal project can be very valuable
- Failure to consider the context in which a renewable energy technology is being implemented can lead to poor performance and increased required maintenance
- Educating the community about new technology before installation can lead to community support

- Working with experienced engineers can make a big difference in the project timeline and post project effectiveness
- Improving a buildings energy efficiency improvements prior to or in addition to upgrading the heating system may lead to increased cost savings
- Public housing rules and regulations can be barriers when implementing a renewable technology project
- Failure to consider context when choosing a metering system can lead to problems with gathering data

While many of our findings are specific to the project sites we studied, it is important to note that these findings can be applied to many renewable thermal project sites to come. From our findings we compiled a list of recommendations (located in the following chapter) that we presented to the DOER. It is our hope that the DOER will be able to use the recommendations to make improvements to future renewable thermal projects.

RECOMMENDATIONS

Each recommendation is supported by our findings and review of relevant literature. It is important to note that our data analysis, and thus our recommendations are not without limitations. We were unable to provide an analysis of projected outcomes and actual outcomes relating to greenhouse gas emissions, renewable system energy efficiency, annual energy use, and annual fuel cost comparison of renewable systems and fossil fuel systems due to the lack of access to quantitative data at each site. Furthermore, our recommendations stem from site visits at only three project sites in a young program. For this reason, our recommendations reflect our analysis of qualitative data we collected including interviews and onsite visits from each of the three project sites. The recommendations are organized into major categories in the following sections.

Recommendations relating to informational material for potential project sites

- We recommend that the DOER continue to create case studies to provide up to date information to potential project sites about existing renewable thermal projects

- We recommend that the DOER bring case studies when consulting with new project sites
- We recommend that the DOER provide examples of cost comparisons of fossil fuels and renewable energy including implementation and operational costs when consulting potential project sites

Recommendation Relating to Community Education

- We recommend that the DOER provide methods or examples for conducting outreach and education of the community on renewable thermal technologies when consulting potential project sites

Recommendations Relating to Feasibility Studies

- We recommend that a feasibility study be completed at each potential project site
- We recommend that potential project sites commission a feasibility study prior to beginning a renewable thermal project
- We recommend that the DOER strongly suggest or make it a requirement of their grant program that renewable thermal project sites commission a feasibility study prior to beginning a renewable thermal project
- We recommend that the DOER provide funding to commission a feasibility study that include a comparison of multiple renewable thermal heating and cooling systems
- We recommend that the DOER provide funding to commission a feasibility study that compares different types of metering systems and their application in the project site before providing funding to sites for metering systems

Recommendations Relating to Experienced Engineers and Contractors

- We recommend that project sites work with engineering firms and contractors that are familiar with renewable technologies
- We recommend that the DOER provide a list of engineering firms and contractors that are familiar with each type of renewable thermal technology to each project site

- We recommend that there be investment in educating contractors and electricians in renewable thermal technology

Through the collection and analysis of data from project site leaders at three renewable thermal projects sponsored by the DOER, we achieved our goal, to support the DOER's commitment to reducing greenhouse gas emissions in the Commonwealth of Massachusetts by evaluating three renewable thermal pilot projects to investigate ways to improve and promote the installation of renewable thermal heating and cooling systems, by producing three informational case studies. It is our hope that the case studies we produced will both promote the DOER renewable thermal programs and provide information to potential project site leaders that will, along with the list of recommendations, aid in improving renewable thermal project processes. As the number of successful renewable thermal projects increases in the Commonwealth of Massachusetts, greenhouse gas emissions and fossil fuel dependence will decrease, resulting in a healthier and more sustainable future.

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INTRODUCTION

Industrialized nations have relied on fossil fuels as the main fuel for electricity, transportation, and industry since the Industrial Revolution. The use of fossil fuels is both harmful to the environment and unsustainable, as it is linked to many problems worldwide such as greenhouse gas emissions which cause climate change and health issues such as cancer and respiratory problems (Ecotricity, 2011; Sharfiee, & Topal, 2009). Climate change from greenhouse gas emissions in turn leads to the melting of polar ice caps, rising sea levels, and changes of localized climate patterns (Samimi, & Zarinabade, 2012; Holdren, 2000). Furthermore, the earth's fossil fuel resources may be depleted by the end of the century (Ecotricity, 2011; Sharfiee, & Topal, 2009).

The U.S. obtains more than 80% of its energy from fossil fuels such as oil , coal, and natural gas, which means that with an increase in energy use comes an increase in greenhouse gas emissions (The National Academies, 2015). Buildings are now the largest sector of energy use, ahead of both industry and transportation, accounting for 41% of all energy used in the U.S. (USGBC, 2015; Perez-Lombard, 2008). Furthermore, buildings are responsible for 50% of the greenhouse gas emissions in developed countries, such as the U.S. (Rezaie, 2013). Public buildings specifically are large energy consumers because they are used by many people, are large in size, and operate frequently. Furthermore, public buildings are sometimes reliant on costly #2 heating oil which emits the most greenhouse gas emissions of any heating source (DOER, 2015). The U.S. views the use of renewable resources as a potential solution to the problem of fossil fuel dependence and the negative consequences that are associated (EIA, 2015). For these reasons, buildings have become a primary focus for reduction of energy consumption and for renewable energy implementation.

The Commonwealth of Massachusetts is working towards using renewable resources to address the issue of greenhouse gas emissions caused by fossil fuel use. In a legislative effort to reduce the use of fossil fuels in the Commonwealth of Massachusetts, the Global Warming Solutions Act (GWSA) was enacted in August of 2008. The GWSA created a framework for reducing heat-trapping emissions to levels that scientists believe gives humanity a chance of avoiding the worst effects of global warming. Pursuant to the GWSA, all sectors of the economy must reach a target of a 25% reduction of Greenhouse Gas (GHG) emissions by 2020 and an 80% reduction by 2050 (EEA, 2015).

As a result of the GWSA, many programs exist regarding energy efficiency and the use of renewable resources. For example, Mass Save (sponsored by the investor-owned utility companies in the state) provides assistance to update old buildings to be more energy efficient and use less fossil fuel by providing free energy audits, LED light bulbs, air sealing, and financial incentives for adding insulation. In addition, the Massachusetts Clean Energy Center (Mass CEC) has offered grants for residential and commercial renewable thermal systems and district energy configurations, where one renewable heating/cooling source provides energy for multiple facilities arranged in a complex. The Department of Energy Resources (DOER) has implemented various programs that provide funding and guidance to project sites looking to implement renewable energy systems in buildings (Mass Department of Energy Resources, 2015). One DOER program is the Renewable Thermal Program, which provides technical assistance and grant funding to municipalities. Included in this program is the Schools and Public Housing Integrating Renewables and Efficiency program (SAPHIRE), which focuses specifically on providing dedicated technical assistance and grant funding to K-12 public schools and public housing developments (Mass Department of Energy Resources, 2015).

These programs had made great strides toward reducing fossil fuel use in the Commonwealth, but were lacking an evaluation and explanation of existing project processes. Evaluations and explanations of renewable thermal project processes would allow for future improvement while also providing information necessary to promote the DOERs programs (DOER, 2015). The goal of our project was to support the DOER's commitment to reducing greenhouse gas emissions in the Commonwealth of Massachusetts by evaluating three renewable thermal pilot projects to investigate ways to improve and promote the installation of renewable thermal heating and cooling systems. In order to achieve this goal, we completed the following three research objectives to produce case studies to evaluate pilot renewable thermal programs:

1. Identify the questions and concerns past project site leaders have had when considering implementing a renewable thermal project.
2. Determine project implementation processes and challenges of renewable thermal projects.
3. Determine how these renewable thermal projects are performing in regards to cost and energy usage.

The three projects we focused on when completing these objectives and producing our deliverables were:

- *Amherst College Bunker Building:* Installed biomass pellet boilers. Funded partially by the Mass CEC Pilot. Operational as of April 2015.
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It is our hope that the case studies we produced on these three DOER renewable thermal projects will enable the DOER to determine where their projects are succeeding in terms of both process and technology performance, and provide information on how these projects can be improved in the future. These case studies may also act as a powerful source of clarifying information for potential renewable thermal project site leaders when considering the implementation of a renewable energy heating system. It is our intention that these case studies will instill confidence among potential project site leaders regarding these renewable technologies and therefore expand the number of these projects. By increasing both the number and effectiveness of these projects, the DOER will be able to decrease fossil fuel use and greenhouse gas emissions within the Commonwealth of Massachusetts.

2

BACKGROUND AND LITERATURE REVIEW

In this chapter we will provide contextual information on the issue of fossil fuel dependence as well as the application of renewable energy sources in public buildings in the U.S. This chapter also includes an explanation and comparison of different renewable energy types to provide background on existing and emerging technologies for thermal heating and cooling and their respective advantages. Additionally, information on how the Commonwealth's energy resources and regulations factor into the success of the DOER's renewable thermal project sites is provided.

2.1 FOSSIL FUEL DEPENDENCE AND ITS CONSEQUENCES

The United States has depended on non-renewable resources as a source of power since the 1800's when oil and coal were discovered to be more energy dense than wood (Samimi, & Zarinabadi, 2012, WaitButWhy, 2015). Figure 1 represents the percentages of the total energy consumed in the United States. More than 80% of the total energy consumed by the country comes from a non-renewable source of energy (U.S. Energy Information Administration, 2015).

These sources are limited and are damaging to public health and the environment. The use of fossil fuels is a threat to public health due to the effects that greenhouse gas emissions and other pollutants can have (Haines, Kovats, Campbell-Lendrum, & Corvaln, 2006). The pollution caused by fossil fuels is directly related to health problems such as asthma, ischemic heart disease, chronic bronchitis, cancers, and increasing mortality rate, among others (Rabl & Spadaro, 2000; Kampa, & Castanas, 2008). The use of fossil fuels is responsible for 76% of the total greenhouse gas emissions released by the United States. Greenhouse gases create a layer around the Earth that keeps solar radiation within the atmosphere in order to keep the Earth's average temperature suitable for life (Samimi, & Zarinabadi, 2012). As the concentration of greenhouse gasses in the atmosphere grows, the gasses will keep more solar radiation and warmth inside the atmo-

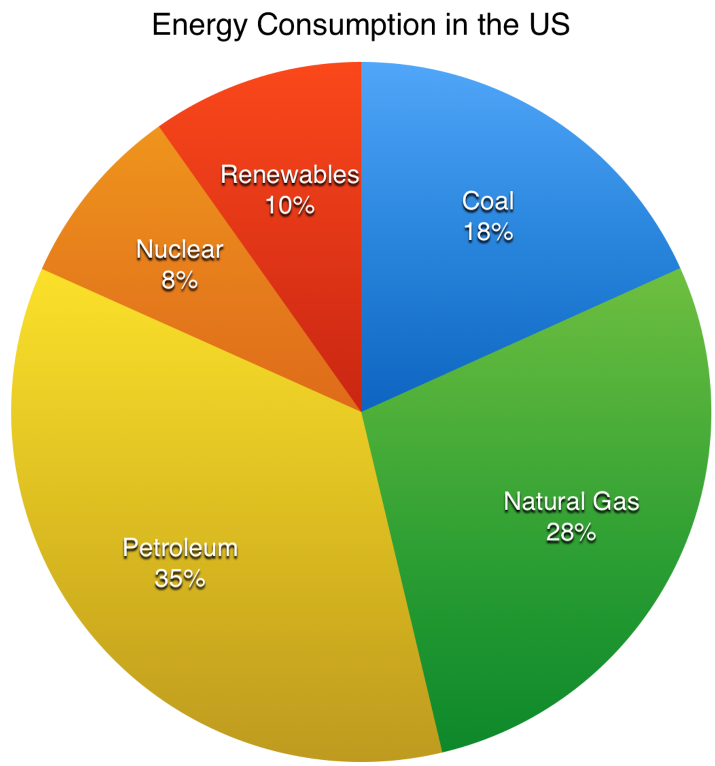

Figure 1: Energy Consumption in the US (U.S. Energy Information Administration, 2015)

sphere, elevating the average temperature of the Earth (Samimi, & Zarinabadi, 2012). This temperature change can lead to catastrophic climate changes in the world such as the melting of the ice poles, sea level rise, and others (U.S. National Climate Assessment, 2014).

Greenhouse gasses are not the only detriment from the pollution that burning fossil fuels produces. Acid rain is directly linked to fossil fuels due to the sulfur dioxide and nitrogen oxides that power plants release when burning fossil fuels (U.S. Environmental Protection Agency, 2012). Acid rain negatively affects the biodiversity of our planet by changing the pH of water and acidifying soils (Likens, 2011). A recent survey in the Northeast of the United States showed that 41% of lakes in the Adirondack Mountain region are acidic or subject to short-term pulses in acidity related to snowmelt and rain storms. Similarly, the same characteristics were found in 15% of the lakes in the areas of Catskill and New England (Likens, 2011).

Fossil fuels also damage the environment through accidents such as oil spills. Oil spills affect a great variety of animals, both in the ocean and in surrounding areas (Office of Response and Restoration, 2015). Light oils such as gasoline or diesel are highly explosive and toxic, therefore they can kill animals and plants that they touch and can also affect human beings who inhale the fumes. Heavy oils are black and sticky substances commonly used to fuel ships. In the short term these oils can cover organisms affecting their mobility and can also affect their ability to keep warm; many birds die from hypothermia due to these oil spills (Office of Response and Restoration, 2015). In the long run, exposure to heavy oils might result in health problems such as tumors in organisms (Office of Response and Restoration, 2015).

In addition to the use of oil, the use of natural gas has negative consequences. Hydraulic fracturing (also known as fracking) is a natural gas harvesting process that uses large quantities of water to fracture the earth and release gas. In fact, annual water consumption by fracking is equivalent to the annual water consumption of 40 to 80 cities with populations of 50,000 each (Gold, 2014). Figure 2 illustrates how natural gas use in Massachusetts has grown while coal and oil use have declined. While not harvested in Massachusetts, the increased use of natural gas results in increased fracking in other areas of the country to keep up with the increasing demand.

The use of fossil fuels is damaging the world in multiple ways, and as the world needs more energy, the pollutants derived from the use of fossil fuels increase. The U.S. Energy Information Administration has projected that the world's energy consumption will increase by 56% by 2040 (Samimi, & Zarinabadi, 2012). Increasingly, buildings are becoming a large portion of this energy consumption and are thus an area for concern (Rezaie, 2013).

2.2 ENERGY USE OF THE BUILDINGS SECTOR

Buildings contribute greatly to our greenhouse gas emissions. In developed countries, 50% of the CO_2 emissions and 40% of the energy consumption can be attributed to buildings (Rezaie, 2013). Because of the development of more buildings and their increased energy use, buildings are now the largest sector of

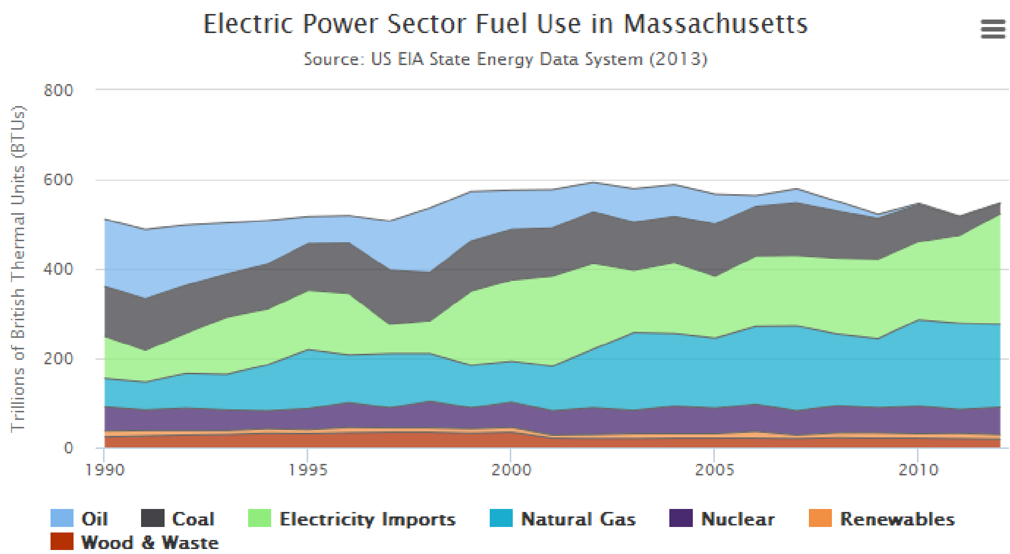

Figure 2: Electric Power Sector Fuel Use in Massachusetts (EIA, 2013)

energy use, drawing more than the transportation and industrial sectors in most developed countries (EIA, 2015). The United States is one of the countries with the highest building energy use rates, consuming 41% of the country's total energy, while the EU and the rest of the world use less energy in buildings at 37% and 24% respectively (EIA, 2014; Perez-Lombard, 2008).

There are many factors contributing to the increased energy use in buildings within industrialized nations. Use of computers and other office equipment drives up the electricity consumption along with lighting, heating, and cooling (Spyropoulos, 2011). As people spend more and more time inside, working, taking classes, etc., the cost of powering those buildings increases (Perez-Lombard, 2008). Office buildings particularly, running mainframes and powering computers for all employees, are drawing increasingly more power (Eichholtz, 2010). Energy consumption due to lighting has also gone up in recent years, although this consumption is predicted to decrease in the near future because of the expected adoption of efficient Compact Fluorescent Lamps (CFLs) and LED lighting with sophisticated controls (Spyropoulos, 2011).

Heating and cooling have large energy demands in most buildings and are becoming more necessary with the amount of time people have been spending indoors. In an energy audit of school buildings in Italy, thermal consumption was 80% of the energy consumed (Desideri, 2002). This is not uncommon: in the average Massachusetts household, thermal energy use represents about 75% of the energy consumption with space heating the biggest component (60%) (EIA, 2015).

With buildings using large amounts of energy, especially for heating and cooling, many alternative and renewable energy options have been researched to decrease the use of fossil fuels for energy use and buildings. Data from one case study in Ontario, presented in Table 2, shows the distribution of different draws of energy in a typical residential building as well as common sources of energy for them. The rightmost column in Table 2 shows possible alternative and renewable energy sources that can improve the energy efficiency of the building and decrease the use of fossil fuels. Appliances, lighting, and other can use electricity generated on site by any solar, wind, or other renewable sources.

Heating, ventilating, and air conditioning (HVAC) systems have the largest demand of energy in buildings, consuming on average 50% of a building's energy (Perez-Lombard, 2008). The energy use in buildings by heating and cooling systems will continue to increase as industrialized nations build more and bigger buildings, although improvements in energy efficiency and smarter building design may be able to mitigate this increase in heating and cooling energy use (Perez-Lombard, 2008). Additionally, older buildings with very low energy efficiency use much more energy in heating and cooling than they otherwise would if newer technologies were used in the buildings (Krawcyzk, 2014). With HVAC being the largest sector of energy use within buildings, which is the largest sector of energy consumption in the developed world, it's clear that heating and cooling in buildings is a huge target for improvement.

2.3 Transitioning between fossil fuels and renewable energy

One of the potential solutions to the problem of fossil fuel dependence and the harm they have on the environment and public health is the use of renewable energy. The Oxford Dictionary defines renewable energy as energy from a source

Table 2: Energy Use in a Residential Building Energy Use in a Residential Building (Rezaie, 2013)

Energy Draw	Amount of Energy	Common Sources	Alternate Technologies
Space heating and cooling	55%	Heating oil, coal, propane, electricity, natural gas	Biomass, solar thermal, geothermal, air & water source heat pumps
Hot water heating	20%	Heating oil, coal, propane, electricity, natural gas	Solar thermal, biomass, heat pumps
Lighting	5%	Electricity generated at power plants using natural gas, coal, or nuclear	Electricity generated by wind, solar, photovoltaic, wood, geothermal for electricity generation
Appliances	15%	Electricity generated at power plants using natural gas, coal, or nuclear	Electricity generated by wind, solar, photovoltaic, wood, geothermal for electricity generation
Other	5%	Electricity generated at power plants using natural gas, coal, or nuclear	Electricity generated by wind, solar, photovoltaic, wood, geothermal for electricity generation

that is not depleted when used. With a growing population and increase in energy demand, the use of renewable energy is intended to promote a sustainable future without large adverse effects on the environment (Samimi, & Zarinabadi, 2012). The transition from fossil fuels to renewables is certainly a complex process requiring the involvement and consideration of many groups and factors. Some of the aspects that impact this transition from fossil fuels to renewable resources include public opinion, overall cost, regulatory incentives and disincentives, any kind of performance metering that may be desired or required, and potential obstacles (EEA, 2015).

2.3.1 *Public Opinion on Renewable Energy Systems*

When implementing a public project with renewable energy, the sponsor needs to take into consideration the public's view of the project. If the project is not socially accepted, it has a higher likelihood of failing. If the public accepts the program, sponsors like the Department of Energy Resources (DOER) will be able to provide grant money and expand the reach of their renewable energy programs.

One reason why the public might not accept the implementation of renewable heating and cooling systems in buildings is the uncertainty as to whether or not renewables are able to maintain climate control as well as current energy sources. The reason for this is twofold: people are often unaware of how these new technologies work because of how recently they have been brought to the energy market, and even if they are familiar with the technologies they often do not trust the systems until they've seen them in use themselves (Karlstrom, Ryghaug, 2014).

Consequently, potential project leaders can change the negative assumptions the public in their community has about renewable technologies by removing the knowledge deficit (Brunk, 2006). This deficit in knowledge could be reduced by education or persuasive communication, where the sponsor can help the public understand that renewable technologies not only perform as well as current energy resources, but also reduce greenhouse gas emissions and do not harm our environment (Brunk, 2006). Studies have shown that the public support for renewable resources increases if they are given thorough information about the pros and cons of the implementation of these technologies (Ogarra, Mourato, and Pearson 2005). The community understanding and supporting the technology does not guarantee that the project will succeed though. They may support the technology, but not the way it's proposed to be implemented, or the cost or timing of the project. But with community support for the technology, the details of the project can then be worked out to maximize support for the project.

Public opinions tend to become more positive once a project is implemented and people understand the economic benefits (Karlstrom, Ryghaug, 2014). One way to address the knowledge deficit after project implementation is through educational programs, such as kiosks at the location of the project or webpages. The Ferrisburgh Solar Farm, which was built in Vermont, is a 3,806 solar panel system, installed by REV Corporate Member Alteris Renewables (Renewable Energy Success Stories, 2015). After the implementation of this project, the Solar Farm created an open-to-the-public educational kiosk where they provide the information about the benefits of the project. They also published a website on the internet that tracks the solar energy output of their farm (Renewable Energy Success Stories, 2015). If the public comes to understand how renewable technologies work, they may begin to support more renewable energy projects, which would aid in their community's transition away from fossil fuels and toward renewable energy sources.

2.3.2 *Cost and Pricing of Renewable Energy Systems*

Making the choice to switch to renewable resources is just like many other long term investments. The upfront cost is high, but in the long term, it will save money. For example: buying a car is a long term investment where generally the longer you keep the car, the more value you get out of the investment, but if you only look at the short term, leasing may be more cost effective. Installing renewable energy sources can pose a large upfront cost, but some renewable resources have lower operating costs than fossil fuels and thus will save money in the long term (BEAM Engineering, 2014; D.C. Architects, 2014; DOER, 2015; RDK Engineers, 2014; Wilson Engineering, 2015). In order to lighten the load of the upfront initial cost, there are many government funds allocated to help renewable energy projects. Despite the effort toward incentivizing renewable energy projects, the World Bank and International Energy Agency put global annual subsidies for fossil fuels in the range of $100 billion to $200 billion, making renewable energy programs appear even more expensive by comparison (Beck & Martinot, 2004).

Many different costs factor into the high upfront cost of installing a renewable thermal technology. The assessing of the property, permitting, and planning add to the upfront cost, as they must be completed by a contracted, qualified, and well-experienced engineering firm (DOER, 2015). These renovations can completely change a building's heating and cooling system, which is an expensive change as well (Beck & Martinot, 2004). After all the support work, the actual renewable energy technologies need to be purchased, and they may face high taxes and import duties (Beck & Martinot, 2004). Where renewable energy technologies excel is in the operations and fuel costs. For example, many renewable resources, such as solar, don't require the purchase of fuel. Additionally, once the system is operational, the maintenance costs of the system are often similar to the costs associated with fossil fuel heating systems (BEAM Engineering, 2014; Wilson Engineering, 2015).

2.3.3 *Performance Metering in Renewable Energy Systems*

When considering the implementation of a renewable thermal project, multiple stakeholders are interested in being provided with an accurate measurement of cost savings (Massachusetts Department of Energy Resources, 2015). Additionally, once a project has been completed many owners want to know exactly how much money they are saving with their new installation. The way to obtain this information is generally through performance metering technology. There are multiple types of performance metering ranging from just looking at total energy consumption per month, to monitoring each circuit in the building on a minute by minute basis.

The Department of Energy Resources uses two metering systems for the installations that they fund: Mass Energy Insight and Energy Star Portfolio Manager. These both only monitor the monthly power consumption, so they do not provide very detailed data on power usage. PowerWise is a metering tool that the DOER has begun working with in order to close this gap. PowerWise consists of hardware installed inside the electrical panels that communicates to an online interface. This interface shows information relating to electricity use for each major appliance including energy use and cost for varying time intervals (i.e. monthly, weekly, daily) (DOER, 2015). For more information on PowerWise, see Appendix 1.

2.3.4 *Potential Obstacles in Transitioning to Renewable Energy Sources*

In any implementation of renewable thermal systems, there are multiple potential obstacles to be aware of. Many renewable energy programs focus on projects in buildings where the fossil fuel systems are in disrepair or need be replaced. Rather than simply replacing an oil boiler, for example, a renewable energy project may require the implementation of a completely new heating and cooling system. With a renovation this large, there are many problems that can be encountered, including but not limited to: old electrical systems, asbestos, and lead paint. These could cause logistical delays and can also result in a more complex and expensive renovation (Massachusetts Department of Energy Resources, 2015).

In addition, renewable systems such as wind turbines, rooftop solar hot-water heaters, photovoltaic installations, and biomass combustion systems may face restrictions based on parameters such as height, noise, and aesthetic concerns (Beck & Martinot, 2004). These restrictions vary based on the implementation site, so extensive background research is required before starting a renewable energy project (Beck & Martinot, 2004).

2.4 Massachusetts and energy efficiency/renewable energy programs

Despite the difficult process of transitioning to renewable energy systems, Massachusetts is committed to increasing the use of renewable resources to decrease greenhouse gas emissions. Focusing on buildings with regards to energy is especially important for Massachusetts because buildings account for 49% of all energy consumed in the Commonwealth, compared to 41% nationally (EIA, 2015). Ranked 5th with the most LEED certified buildings in the United States, the Commonwealth of Massachusetts has become a leader in energy efficiency and alternative/renewable energy use (USGBC, 2015). This success in LEED certifications is due in part to the many supportive energy efficiency and renewable energy grants, programs, and regulations in the Commonwealth of Massachusetts. An important part of Massachusetts' efforts to promote the use of renewable energy resources is the Green Communities Act of 2008.

The Green Communities Act prompted programs to boost energy efficiency and encourage investment in renewable energy (Conservation Law Foundation, 2010). This act also requires utilities to increase investment in energy efficiency, reducing demand and delivering savings to customers. The Green Communities Act mandates the design and implementation of three year energy efficiency plans for gas and electric utilities, provides funding for energy efficiency projects, and requires that 15% of all electricity be supplied by new renewable power facilities by 2020 (Conservation Law Foundation, 2010).

With the Green Communities Act of 2008 legislation in place, funding and guidelines became available for emerging energy efficiency and renewable energy programs to utilize. As a result, many programs within Massachusetts aim to further the Commonwealth's energy efficiency and renewable energy successes. The Massachusetts Clean Energy Center (Mass CEC) is an agency that was developed in 2009, immediately following the Green Communities Act. The Mass CEC is dedicated to accelerating the success of clean energy technology through providing funding for renewable energy rebates for residents and businesses (Mass CEC, 2015). Another important program for the progression of energy efficiency and renewable resources is the Massachusetts School Building Authority (MSBA). The MSBA has started sustainable programs with emphasis on reducing energy and water consumption (MSBA, 2011). The MSBA also utilizes the MA Collaborative point system to assess potential projects in high performance schools and how much, if any, funding they will provide to aid these projects (MSBA, 2011). This Green Schools program under the MSBA pays a percentage of the total cost to renovate schools that wish to increase energy efficiency and/or install a renewable energy heating and cooling system (MSBA, 2011).

2.4.1 *Specific Energy Efficiency/Renewable Energy Programs in Buildings*

There are many building focused energy programs within the Commonwealth of Massachusetts. For example, the *Building America: Bringing Buildings Innovations to Market* program focuses on improving building energy performance in residences all over the country; however, it has a concentrated focus on the Commonwealth of Massachusetts due to the Commonwealth's energy programs and legislation (EERE, 2015). Another similar program with large focus in Massachusetts is *Better Building Partners*, a program that works with communities to promote energy efficiency in homes and other buildings. In order to achieve these goals, the program works with city and statewide partners (EERE, 2015).

2.4.2 *DOER's Renewable Thermal Programs*

Among the different programs for the implementation of renewable resources offered in Massachusetts are the focuses of our project: the DOER's Renewable Thermal Program and the Schools and Public Housing Integrating Renewables Efficiency (SAPHIRE) Program. The goal of these DOER programs is to help municipalities, schools, and public housing initiatives install renewable heating and cooling systems across the Commonwealth (Massachusetts Department of Energy Resources, 2015). The programs have begun to reach their goal of implementing renewable thermal heating and cooling systems in different types of buildings.

The DOER's Renewable Thermal Program and SAPHIRE Program focus mainly on public buildings for a few reasons. The first is that the programs are using government funding, so it makes logical sense to use these resources to improve public resources and decrease the expenses of public facilities. The second reason is that public buildings require a lot of energy: 49% of all energy in Massachusetts. Public buildings are often relatively large in size, and thus consume a lot of energy for heating and cooling. Lastly, even if individuals change their residences to use renewable energy for heating and cooling, a community won't be completely sustainable until the public resources are addressed, which is the responsibility of the government (Office of Energy Efficiency and Renewable Energy, 2015).

2.5 RENEWABLE ENERGY TECHNOLOGIES

Renewable energy is a potential solution to the use of fossil fuels, specifically in public buildings. There are multiple renewable sources of energy in the market used to generate either electricity (measured in kilowatt hours (kWh)) or heating energy (measured in British Thermal Units (BTUs)). With the relatively high consumption of BTUs in buildings in the Northeast, the DOER has developed incentive programs to support renewable sources of heating and cooling: solar thermal, geothermal, biomass and most recently, air source heat pumps. In this section, we will provide a description of each renewable energy technology as well as its advantages and disadvantages. Since the scope of our project is within Massachusetts, we will provide relevant information on these technologies with regards to their application in the Commonwealth of Massachusetts.

2.5.1 *Solar Thermal*

A solar thermal system consists of panels that absorb the energy of the sun to heat pipes with water (or another liquid) that then will heat the building spaces or provide hot water heating (as seen in Figure 3) (Massachusetts Department of Energy Resources, 2015).

Solar thermal systems differ from solar photovoltaic (PV) systems in that they generate thermal energy instead of electricity. Solar thermal systems have multiple advantages and disadvantages related to the use and installation, which are

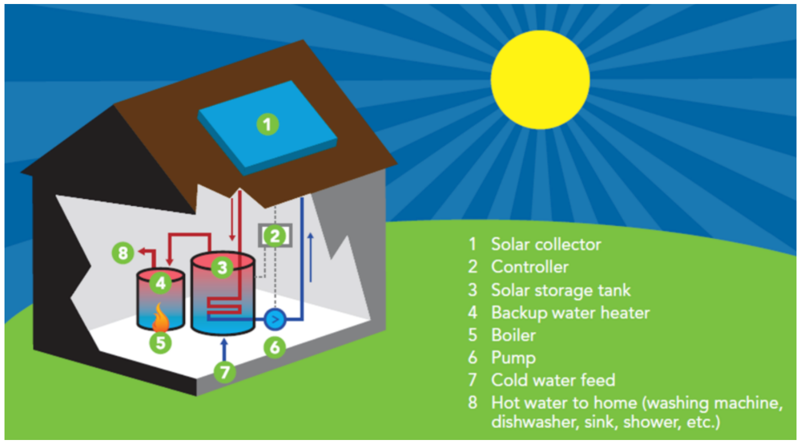

Figure 3: Solar Hot Water Heating System (Massachusetts DOER, 2015)

important to consider in order to understand when and where this solar thermal system might be applicable and efficient. Below we provide a summary of the advantages and disadvantages of using a solar thermal system.

Advantages of a Solar Thermal System include:

- The ability to heat liquids such as water that then can be used for showers, pools and laundry (Massachusetts Department of Energy Resources, 2015).
- The ability to be installed in such way that it will integrate with the HVAC system and provide space heating (Massachusetts Department of Energy Resources, 2015).
- The capacity to provide between 50-75% of the total building's hot water needs (depending on roof exposure, weather, and system size) (Massachusetts Department of Energy Resources, 2015).
- The ability to store energy for when the sun sets and is able to provide some energy during cloudy days (Massachusetts Department of Energy Resources, 2015).
- The low price after incentives save customers up to 50% of the cost of the system through the Commonwealth Solar Hot Water Rebate program and the 0% interest HEAT loans available through Mass SAVE (Massachusetts Department of Energy Resources, 2015).

Disadvantages of a Solar Thermal System include:

- The inability to be used as the only source of power to meet the base load energy demand of a building (Massachusetts Department of Energy Resources, 2015).
- The potential to emit some greenhouse gases such as nitrogen trifluroide and sulfur hexafluoride (Maehlum, M. A., 2014)

2.5.2 *Geothermal Heating and Cooling*

A geothermal system consists of pipes placed around 300-900 feet underground that carry water via either a closed-loop or open-loop configuration (Massachusetts Department of Energy Resources, 2015). In the winter, the water absorbs the underground heat, as the temperature under the surface of the Earth is a relatively consistent 50 degrees Fahrenheit (Massachusetts Department of Energy Resources, 2015). This process can be reversed in the summer. Indoor heat is extracted from the building and transferred to the earth through the liquid (Massachusetts Department of Energy Resources, 2015). Geothermal heat pumps are 3.5 - 5 times as efficient as the most efficient fossil fuel furnace. Instead of burning a combustible fuel to make heat, they simply move heat that already exists. By doing so, they provide 3.5 - 5 units of energy for every unit used to power the heat-pump system (Massachusetts Department of Energy Resources, 2015). Figure 4 is a graphic representation of how a geothermal system operates.

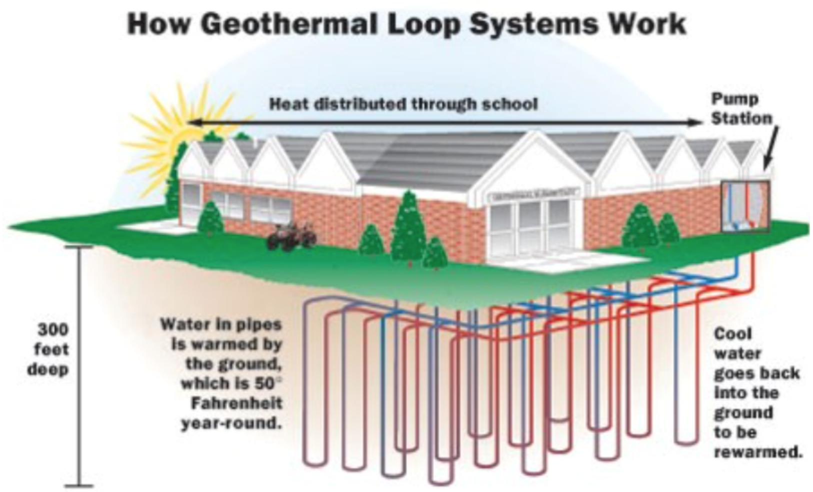

Figure 4: Geothermal Loop System (Massachusetts DOER, 2015)

The following list shows the advantages and disadvantages of the use and/or installation of Geothermal heating systems.

Advantages of a Geothermal Heating System include:

- The ability to provide heat during the winter since the temperature in the Earth will be constant and warmer than the outside air (Massachusetts Department of Energy Resources, 2015).
- The ability to cool in the summer by reversing the process and extracting indoor heat from the building and transferring it to the earth through the liquid (Massachusetts Department of Energy Resources, 2015).
- That the system lasts for at least 25 years and all the underground components last for more than 50 years (Massachusetts Department of Energy Resources, 2015).
- That the properly installed system can deliver more energy than conventional heating systems, reduce winter costs of heating by half, and heat water for free during the summer (Massachusetts Department of Energy Resources, 2015).
- That there are multiple financing programs and incentives available across the country and especially in Massachusetts through the Department of Energy Resources' programs (Massachusetts Department of Energy Resources, 2015).

Disadvantages of a Geothermal Heating System include:

- That there is a large upfront installation cost associated with geothermal systems (Massachusetts Department of Energy Resources, 2015).
- That geothermal systems' efficiency can also be very location and geology dependent, which means that in some cases they might not be cost effective (Maehlum, 2014).

2.5.3 *Biomass*

Biomass is a technology that produces energy by burning organic materials. This method is mainly used in buildings to heat the indoor environment or water (Massachusetts Department of Energy Resources, 2015). Figure 5 is a graphic representation of a wood fueled heating system; in these systems not only logs of wood can be used, but also wood chips and pellets that are more efficient at heating the building and require less storage space (Massachusetts Department of Energy Resources, 2015).

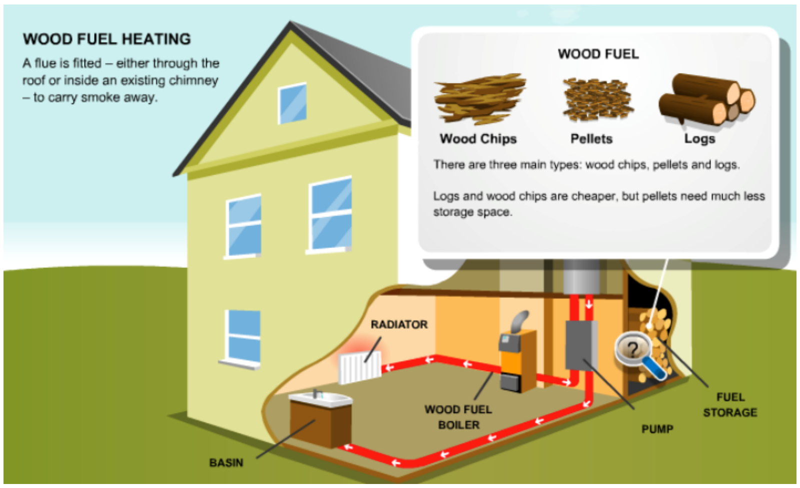

Figure 5: Biomass System (Massachusetts DOER, 2015)

Biomass systems have a variety of positive and negative characteristics related to their use and installation.

Advantages of a Biomass System include:

- That it strengthens the market for locally-sourced energy products, particularly when biomass is produced from waste and residual woods which are byproducts of forestry and manufacturing within the region. This supports the local clean energy economy and job growth (Massachusetts Department of Energy Resources, 2015).
- That the low carbon emissions are very suitable for woodlands (Massachusetts Department of Energy Resources, 2015).
- That most conventional systems are fully automated making them easy to operate and maintain (Massachusetts Department of Energy Resources, 2015).
- That the cost of wood is generally cheaper than the conventional sources of energy such as oil, propane, and electric heat (Massachusetts Department of Energy Resources, 2015).

Disadvantages of a Biomass System include:

- That it can actually contribute to deforestation if used incorrectly (Massachusetts Department of Energy Resources, 2015).
- That it requires a rather large space for storage of the biomass supply. Usually several weeks supply is stored on site, sometimes in 20-foot tall silos (Massachusetts Department of Energy Resources, 2015).
- That the cost of acquiring a completely new heating system can be higher when compared to conventional fossil fuel heating systems (Massachusetts Department of Energy Resources, 2015).

2.5.4 *Air Source Heat Pumps*

An air source heat pump system consists of an outdoor air compressor/condenser and an indoor air-handling unit. This system is able to heat and cool air by transferring inside and outside air and cooling or heating it through pipes. A mini-split system consists of one air compressor and multiple smaller, indoor air-handling units (Massachusetts Department of Energy Resources, 2015). Figure 6 shows how air source heat pump systems function in winter and summer.

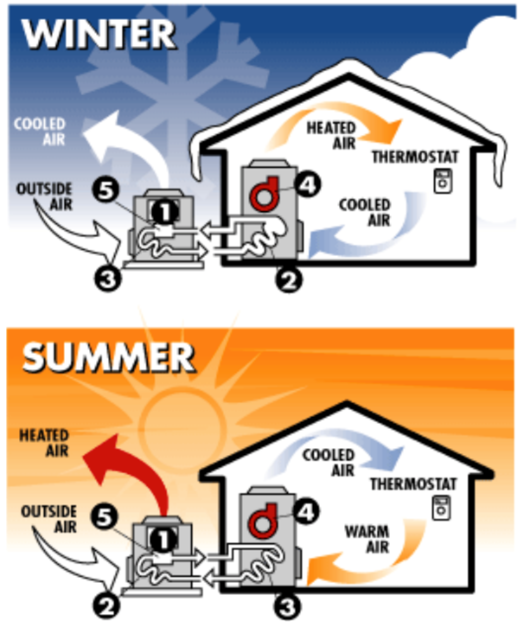

Figure 6: Air Source Heat Pumps (Massachusetts DOER, 2015)

An Air source heat pump system is a very versatile and affordable system but there are certain conditions that must be met in order to make it efficient. Advantages of an Air Source Heat Pump include:

- That it can be powered by electricity obtained from solar panels making them energy efficient and clean (Massachusetts Department of Energy Resources, 2015).
- That a ductless mini-split system is a great add-on for non-ducted houses[1]
- That mini-split systems are small and have great flexibility on installation for zoning or heating/cooling individual rooms (Massachusetts Department of Energy Resources, 2015).
- That it has low installation costs while still being environmentally friendly (U.S. Department of Energy, 2001).

Disadvantages of an Air Source Heat Pump include:

- The fact that it needs regular maintenance (every 2-6 months) including inspecting ducts and lubricating motors (U.S. Department of Energy, 2012).
  - That a severely neglected system will have a lower efficiency by a range of 10-25% (U.S. Department of Energy, 2001).
- That there can be many installation and service problems such as leaks in ducts, low airflow, and incorrect refrigerant charge (U.S. Department of Energy, 2001).

2.6 SUMMARY

Industrialized nations' dependence on fossil fuels is unsustainable, damages the environment, and is a threat to public health. Buildings are the largest sector of energy consumption both nationally and in Massachusetts, and heating and cooling account for 50% of energy consumption within the building energy consumption sector nationally. Consequently, a variety of programs and legislation have been established in Massachusetts that provide funding for and encourage the installation of renewable energy sources to reduce the dependence on fossil fuels. Our sponsor, the Department of Energy Resources, created the DOER Renewable Thermal Program and SAPHIRE, that focus on the installation of renewable thermal heating and cooling systems in different types of buildings. The DOER's renewable thermal programs lack complete narratives explaining the full details and hurdles along the process to implementing a renewable thermal system. This information can help the DOER improve their own program and promote further installations of renewable thermal technologies.

3 METHODOLOGY

The goal of our project was to support the DOER's commitment to reducing greenhouse gas emissions in the Commonwealth of Massachusetts by evaluating three renewable thermal pilot projects to investigate ways to improve and promote the installation of renewable thermal heating and cooling systems. In order to achieve this goal, we completed the following three research objectives.

1. Identify the questions and concerns past project site leaders have had when considering implementing a renewable thermal project.

2. Determine project implementation processes and challenges of renewable thermal projects.

3. Determine how these renewable thermal projects are performing in regards to cost and energy usage.

Once this goal was completed, we used the information gathered in the objectives above to produce our deliverables: a set of three case studies that explain the project process and lessons learned from each project site we studied.

3.1 RENEWABLE THERMAL PROJECT SITE INFORMATION

We focused on three existing DOER renewable thermal projects to develop case studies that will act as promotional material for the DOER and informational material for potential project site leaders. These case studies serve as the basis for a methodological approach that can be used provide potential project sites with information from all aspects of previously completed renewable thermal project. These three projects were chosen as the focus of this project because they encompass a variety of the types of projects the DOER oversees. While all three project sites utilize renewable thermal heating and cooling, the sites utilize different renewable thermal technologies. Two of our three projects are schools that involve biomass boiler systems at different stages of implementation and span three government funding programs. The third project is a public housing development utilizing air source heat pumps. These three sites are described in the following sections.

3.1.1 *Amherst College Bunker Building - Biomass Pellet Heating*

Amherst College has had a biomass pellet heating system in operation since April 2015. This project was done through the Renewable Thermal Program at the DOER. Our sponsor chose this project to be a focus as the biomass heating system has been in operation for half a year and can provide a tangible comparison between pre and post implementation cost and energy usage.

3.1.2 *Southern Berkshire Regional School - Biomass*

The Southern Berkshire Regional School District project was funded under the SAPHIRE program and began construction during Summer 2015. The construction was not completed by the time we created the case studies, so post project implementation data could not be obtained. It was therefore used as a reference to understand the process of planning, designing, acquisition, and installation of these biomass systems. This site illustrates setbacks that can occur in the construction process as well as the solutions to the problems these setbacks can cause.

3.1.3 *Sudbury Public Housing Development - Air-source Heat Pumps*

The Sudbury Housing Development is a low income housing development that has had air source heat pumps installed in four pilot units. This project was funded by the SAPHIRE program. This project was chosen as a focus due to the use of air source heat pumps, a fairly new technology in New England. This project also illustrates challenges relating to metering and data collection.

3.2 Objective #1: Identifying Concerns of Past Project Site Leaders

Our first objective was to identify the questions and concerns past project site leaders, including but not limited to school superintendents, housing development directors, department of housing representatives, school facilities managers, and grant coordinators at the three case study sites have had when considering implementing a DOER renewable thermal project. In order to answer these questions and provide summative information in the case studies we produced, we first needed to understand what questions and concerns were involved in the decision of whether or not and how to implement a DOER renewable thermal project.

3.2.1 *Consulting the Sponsor*

In order to determine which metrics we would use when gathering information at each project site we interviewed our sponsor about the questions onsite stakeholders and project site leaders including town officials, school administration, and housing managers have asked when considering implementing a DOER renewable thermal program in their communities. The Department of Energy Resources has worked with the leaders of several communities each considering different renewable thermal technologies in different applications. Through this work, the DOER has likely encountered many questions and concerns that individuals in the communities have had during the project process.

3.2.2 *Consulting Onsite Stakeholders*

We interviewed onsite stakeholders and project leaders of the sites we studied, including but not limited to maintenance faculty, building administrators, and town officials about questions, concerns, and doubts they had when beginning the projects as well as comments they have now that the projects have been completed. In order to produce interview questions and interview methods for the onsite stakeholders and project leaders, we utilized the information gathered from our interview with our sponsor to define categories for interview questions and compiled these in our information gathering guide, found in Appendix 4.

These categories included cost, maintenance, aesthetics, feasibility, and community acceptance, among others. Once we determined these categories, we drafted interview questions to provide a full understanding of how each large category played into the project process. These interview questions were created taking into consideration the information that was presented to each site in the feasibility studies, as the nature of a feasibility study is to provide a full explanation of a potential project at each specific location. We also took into consideration the experience we had when on a site visit to a potential new project for the DOER, Petersham Center Elementary School, where we were able to directly see how the pre implementation process works and talk with the representative of the school in charge of the renewable project. After drafting interview questions, we created on-site information gathering guides to act as checklists for each project site to ensure we gathered information addressing each interview question we had created.

Before each interview, we provided the interviewee with an informed consent form which explained that their identities would be kept confidential and that the information they provided us would be used when producing the case studies for each site. We also asked each interviewee if we could record the audio for the interview to allow us to create an accurate interview transcript to analyze. The interviewees for each site are as follows:

- At Amherst College we interviewed an individual who worked closely with the project design process and works closely with maintaining the biomass boilers now that they are in operation. We chose to speak with him/her since he/she is very familiar with the project process and works closely with maintenance of the system.

- For Southern Berkshire Regional School District, we interviewed two individuals who worked very closely with acquiring the grants from the DOER as well as communicating with the contractors prior to project implementation. These individuals continue to play large roles in ensuring the construction of the project is going well.

- At the Sudbury Public Housing Development we spoke with five individuals. One individual we spoke with worked very closely with the DOER grant process and the PowerWise metering system. The second individual we spoke with works very closely with the housing development and its day-to-day operation. The other three individuals we spoke with are tenants of the housing development. We asked these individuals questions about their thought processes in both deciding to move forward with the program as well as when making decisions and adapting to new situations, such as unexpected obstacles during the the construction phase.

Once we interviewed both the onsite stakeholders and our sponsor, we created interview transcripts from the interview recordings and applied codes to the transcripts in order to identify topics to focus on in our case studies such as cost, aesthetics, feasibility, and energy performance. This information gave us further insight into the information people considering similar projects may find useful. It also provided us with qualitative data about how the project has been performing since implementation. These are the people that are in direct contact with the renewable heating and cooling systems, and in some cases, deal with the maintenance of the systems. They were able to provide insight into maintenance costs, time commitment, and feasibility. The full list of interview questions and on-site information guides can be found in Appendices 3 and 4 respectively.

3.3 OBJECTIVE #2: DETERMINING PROJECT IMPLEMENTATION PROCESSES AND CHALLENGES OF RENEWABLE THERMAL PROJECTS

Our second objective was to determine project implementation processes and challenges of renewable thermal projects. The application of renewable resources in buildings such as schools and public housing initiatives is relatively new in Massachusetts (DOER, 2015). Because of this, we found it important to produce an explanation of the entirety of the project process including decisions and how they were made, incentives and assistance that were provided, and any barriers encountered and how they were overcome. It is the hope that this information will allow for a better understanding within the public of these new technologies and the best practices associated.

In order to achieve this objective, we consulted those who were/are in charge of each site in regards to the DOER renewable thermal programs. The list of who we interviewed and the reasoning behind our choices can be found in the previous objective. The full list of interview questions and on-site information guides can be found in Appendices 3 and 4 respectively. This information acted as another addition to the information we compiled when creating the case studies of the three locations.

3.4 Objective #3: Determining Renewable Thermal Project Performance

Our third objective was to determine how these renewable thermal projects are performing in regards to cost and energy usage. When producing these case studies, we desired quantitative data to illustrate the status of the project. In an effort to achieve this goal, we attempted to gather information from utility bills and projected values from feasibility studies as well as utilized existing energy auditing tools to collect and categorize numerical data from each project site.

3.4.1 *Data Collection and Analysis*

In order to produce the evaluation of quantitative data necessary for the case studies, we attempted to gather quantitative data from each of the three project sites, listed below.

- At Amherst College, we collected quantitative data regarding project performance partially from utility bills and partially from the interviews with the individual who works closely with the maintenance of the boilers.
- For the Southern Berkshire Regional School District, we could only utilize the projected outcomes presented in the feasibility studies, because the project is still under construction.
- For the Sudbury Public Housing Development, we spoke with an individual who works very closely with the housing development and its day-to-day operation regarding how the project is performing in her opinion and utilized the PowerWise tool, a web based online application used for metering different utilities. This information gave us important data on cost as well as use and efficiency of the newly installed systems. More information regarding specifics of the PowerWise tool can be found in Appendix 1.

3.5 DELIVERABLES: CASE STUDIES ON THREE PROJECT SITES

Using the information obtained through the previous tasks, we produced case studies on the three renewable thermal projects to promote future renewable thermal energy projects. An example of one such case study, which was created during the previous summer about an earlier DOER project, was provided to us to show how our case studies should be formatted. This case study can be found in Appendix 2. Through analyzing this example case study, we extracted the key components and important pieces of information that were included, namely the history of the site, the system design, the funding sources, the project outcomes, and the overall lessons learned from the project process. We then compiled this information for each of our three sites using the data we collected and organized from the interviews and qualitative data analysis we conducted.

To present the full undertaking and address the questions and concerns that site leaders have had, we included an overview of the process, including obtaining financial and community support, and the design of the system. As far as results go, we compared the projected cost, timeline, and performance with the actual results and presented these comparisons in the Project Outcomes section. To maximize the breadth of our recommendations, we emphasized different points in the Lessons Learned section for each case study.

It is our hope that these case studies will not only provide potential future site leaders with information about the process of implementing one of these renewable thermal technologies, but they will also help to inform the public about the types of renewable technologies used in our three cases in an effort to dispel common misconceptions that people may have about these technologies being too complicated, inefficient, or expensive.

4 RESULTS

The findings from our fieldwork and data analysis are presented in this chapter. We first discuss the metrics used when collecting data, and then present the most relevant aspects of each of the following DOER-sponsored renewable thermal project sites we investigated: the Amherst College bunker building, the Southern Berkshire Regional School, and the Sudbury Public Housing Development. We then provide the list of findings we compiled from our data collection at each of the three project sites.

4.1 DETERMINATION OF METRICS

Before visiting each project site to collect data, we needed to determine which metrics we would use in our analysis of the project. To determine these metrics, we met with our sponsor and point of contact at the DOER. We spoke with her about what concerns and questions the DOER has encountered working with past renewable thermal heating and cooling project sites. From this interview, we identified the following findings, some of these overlapped with the metrics we found in our literature review, specifically in Section 2.3 Transitioning Between Fossil Fuels and Renewable Energy.

4.1.1 *Cost is a Metric for Assessing Renewable Thermal Projects*

In our interview with our sponsor, we asked what she thought were the main concerns of potential project site leaders when considering implementing a renewable thermal project. Her response was A lot of it is cost, I think. They [potential project site leaders] want to know how much it is going to cost. She then elaborated that project sites request funding for the amount presented on the feasibility study. Say its underestimated and the bids come in at $100,000 more; the project sites are in a bind because they only asked for funding up to what the feasibility study presented. We identified similar concerns in Section 2.3.2 of our literature review.

4.1.2 *Community Acceptance is a Metric for Assessing Renewable Thermal Projects*

Community acceptance was also presented to us by our sponsor as an important metric to be considered and investigated when talking to project sites. Our sponsor states Community acceptance is also important because they have to go to town meetings or the school board in order to get approval for something like this so they have to sell it. This is consistent with what we found in Section 2.3.1 of our literature review.

4.1.3 *Operational Logistics and Aesthetics are Metrics for Assessing Renewable Thermal Projects*

Operational logistics (pellet delivery for biomass systems) and aesthetics were also brought to our attention from our interview with our sponsor. She states Space and aesthetics regarding the silo are also concerns that I have seen. Where the silo would go, how they would get the delivery, price of the pellets, and pellet availability.

4.2 SITE DESCRIPTIONS

After determining which metrics we would be focusing on, we began gathering data for each project site. For each project site, we compiled a document containing information we would need to collect relating to each metric and the decision making process, and included information we already had access to in the feasibility studies from each site. We took this information gathering guide, found in Appendix 4, to each site in order to ensure that we collected all the information necessary to compile case studies.

4.2.1 *Amherst College Bunker Building*

Amherst College is a privately funded university that has an off campus book storage bunker. This bunker, seen in Figure 7, has an area of 50,000 ft^2 and must be climate controlled 24 hours a day, 7 days a week, for the entire year. The bunker is climate controlled year round in order to ensure that the integrity of the books, especially the antique books, is not compromised. In order to supply a proper climate for these books, the building is first cooled to remove moisture from the air and is then heated to achieve desired room temperature. Prior to the installation of the new biomass boilers, this bunker was cooled with a stand alone air conditioning system and heated with two 15 year old Burnham cast iron, oil boilers, each rated at 560,000 BTU/hour. The annual heating cost of the bunker when using the oil boilers was approximately $16,000. Under the new system, it is expected to decline to $11,050 per year. The facilitys management has greatly reduced its energy use in recent years by increasing the range of temperatures and humidity allowed within the building and decreasing ventilation. We interviewed an individual who worked closely with the project process and continues to work with the maintenance of the system in order to gather the information presented in the following sections.

Figure 7: Amherst College Bunker Building

4.2.1.1 *The Introduction of Renewable Technology to Amherst College*

Amherst College applied for a grant through the DOER when their oil boilers were approaching end of life expectancy. When considering their options for heating this space, they contacted an outside contractor to become informed about the different heating options available on the market. Initially, the project site leader considered the implementation of a propane heating system. During discussions with their contractor, the idea of a biomass system was suggested due to the availability of a grant through the DOER. They applied for this grant with the help of the consulting firm, and once it was received, the decision was made. They were granted 75% of the expected cost of the biomass boiler project, equating to \$205,000 out of the expected \$275,000.

After the engineers analyzed the load of the building and the usage patterns, they determined that two biomass boilers would be preferable. Having two boilers provides a 100% redundancy which allows them to shut off one boiler for maintenance while the other still fully heats the building. After considering the space available inside the old oil boiler building, the consulting firm determined that building a new boiler room closer to the bunker would be the best option. A closer boiler room would decrease the amount of piping required and allow the old oil boilers to be operational during construction. This new boiler building would also allow for a 600 gallon thermal storage tank sized to fit the load of the building. Figure 8 shows a picture of the new boiler room and wood pellet silo.

Figure 8: Amherst College New Boiler Building

4.2.1.2 *Aesthetics and Operational Logistics*

The biomass boilers require pellets as a fuel source. Therefore, it is desired that there be nearby pellet storage to allow for easy access between the boilers and the pellets. Amherst College chose to use a silo for their on-site storage rather than construct an indoor pellet storage bin. When implementing a biomass heating and cooling system, a frequent concern of our interviewees was the aesthetics of the silo as they are rather large and can obstruct from the aesthetic quality of the building. Since the bunker building at Amherst College is off campus and in a remote location, aesthetics were not of concern. The silo at Amherst, which is can be seen in Figure 9, is 12 feet in diameter by 26 feet tall. The sizing of the silo provides enough room for 4 to 5 months worth of pellet storage which allows them to buy pellets in bulk and save money on delivery charges as they only have to get delivers 2-3 times a year. Depending on the site, delivery logistics can be a concern. A requirement for a biomass system is that the space/roadways allow for a large truck to provide wood pellet deliveries to the silo. The bunker building has ample parking space surrounding the silo and bunker building, so there were no issues with delivery logistics.

Figure 9: Silo at Amherst College

4.2.1.3 *Construction*

Amherst College was referred to Froling Energy for the construction by the same contractor who referred them to DOER for the grant. Although the construction was set to begin on October 2nd, 2014, due to delays in the design process and in getting permits from the town, it was not actually started until December. The chosen boilers were produced by Froling, an Austrian company with no relation to the energy company based in New Hampshire. Froling has been described as the Cadillac of biomass boilers by the DOERs biomass expert. Construction was set to be completed by November 26th 2014, but the boilers were not fully online until April 1st, 2015. The process of installation required digging trenches in order to lay down piping from the new boilers to the bunker building. The timeline delay was a result of the harsh winter experienced in 2014 which inhibited the ability of the contractors to dig the necessary trenches.

4.2.1.4 *Current Operations and Maintenance*

The boilers were operational for approximately six months as of September, 2015. The annual maintenance cost of the old oil boilers was $500. Amherst now has a $2500 per year contract with Froling Energy for annual cleaning and 24/7 monitoring. As part of the maintenance requirements for biomass boilers, an ashtray is to be emptied every 6-8 weeks. Besides that, it is very similar to the oil boilers with an annual cleaning, annual inspections and weekly checkups. Additionally, the old oil boiler system produced a coating of soot that had to be removed each year whereas the biomass boilers produce only a thin layer of biodegradable wood dust from the pellets that can be easily removed. To aid in the maintenance process, the boilers are equipped with sensors that monitor different components of the system. Amherst College has a contract with Froling Energy to remotely supervise the system through these sensors and notify the facilities faculty if any abnormality occurs. In general, the new biomass system has a comparable maintenance schedule to the old oil boilers, and with time and experience, the Amherst facilities personnel expect it to become a faster and cleaner process. The Froling boilers at the Amherst College Bunker Building can be seen in Figure 10.

Figure 10: Froling Boilers at the Amherst College Bunker Building

4.2.1.5 *Major Lessons Learned*

From our interview and onsite visit at the Amherst College Bunker Building, we developed a list of lessons learned that will be included in our case studies.

First, it is helpful, to seek an experienced team. Amherst College was fortunate to work with experienced engineers throughout this project which allowed for a relatively smooth project process. Wood pellet boilers are relatively new to the United States, though the industry is well developed in Europe. Because of key differences in operation between wood pellet and fossil fuel systems-such as longer startup and shutdown times and the importance of thermal storage- working with engineering firms with relevant experience makes a renewable thermal project process run more smoothly.

Second, the timeline for these projects can change even when working with experienced engineers. Construction was set to take place between October 2nd-November26th. Due to delays in the design process, construction began in December. As the construction occurred in the winter, there were weather related setbacks and the biomass system was not placed online until April 1st. However, due to proper planning and preparation, this delay did not affect the bunkers ability to maintain proper climate for the books. Since the project involved constructing a separate boiler building, the school was able to use their old oil boilers throughout the project installation process.

4.2.1.6 *Site Summary*

Overall, the Amherst College biomass installation was a success, as the boilers are operational. The staff and project coordinators are very happy with the project process and the performance of the new boilers. The individual we interviewed from Amherst College expressed that they are very pleased with the contractors they used to install the boilers, and the boilers themselves. The individual states In the short time that weve had this system up and running, we are pretty impressed with it. I think were glad that we made the decision to go with this and we are looking forward to many years of trouble free operation years of trouble free operation. He mentioned that they were comforted knowing that Froling Energy was familiar with the technology and the installation process. The advanced sensor system of the Froling boilers allows for remote access to information regarding maintenance needs, and the maintenance of the system is comparable to that of their old system. Cost was a concern for the stakeholders at Amherst College, but with funding from the DOER, the project became very affordable. The timeline for the project did shift, and the installation did take longer than expected, but since this construction involved creation of a new building for the biomass boilers, the old oil boilers were able to maintain the climate of the bunker building throughout the construction process. Aesthetics were not a concern for this project due to the off-campus location of the bunker building.

4.2.2 *Southern Berkshire Regional School*

The Southern Berkshire Regional School, seen in Figure 11, is a public school in Sheffield, Massachusetts. It has a total area of 220,000 $ft.^2$ and is comprised of a high school and an elementary school separated in two wings. The building serves a total of 845 students, faculty, and staff. Originally the school was equipped with two oil boilers, providing 9.146 billion BTUs of heating annually, which were approaching the end of their lifespan and would need to be replaced. The school district researched a grant provided by the Massachusetts School Building Authority through their Accelerated Repairs Program to help fund new boilers and a new roof, another renovation that needed to be done at the time. During this grant search, they found the DOER SAPHIRE program, which introduced them to the idea of using a renewable energy production method such as biomass or geothermal heating. We interviewed two individuals who worked very closely with acquiring the grants from the DOER as well as communicating with the contractors prior to project implementation to obtain the information presented in the following sections.

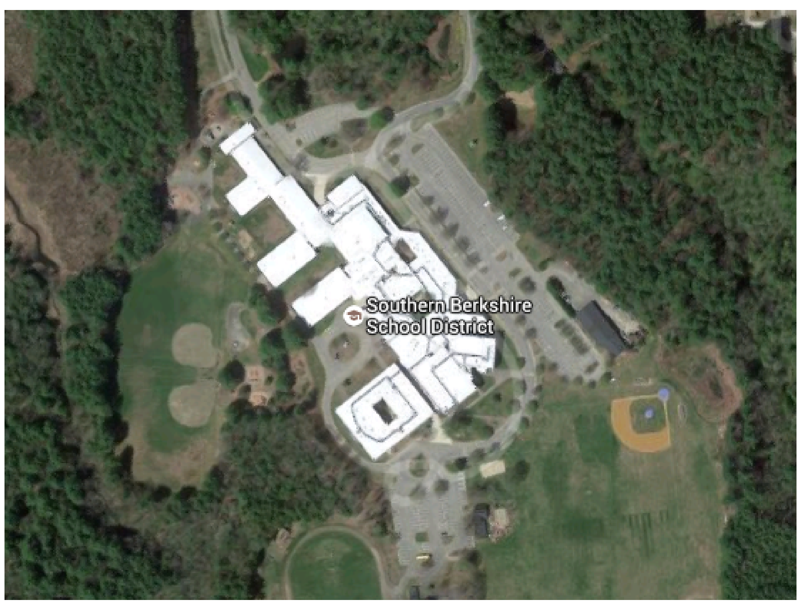

Figure 11: Aerial View of the Southern Berkshire Regional School

4.2.2.1 *The Introduction of Renewable Technology to Southern Berkshire Regional School*

After school project leaders spoke with the DOER about the different potential renewable technology options, they decided to commission a feasibility study. This study, completed by BEAM engineering, compared the installation of a biomass system to the installation of a geothermal heat pump system. This study quickly found that a geothermal heat pump system would have been prohibitively expensive, as it normally is in retrofit scenarios. Therefore, they decided to install biomass boilers as well as an oil boiler for a backup source as it was the most cost effective option.

4.2.2.2 *Grants Awarded*

Once the decision was made to move forward with a biomass heating system, the school hired contractors to complete design and cost estimates. Cost was a concern for the school and the taxpayers. The DOER provided a grant of $360,000 and the MSBA provided a grant of $195,000. These grant amounts were calculated based on the BEAM feasibility studys cost estimate of $1,028,000. In order to gain community support for the funding of this project, the school had an information communication system. They hosted meetings and distributed newsletters informing taxpayers about the process of this project, addressing concerns and presenting information on the different costs that the project would involve. According to our interview, the most effective information that was distributed was a cost breakdown that illustrated how much each taxpayers taxes would increase when paying for the portion of the project that was not funded by grants. According to our interview, this breakdown of cost eased the minds of the taxpayers because it showed that the average taxpayers taxes would only increase by around $20 annually.

4.2.2.3 *Design Phase*

The BEAM engineering feasibility study included general information on the building including old oil fuel usage annually, boiler room size, school size, and potential specifications for a new biomass system. This study included creating a new 25 feet by 30 feet boiler room housing a 4,000 gallon thermal storage tank and two Veissmann KOB 540 biomass pellet burning boilers of approximately 3.7

MMBtu/hr (1,080 kW) in total capacity based on a peak usage calculation of 3.9 mmBtu/hr.

When the school began searching for contractors to complete the construction and installation for the project, they contacted RDK Engineers through the DOER. RDK used the background information about the school presented in the case study from BEAM to produce a feasibility study and preliminary design of their own. Once this feasibility study was completed, it was apparent that there were some large differences between the two studies. RDK identified that the old boiler room could function with the new biomass boilers, if rearranged appropriately. RDK also identified some costs that were not included in the BEAM feasibility study. The RDK study included a 1,500 gallon thermal storage tank and estimates for boiler size including two Veissman Pyrot 540 each with 1,843 MBH and one Weil McClain boiler with 5,304 MBH, based on a peak usage calculation of 7.0 mmBtu/hr which is much more conservatively sized.

In order to determine which solution was appropriate for the school, Southern Berkshire had Wilson Engineering, a third party contractor, produce a third feasibility study. This study determined that the peak usage is actually around 5.5-6.0 mmBtu/hr and recommended a smaller version of the Veissman Pyrot biomass boilers, which can be seen being installed in Figure 12. The school accepted a bid from RDK Engineering which was substantially larger than the cost presented in the BEAM feasibility study, coming in at $1,543,662.00.

Once the correct boiler specifications were agreed upon, the final design was created. Due to the location of the boiler room, the pellet silo was positioned in the back of the school building, and would thus not be visible from the street. According to our interview, this alleviated any concerns regarding the aesthetics of the silo. However, an issue with the thermal storage tank developed once the design was submitted to the DOER.

A requirement of the DOERs grant programs is that the boiler rooms contain an appropriate amount of thermal storage, 7,000 gallons in this case. When the DOER analyzed the design to approve funding the project, they noticed that the thermal storage design presented wasnt sufficient for their requirements. This problem was resolved by compromising on the size of the thermal storage tank, pictured in Figure 13, to contain 3,000 gallons of storage, but added delays to the entire project timeline. After this issue had been resolved, construction began. Originally, the project was set to be completed by September 31, 2015. However, due to delays with boiler delivery, the new estimated project completion date is October 15, 2015. While this setback prolonged the project process, it is something that can be planned for. Most biomass boilers are sourced from Europe and have an estimated delivery time around 3-4 months after the order is placed. While this time delay with the boiler delivery was a reason for worry, it is important to note that had the boilers not arrived and been placed online before winter, an oil boiler could have been brought in on a large truck and used to heat the building in the interim.

Figure 12: Veissman Boilers at Southern Berkshire Regional School

4.2.2.4 *Current Project Status*

Once the boilers arrived, the stakeholders at the Southern Berkshire Regional School started to consider the maintenance requirements of the system. The projected annual cost of maintaining the new biomass boiler system is approximately $10,000, which is comparable to the maintenance cost of the old system. According to our interview, the concern of the facility faculty is that they wont have the proper knowledge and experience to maintain the boilers appropriately.

Once this project has been completed, it will act as a solution to the schools failing oil boilers. Based on the feasibility study, the school should see a $91,000 fuel cost savings per year, allowing for a 5.3 year break even point. The project is also projected to decrease greenhouse gas emissions by 85% or 801.4 tons annually.

Figure 13: Thermal Storage Tank at Southern Berkshire Regional School

4.2.2.5 *Major Lessons Learned*

From our interview and onsite visit at the Southern Berkshire Regional School, we developed a list of lessons learned that are included in our case studies.

First, it is important to obtain community acceptance. The taxpayers had concerns when the project was first proposed regarding the cost of funding such a large project. In order to mitigate these concerns, the school district presented the taxpayers with an exact breakdown of how much each persons taxes would increase due to the project costs. When presented this way, the project cost was much more manageable, and community acceptance was achieved. They also brought in biomass technology experts to help educate the community members.

Second, it is important to obtain multiple trustworthy opinions on the project. Since wood pellet boilers are relatively new to the United States, the Southern Berkshire Regional School District had three feasibility studies done for this project. By comparing these feasibility studies, they were able to clearly see the difference in experience of the different engineering firms by the boiler sizing and cost estimates provided. After comparing all three studies, they had a much more appropriate boiler sizing estimate and an accurate projection of project cost.

4.2.2.6 *Site Summary*

The differences in technical experience and opinions with the biomass system between contractors created a delay in the design process. The project was expected to be completed by the end of September of 2015, but due to shipping delays of the biomass boilers the project is still currently under construction and expected to be done by mid-October.

4.2.3 *Sudbury Public Housing Development*

The Sudbury Public Housing Development is composed of 21 single family and duplex rental houses for low income families. A panorama of one of these units can be seen in Figure 14. The housing development is occupied almost exclusively by elderly people and couples. These apartments were built in the 1960s and almost all of them were heated with electric baseboards. These electric baseboards have a number of issues including having low energy efficiency, producing particulate emissions, and becoming dangerously hot. The state organization responsible for acquiring funding to upgrade the housing development is the Department of Housing and Community Development (DHCD). Sudbury was on the DHCDs list of sites to improve because of electricity metering data that indicated that the development was spending too much money on electricity per square foot. We interviewed five individuals at the Sudbury Public Housing Development in order to gather the information in the following sections. One individual we spoke with worked very closely with the DOER grant process and the PowerWise metering system. The second individual we spoke with works very closely with the housing development and its day to day operation. The other three individuals we spoke with are tenants of the housing development.

Figure 14: Duplex at the Sudbury Public Housing Development

4.2.3.1 *The Introduction of Renewable Technology to the Sudbury Public Housing Development*

In order to reduce this electricity cost the DHCD applied for funding through the DOER for a pilot program for the Sudbury Public Housing Development to replace the electric baseboards in four apartments with Air Source Heat Pumps (ASHPs). The outdoor condensers are pictured in Figure 15, and the indoor vent is pictured in Figure 16. Since the DHCD is concerned with saving money for the state, they did not have a feasibility study commissioned for this renovation. Four ASHPs were installed within the Sudbury Public Housing Development with a grant from the DOER providing 100% of the $32,550 project cost.

Figure 15: ASHPs at Sudbury Public Housing Development

4.2.3.2 *Timeline*

A typical installation of four ASHPs should take about a week to complete. Due to the need to secure funding, the state requirement is to source the lowest bid for the installation. With a conflict with one resident not wanting the system installed in their unit and an atypical installation process, the Sudbury Public Housing Development took 1.5 years from start to finish.

Figure 16: Indoor ASHP vent at Sudbury Public Housing Development

4.2.3.3 *Resident Feedback*

Aside from one resident who wished to not have the system installed in their unit, the feedback from the residents has been positive. One resident spoke very highly of the new system and the reliable heating, cooling, and dehumidification it provides. He is quoted as saying that it is the best invention ever and that he wished it had been around 50 years ago. When asked about the maintenance of the system, he explained that all he does to maintain the systems is clear out the filters every three months, though the manufacturer recommended maintenance is to clean the filters every six months. This resident also mentioned that he has helped others to clean their filters as well. A second resident voiced that while she has heard good things about the systems, she knows that some residents struggle with the remote control that is used to change settings. She mentioned that there are different types of remotes in the different units, and that some people wish they were taught how to use it. Once the four pilot units had been installed and online, the focus of the project shifted toward metering the performance of the ASHPs.

4.2.3.4 *PowerWise Metering*

The Sudbury Public Housing Development installed a metering tool, PowerWise, to measure the electricity usage of units with ASHPs and compare to the electricity usage of the control units. Other public housing developments have installed ASHPs, but have not been able to effectively monitor the energy savings due to a lack of accurate and specific data. In the previous installations, the only accessible information was the billing information from an entire buildings electricity use. From this, the DHCD has been able to estimate how much money the installation of the ASHPs has been saving them, but they do not have concrete data on what percentage of the savings are actually coming from the switch to ASHPs. Sudbury was to be the test site for their new metering technology to obtain that missing data.

The PowerWise metering system was first installed in four cold climate one-to-one air source heat pumps, and four control units with electric baseboard heat. This was done to determine the baseline KWH usage over a full year by comparing the four pilot units with the four control units. However, due to the manner of ASHP installation and difficulties with unorganized circuit breakers, the DHCD hadnt been able to obtain and analyze the data. In September, 2015, the PowerWise engineers worked with the DHCD engineer in an effort to correct the wiring mistakes in order to produce accurate and usable data for the pilot and control units. However, due to the nature of the older buildings and the complicated circuitry, this took several attempts. As of 9/17/2015, the electricity usage is said to be accurate. Due to the late availability of accurate data, we were not able to provide substantial data analysis regarding electricity usage trends and cost savings.

4.2.3.5 *Major Lessons Learned*

From our interview and onsite visit at the Sudbury Public Housing Development, we developed a list of lessons learned that is included in our case studies.

First, it is important to investigate the feasibility of the project before beginning. There was no feasibility study commissioned at the Sudbury Public Housing Development, and feasibility studies provide not only recommendations for the specifics of the renewable technology to be installed, but in many cases also provide background information on the building/units themselves. Had this study been conducted, the many challenges of installing a pilot program and working with PowerWise in this situation would have been exposed.

4.2.3.6 *Site Summary*

There are a number of qualities about the Sudbury housing development that make it unsuitable for a pilot program to determine the effectiveness of a new technology. First, the tenants at Sudbury have fairly irregular usage habits. This site becomes more unsuitable when we add the fact of Sudbury not having any historic, per-unit power usage data. Another issue is that the tenants were not instructed on how to use new technologies, and since they control the temperature in their own apartment, this caused more irregularities in the metering and effectiveness of the systems. There also isnt a maintenance plan for the new systems, which places the responsibility of maintaining the ASHPs on the tenants.

Several issues can be worked around by effectively educating the tenants about the systems being installed in their homes and setting up the appropriate infrastructure. The tenants that had the new systems installed in their apartment at Sudbury were not instructed on how to use or maintain their new ASHPs. In fact, not even the housing director was given any instruction on the operation or maintenance of the systems. The control for an ASHP is more complex than a traditional thermostat, but according to our interview if it is explained to the tenants, it can be just as easy to use. In a more complete installation where every unit in the housing development is upgraded, the responsibility of maintenance would become a routine for the facilities staff and no longer fall to the tenants. In the realm of electricity usage metering, a full installation would increase the sample size and possibly normalize out some the outliers from the data.

4.3 SITE FINDINGS

After we interviewed stakeholders and project leaders from each project site we studied, we noticed that each project process was complex in its own way, and each project involved different successes and challenges. We compiled the following findings after analyzing the interview transcripts and feasibility studies from each project site. Included with each finding is information and evidence from various project sites. Site Findings:

- Commissioning a feasibility study prior to beginning a renewable thermal project can be very valuable
- Failure to consider the context in which a renewable energy technology is being implemented can lead to poor performance and increased required maintenance
- Educating the community about new technology before installation can lead to community support
- Working with experienced engineers can make a big difference in the project timeline and post project effectiveness
- Improving a buildings energy efficiency improvements prior to or in addition to upgrading the heating system may lead to increased cost savings
- Public housing rules and regulations can be barriers when implementing a renewable technology project
- Failure to consider context when choosing a metering system can lead to problems with gathering data

4.3.1 *Commissioning a Feasibility Study Prior to Beginning a Renewable Thermal Project Can Be Very Valuable*

For many renewable thermal project sites working with DOER funding, the first step in the process is to commission a feasibility study from an engineering firm. These feasibility studies provide information pertaining to the specific project site including cost estimates of project construction, estimated payback period or break even point, renewable technology sizing recommendations, and annual comparisons of fossil fuel cost to renewable energy technology fuel cost.

These feasibility studies can prove to be very valuable resources when beginning a renewable thermal project. Along with providing information regarding various aspects of the project, the investigative work needed to produce these studies can also uncover underlying issues within the building that were not previously known such as the presence of asbestos, poor insulation, and energy management system efficiency problems. In the following sections, we provide evidence for this finding from each project site

4.3.1.1 *Amherst College Bunker Building*

When Amherst College learned of the grant opportunities from the DOER and that their oil boilers were reaching the end of their life expectancy, they commissioned a feasibility study to be completed comparing the initial cost and fuel cost of installing a propane boiler system and a biomass boiler system. This feasibility study aided in making their decision to work with the biomass boiler system as it showed that using a biomass boiler system would be more cost effective and could sufficiently provide heat to meet their usage needs (Kohler, 2014; Amherst College, 2014).

4.3.1.2 *Southern Berkshire Regional School*

Southern Berkshire Regional School District (SBRSD) commissioned a feasibility study from BEAM engineering before contacting potential contractors in order to determine if biomass boilers would be functional in the school. This feasibility study provided a cost estimate of the project, general boiler technology information, general construction process information, a comparison of fossil fuel costs and biomass pellet costs as well as two different options regarding boiler sizing and oil boiler backup logistics. Not only did this feasibility study provide the SBRSD with a general understanding of what this project would involve, but the SBRSD was also able to use this feasibility study as informational material when looking for contractors to complete the construction. While the selected contractors, RDK Engineering, conducted their own research to produce a second feasibility study, this first feasibility study provided RDK with basic information regarding the project so that they could determine if they were well suited for the project as a contracting firm.

Once RDK produced their own feasibility study, the SBRSD and the DOER noticed a few discrepancies between the two feasibility studies. The BEAM feasibility study and the RDK feasibility study did not agree on some aspects of the project including boiler sizing and boiler room configuration. Since the SBRSD had commissioned these two feasibility studies with the help of the DOER, they had the opportunity to be proactive and commission a third feasibility study which produced more consistent information regarding project specifics (BEAM Engineering, 2014; D.C. Architects, 2014;RDK Engineers, 2014, Wilson Engineering, 2015).

4.3.1.3 *Sudbury Public Housing Development*

The Sudbury Public Housing Development did not commission a feasibility study when implementing the pilot Air Source Heat Pump project. There were many unknowns throughout the project process and the installation of some units needed to be adjusted after the initial installation. It was also unknown at the beginning of the project whether or not the use of ASHPs in this setting would be cost effective compared to the existing electric baseboard heating system. If a feasibility study had been commissioned, more information would have been known been known about this application of ASHPs and these issues may have been avoided.

4.3.2 *Failure to Consider the Context in which a Renewable Energy Technology is being Implemented can Lead to Poor Performance and Increased Required Maintenance*

Similarly to how various types of renewable technology differ no two buildings are exactly alike. Moreover, each building is used for a different purpose and houses different types of people doing different activities. After investigating different aspects of the project processes at each different project site, analysis revealed that not considering the context of the renewable technology before beginning construction can lead to poor project performance and increased required maintenance. Furthermore, we learned that when the context of the renewable technology is considered prior to project implementation, the project runs more smoothly. Evidence of this finding from each project site is presented in the following sections.

4.3.2.1 *Amherst College Bunker Building*

The Amherst College bunker building is certainly a unique building with unique heating requirements. Unlike a usual school building, the bunker building is climate controlled year round to maintain the physical integrity of the books it houses. Also, the bunker building is below grade. This means that the heating load would remain relatively constant between the winter and summer months since the earth surrounding the bunker building maintains a mostly constant temperature. Fortunately, these factors were considered when purchasing appropriately sized boilers and accompanying silo.

Aesthetics was considered when planning the biomass boiler system installation at the bunker building. A new above grade boiler building was constructed to house the boilers adjacent to the new silo. Since the bunker building is off campus, the issue of silo aesthetics was not a problem. However, the individual we interviewed stated I dont think we would get away with putting a silo in the campus, highlighting the importance of considering the application of the technology when planning the design.

Another aspect of the biomass boiler system installation that was considered at Amherst College was who would be maintaining the new boilers and how they would be maintaining them. With such a large campus, Amherst College has a robust maintenance plan with sufficient staff members. Before the system was installed, the maintenance team became familiar with the maintenance requirements of biomass boilers in order to determine if their staff would be capable. The boilers they chose provide updates regarding any maintenance needs via the internet which decreases the learning curve of maintaining a new system. The maintenance team is also planning on working with Froling Engineers during the first annual maintenance. The plan is that the Amherst College maintenance staff will use this opportunity to learn how to complete the annual maintenance, and after the first year, will begin to do the annual maintenance on their own. This maintenance requires turning the boiler off, however, Amherst College has two boilers with 100% redundancy each, this means there will be no gap in climate controlling in the building while the maintenance process takes place.

4.3.2.2 *Southern Berkshire Regional School*

When determining which renewable thermal technology would be best applicable in the context of the Southern Berkshire Regional School, many factors were considered. Very quickly, geothermal heat pumps were eliminated as an option due to the large upfront cost. When looking into biomass boilers as an option, the school made sure to look into how this system would affect air quality and whether or not the boilers would produce unpleasant noise. In a school setting, air quality is very important, as children spend a big portion of their days there. Noise is also a concern for schools because they dont want anything distracting students from their education. Fortunately, biomass boilers are comparable in terms of noise to oil boilers, which the school previously used to heat the building, and do not affect air quality in the classrooms as they burn very cleanly.

In our sponsor at the DOERs experience, many schools have concerns regarding the aesthetics of the biomass pellet storage silo. Fortunately, this was considered when designing the layout of the new system, and it was deemed possible to place the biomass silo in the back of the building near the boiler room, where it would not be visible from the street.

One aspect of the project that was not considered as strongly when planning the project was maintenance. Unlike Amherst College, the Southern Berkshire Regional School is a public school with only one building and thus a need for smaller maintenance staff. Whereas the maintenance staff at Amherst College is more experienced with robust boiler systems in different buildings across campus, the maintenance staff at Southern Berkshire Regional School is not as experienced with different boiler types, as this has not been a requirement to satisfy the schools maintenance needs. The SBRSD also did not make a maintenance plan or contract for once the boilers are on line. They are currently concerned with who will maintain the new boilers and how they will learn the proper maintenance techniques. One individual we interviewed from the SBRSD states in regards to the biomass boiler system who will maintain it? Who has the expertise in these types of boilers to maintain it, and then its going to be a little bit of a learning curve for our maintenance staff to learn how to operate and all that, so that was one of the concerns. This concern also highlights the importance of considering all aspects of the renewable technology application for each site, including the people who will be working with the technology.

4.3.2.3 *Sudbury Public Housing Development*

Since the Sudbury Public Housing Development was concerned with quickly reducing their electricity costs per unit, there were a lot of aspects about this particular context of ASHPs that were not considered or planned for. The first aspect of applying ASHPs in a public housing development that was not considered was how a community of mostly elders would respond to and use the ASHPs. Many of the elderly residents were not familiar with ASHPs and thus some residents responded negatively to the idea of having this new technology placed in their units. After the ASHPs were installed and the PowerWise metering system was being implemented, many of the residents became upset with the electricians coming in and out of their units and moving their belongings. Since the residents were not educated on how to use the ASHPs, they used them like they would an electric baseboard heating system with a thermostat: by turning it on and off to maintain their comfort level. However, ASHPs function best and is the most energy efficient when set to a temperature and left on automatic mode. Using an ASHP like an electric baseboard heating system increases the operating cost and decreases the effectiveness of the system. The individual we interviewed that worked closely with the PowerWise system states that is one of the concerns we have in elderly units. This is not a thermostat that you dial forward and backwards. Its a hand-held remote control and it has the options to keep the system in heating, cooling, and even dehumidification. So you have to choose the right mode.

Another aspect of the public housing development application of ASHPs that was not considered and poses as an issue is maintenance. Since only four units at the housing development have had ASHPs installed, the maintenance of these systems hasnt been integrated into the housing developments maintenance plan. The filters in the unit need to be cleaned out every six months, and this responsibility is left to the residents. One resident doesnt mind the maintenance and he helps out the other residents who either dont know how to or are unable to maintain their systems themselves.

4.3.3 *Educating the Community about New Technology before Installation can Lead to Community Support*

Since most of the DOERs grant money goes to public organizations, ensuring that the projects have the support of the community is very important. In most cases, the DOERs contribution only partially funds these projects, so it is up to the community members who use these public buildings to pay for any work on them in the form of local taxes. Lack of community support can be a barrier to both implementation and effective operation. We found that educating the community about the new technology before installation can lead to community support. In the following sections, we present evidence for this finding from each project site where it was applicable.

4.3.3.1 *Southern Berkshire Regional School*

The Southern Berkshire Regional School District received grants totalling around 40% of the total project cost. This meant that the remainder of the project was to be funded using the taxpayers contributions. Even though the money would be going to improve the local school building, the community members were hesitant to approve the spending. This almost prevented the project from being implemented.

By providing effective education and instruction to the community, the Southern Berkshire Regional School District was able to obtain the community support necessary for the project to move forward. According to one of the two individuals we interviewed who worked very closely with acquiring the grants from the DOER, the school district brought a [biomass] expert to have him participate in several meetings so that the public could be educated. In addition, there was a community press release that showed breakdown of taxpayer increases per year because of the renovation. For this community, this method worked to ease the minds of the taxpayers that this project could be paid for with only a minor increase in taxes each year. Through information on the technology and on the personal impact, the Southern Berkshire Regional School District was able to secure support and funding for their renovation.

4.3.3.2 *Sudbury Public Housing Development*

At the Sudbury Public Housing Development, the installation of the ASHPs was fully funded by the DOER, and the DHCD went ahead with the installations without first gaining support from the tenants. This has proven to be an issue with regards to operation and maintenance of the ASHPs. Since the tenants were never instructed how to operate or maintain their units, there have been complaints about the technology including one tenant who demanded that ASHP be removed from his unit. Some tenants also expressed that they did not believe that the new systems would work, and once it was installed, they confused the unpleasant sound of the previously installed water heater with the ASHPs.

The Sudbury Public Housing Development, while not proactive about educating their tenants, did eventually provide maintenance instructional materials to the tenant who asked for them. That tenant eventually went and personally taught the other tenants how to operate their ASHPs. Prior to the education, the tenants were incorrectly controlling the units, which caused much more energy to be used. Instead of leaving the ASHPs in automatic mode, some tenants were turning the ASHPs on and off which causes a greater power consumption.

It is important for people to know that the new system they are implementing actually works. When the community trusts and understands the system, there will in some cases be more support for it and in some cases more efficient operations and maintenance. The management of all of the projects we investigated found it useful to visit other sites that have installed similar technologies. Seeing proof of it working for another community boosts the trust in the technology. The housing director at Sudbury told us that just hearing from other tenants about it and the comfort level that you /[a tenant/] felt is the best recommendation. Even hearing the stories of other sites, in a case study for example, can serve this purpose for many sites in the planning phases.

4.3.4 *Working with Experienced Engineers Can Make a Big Difference In The Project Timeline and Post Project Effectiveness*

Since the implementation of renewable thermal technologies for heating and cooling systems is just starting in Massachusetts, there are not many engineers that are familiar with these systems. Working with experienced engineers on this type of project makes a big difference to the success of the project. In the following sections, we provide evidence from each of the three case studies that support this finding.

4.3.4.1 *Amherst College Bunker Building*

Amherst College was recommended, by the DOER, to contract Froling, an Austrian company that has more than four decades of experience in wood heating technology. Since Amherst worked with a firm that is considered the pioneers in this field, their construction phase went almost perfect. They did not have many discrepancies when deciding what type of system to install. Since Amherst College worked with experienced engineers, they were well prepared for any unknown obstacle. During the construction phase, they suffered from a harsh winter that produced a delay in the timeline of the project. Nevertheless, this delay was minimal and they were not really affected in terms of cost or comfort.

Another benefit of working with experienced engineers is that once the system is running they can provide technical assistance to the maintenance staff if situations arise. Froling Energy has been contracted to do the first annual maintenance, and helping Amherst College maintenance staff take care of the system. Furthermore, Froling Energy monitors the system remotely, informing Amherst College if there is any problem with the boilers. Working with experienced engineers is very important since it can make a difference in project effectiveness during and after the project implementation. The individual we interviewed from Amherst College said that working with Froling Energy has been the best decision since wood heating for this company is their bread and butter.

4.3.4.2 *Southern Berkshire Regional School*

Southern Berkshire Regional School District is an example of how important the engineer's experience is. As mentioned before SBRSD selected RDK Engineering as their contractors. This company did not have much experience with renewable thermal technology, and decided to conduct their own feasibility study. SBRSD and RDK feasibility study had a few differences that cause the project planning phase to get delayed. Due to these differences SBRSD and the DOER were able to bring a third party, Wilson Engineering which had more engineer experience than RDK, to produce a third and more accurate feasibility study.

After settling the discrepancies among the feasibility studies, SBRSD was able to continue their project and start the construction phase. The bid was given to RDK Engineers, but due to the delays of solving the differences among the studies, the oil boilers were not ordered on time, and so the project timeline is behind schedule. This is an example of how important the contractors engineering experience is, and how contracting firms that does not know about this type of technologies could make a project timeline set behind.

4.3.4.3 *Sudbury Public Housing Development*

Since Sudbury Public Housing Development is owned by the government they needed to accept the contractor who offered the lowest bid. Sometimes contractors who offer lower price quotes will not have as much engineering experience as those who offer a higher price quote. In this case they had several setbacks during their implementation process. One of these setbacks was that the contractors were not HVAC engineers; they were electricians and they are not familiar with this type of system. Thus, the system was not installed correctly the first time and electricians had to keep going into the tenant's room to fix it.

4.3.5 *Improving a Buildings Energy Efficiency Improvements Prior to or in Addition to Upgrading the Heating System May Lead to Increased Cost Savings*

Making improvements to a buildings energy efficiency can affect the amount of energy that the building is consuming and reduce fuel costs. This finding was exemplified in the case of the Southern Berkshire Regional School.

4.3.5.1 *Southern Berkshire Regional School*

The Southern Berkshire Regional School had a energy management system renovation in 2010, making the building more energy efficient. In addition, this project was funded by DOER grants.Annually were looking at savings of 3,508 gallons of heating oil because of these changes... said one individual we interviewed who worked closely with increasing the buildings energy efficiency (Southern Berkshire Regional School District, 2010).

4.3.6 *Public Housing Rules and Regulations Can Be Barriers When Implementing a Renewable Technology Project*

While investigating different aspects of the project process at the Sudbury Public Housing Development, we learned that public housing rules and regulations can be barriers when implementing a renewable technology project.

4.3.6.1 *Sudbury Public Housing Development*

A requirement of public housing developments is that when they are undergoing a construction project that is estimated to cost more than $10,000, they must put the project up to public bid, and accept the lowest bid they receive. While this method is effective at ensuring the public housing development saves money on a project, it also means that the electrician with the lowest bidder was not necessarily the most competent or familiar with ASHPs and their installation. This lack of experience with relatively new ASHP technology leads to several setbacks in the timeline of the installation as well as several instances of correcting mistakes, which involved entering the residents units, a slightly invasive process.

4.3.7 *Failure to Consider Context when Choosing a Metering System can Lead to Problems with Gathering Data*

Metering systems can be extremely useful for getting detailed information on energy usage of a house or other building. There are however many things to consider when looking into using a metering system for a certain application. One consideration is that the site must have reliable internet access if the system is to upload its data to a remote server. The Sudbury Public Housing Development did not correctly evaluate the effectiveness of a metering system at their complex.

4.3.7.1 *Sudbury Public Housing Development*

The public housing complex in Sudbury is not well suited for an internet based metering system for many reasons. There is inconsistent connection to the internet because the housing development is in a somewhat rural location. Additionally, public housing developments in general arent practical applications for a small scale pilot program using a metering system due to the wide range of tenant behaviors that will skew the data. A requirement of the PowerWise metering system is that the breaker panel be organized to accurately connect and label individual circuits. However, the breaker panels at Sudbury were very disorganized, having had many changes in the 50 years theyve been in service. Had the Sudbury Public Housing Development properly evaluated the application they were looking at implementing this metering system in, they may have realized the pitfalls before installing it.

4.4 SUMMARY

While many of our findings are specific to the project sites we studied, it is important to note that these findings can be applied to many renewable thermal project sites to come. From our findings we compiled a list of recommendations (located in the following chapter) that we presented to the DOER. It is our hope that the DOER will be able to use the recommendations to make improvements to future renewable thermal projects.

5 RECOMMENDATIONS

In this chapter we present recommendations to improve the planning and implementation process for renewable thermal technologies through DOER renewable thermal programs. Each recommendation is supported by our findings and review of relevant literature. It is important to note that our data analysis, and thus our recommendations are not without limitations. We were unable to provide an analysis of projected outcomes and actual outcomes relating to greenhouse gas emissions, renewable system energy efficiency, annual energy use, and annual fuel cost comparison of renewable systems and fossil fuel systems due to the lack of access to quantitative data at each site. Furthermore, our recommendations stem from site visits at only three project sites in a young program. For this reason, our recommendations reflect our analysis of qualitative data we collected including interviews and onsite visits from each of the three project sites. The recommendations are organized into major categories in the following sections.

5.1 Recommendations relating to informational material for potential project sites

5.1.1 *We recommend that the DOER continue to create case studies to provide up to date information to potential project sites about existing renewable thermal projects*

By continuing to create these case studies, found in Appendix 5, the DOER will be able to present more examples of similar projects for potential site leaders to learn from. As seen in the following section, we learned about the importance of providing feasibility studies to potential project sites from the interview with our sponsor. It is our hope that this will lead to more renewable thermal projects each with smoother project processes.

5.1.2 *We recommend that the DOER bring case studies when consulting with new project sites*

In the interview with our sponsor from the DOER, we learned that potential project site leaders often ask the question of who else has implemented a similar renewable thermal project to the one theyre considering. Our sponsor mentioned that while potential project site leaders seemed wary at first, due to many of these technologies being so new, when they learned that similar projects had been implemented in similar municipalities, the potential project site leaders felt more comfortable and at ease. When we interviewed the two individuals Southern Berkshire Regional School District, we showed them an example case study, found in Appendix 2. They said that they would have liked to have seen a similar case study at the beginning of their project process. These project site leaders from the Southern Berkshire Regional School District and the project site leaders from Amherst College both mentioned that they visited other sites that had already implemented biomass heating systems before making the final decision to move forward with their projects. By providing the potential project sites with case studies of similar projects, the DOER will be able to continue to provide the potential project sites not only with information regarding an example project process but also a point of contact for potential project site leaders to use when making their final decisions regarding their renewable thermal project.

5.1.3 *We recommend that the DOER provide examples of cost comparisons of fossil fuels and renewable energy including implementation and operational costs when consulting potential project sites*

Given the strong interest in the financial aspects of proposed projects we recommend presenting factual data that shows the cost comparison of the renewable systems considered along with a comparable fossil fuel system as an incentive for potential project leaders. Frequently, renewable resources can be more affordable than fossil fuels but project site leaders can be unaware of this since they do not have a concrete comparison between the two. For example, Amherst College and Southern Berkshire Regional School both initially considered non-renewable resources and it was not until they did a long-term cost comparison between renewable and non renewable heating sources that they noticed that a renewable resource would be more affordable overall, especially with the DOER incentive.

5.2 Recommendation relating to community education

5.2.1 *We recommend that the DOER provide methods or examples for conducting outreach and education of the community on renewable thermal technologies when consulting potential project sites*

It is important to educate the community about the new technology that project site leaders are aiming to implement, especially if a portion of the project is to be publicly funded. As noted in finding 4.3.3, if Southern Berkshire had not educated the community and gained community support, they would not have been able to fund the project. Fortunately, the DOER was aware of the importance of community education and provided the Southern Berkshire Regional School District with the necessary support to educate the community. In the case of the Sudbury Public Housing Development, also listed in finding 4.3.3 the community wasnt educated and the technology was used incorrectly, decreasing the effectiveness of the project.

5.3 Recommendations relating to feasibility studies

5.3.1 *We recommend that a feasibility study be completed at each potential project site*

Since each municipal building is not the same in design, each renewable thermal system installation will be different. Occasionally, especially in older school buildings, there are issues with the building (leaking pipes, asbestos, etc.) that can be uncovered during the investigative work involved in producing a case study. If a project began and issues like asbestos were present in the building, many problems would arise including time delays, and increased expenses. Feasibility studies can also include options involving different renewable system designs as well as cost and maintenance comparisons of the proposed renewable system and the existing fossil fuel system. As stated in finding 4.3.1, commissioning a feasibility study prior to beginning a renewable project can be very valuable. Therefore, we recommend that a feasibility study be completed at each potential project site. Since this recommendation can be aimed at both the DOER and potential project sites, we have provided both as recommendations that follow.

5.3.2 *We recommend that potential project sites commission a feasibility study prior to beginning a renewable thermal project*

As explained above, it would be in the potential project site leaders and communitys best interest to commission a feasibility study prior to beginning construction on a renewable thermal project. Not only do feasibility studies provide information regarding potential design of a new system and can uncover underlying issues within the building, they can also be used as informational materials for both potential engineering firms/contractors and the community. Since feasibility studies often include information regarding the general design requirements for a new system, this information can be used to inform potential engineering firms/contractors so that they are more informed about the project before they take it on. Feasibility studies can also be used to educate and increase community support. As discussed in section 2.3.1, it can be beneficial to a community to see a written document explaining the details of a project and that using a renewable thermal system is feasible in their application. For these reasons, we recommend that potential project sites commission a feasibility study prior to beginning a renewable thermal project,

5.3.3 *We recommend that the DOER strongly suggest or make it a requirement of their grant program that renewable thermal project sites commission a feasibility study prior to beginning a renewable thermal project*

We recognize that the DOER does not only fund these renewable thermal projects, but also provides the project site leaders and communities with guidance and support throughout the project process. Since the DOER provides funding to the project sites, they have the ability to leverage this funding when suggesting that the project sites commission a feasibility study. For this reason, we recommend that the DOER make it their responsibility to ensure that a feasibility study be completed at a project site before construction begins.

5.3.4 *We recommend that the DOER provide funding to commission a feasibility study that include a comparison of multiple renewable thermal heating and cooling systems*

As mentioned in section 4.3.2. before deciding to install a biomass boiler system, the Southern Berkshire Regional School District considered both geothermal and biomass technologies. The feasibility studies commissioned at the SBRSD were extensive, and illustrated that both options were feasible in this application, but the geothermal system had an incredible large installation cost. These feasibility studies provided them with enough information to make the decision that best fit their application of renewable thermal systems.

5.3.5 *We recommend that the DOER provide funding to commission a feasibility study that compares different types of metering systems and their application in the project site before providing funding to sites for metering systems*

Similar to how a feasibility study should be commissioned to determine which renewable technology will work the best in a given project, project sites that wish to utilize a metering system should conduct a feasibility study prior to metering system installation. The feasibility study could help determine which metering system would work best in any given project application. As explained in finding 4.3.7, in the Sudbury Public Housing Development, a feasibility study was not commissioned to determine which metering system would work best within the development. Because a feasibility study was not commissioned, there were many problems with the metering system.

5.4 RECOMMENDATIONS RELATING TO EXPERIENCED ENGINEERS AND CONTRACTORS

5.4.1 *We recommend that project sites work with engineering firms and contractors that are familiar with renewable technologies*

As mentioned in finding in 4.3.4.1 Amherst College we learned that having experienced engineers can improve the implemantation of the project. Working with experienced engineers allowed the maintenance staff at Amherst College to have access to support when dealing with small issues in the startup of their biomass boiler system. The engineers Amherst College worked with were very experienced with biomass boilers and installations. This experience instilled a sense of confidence and comfort in the staff at Amherst College. On the other hand, as listed in findings 4.3.4.2 and 4.3.4.3,after studying Sudbury Housing Development and Southern Berkshire Regional School we learned that having inexperienced engineers could delay the schedule of the project and the construction itself.

5.4.2 *We recommend that the DOER provide a list of engineering firms and contractors that are familiar with each type of renewable thermal technology to each project site*

The use of renewable resources is something relatively new so it is no surprise that sometimes it can be hard to find experienced engineers and contractors when installing these renewable heating and cooling systems. For this reason, we recommend that the DOER provide a list of engineering firms and contractors that are familiar with each type of renewable thermal technology to each project site. Project site leaders could use this list when searching for engineering firms/contractors to complete the installation of a renewable thermal technology, and also if they feel that they require a second opinion regarding any aspect of the project design.

5.4.3 *We recommend that there be investment in educating contractors and electricians in renewable thermal technology*

As the renewable thermal industry expands, these renewable thermal projects can have a big impact on fossil fuel dependence and greenhouse gas emissions in communities, and in a greater scale, they can impact the U.S. and the world. The DOER aims to implement more as renewable thermal projects and as this industry grows, they will require more and more engineering firms/contractors with experience in renewable technologies.

In order to meet the increasing demand for engineering firms/contractors that are experienced with different types of renewable thermal technologies, there must be a large effort placed into education regarding these renewable thermal technologies. This education gap could be filled a number of ways. A few examples include educational programs for contractors from the federal or state governments, incentives from federal/state governments for contractors to attend renewable technical courses in existing community college programs, and increased education on renewable technologies within engineering firms themselves.

5.5 CONCLUSION

Through the collection and analysis of data from project site leaders at three renewable thermal projects sponsored by the DOER, we achieved our goal to support the DOER's commitment to reducing greenhouse gas emissions in the Commonwealth of Massachusetts by evaluating three renewable thermal pilot projects to investigate ways to improve and promote the installation of renewable thermal heating and cooling systemsby producing three informational case studies. These case studies can be found in Appendix 5 along with a list of recommendations to both the DOER and potential project site leaders. The case studies produced will both promote the DOER renewable thermal programs and provide information to potential project site leaders that will, along with the list of recommendations, aid in improving renewable thermal project processes. As the number of successful renewable thermal projects increases in the Commonwealth of Massachusetts, greenhouse gas emissions and fossil fuel dependence will decrease, resulting in a healthier and more sustainable future

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APPENDICES

APPENDIX 1: POWERWISE INFORMATION

Enclosed in this appendix are some examples and information about the PowerWise monitoring service and its interface. This is the power monitoring system that is being used in the Sudbury Public Housing Development. The data comes from ammeters that are hooked into the circuit breaker panel of the house. Those ammeters wirelessly transmit their readings to a server every minute, so minute by minute data is available to be inspected and analyzed in real time. If all the ammeters are connected and labeled properly, it is possible to differentiate between appliances and get powerful insights.

APPENDIX 2: EXAMPLE CASE STUDY

Enclosed in this appendix is the example case study that was provided to us by the DOER. This case study acted as a guideline and template when we created case studies for the three project sites that we focused on.

APPENDIX 3: INTERVIEW QUESTIONS

APPENDIX 4: ON-SITE INFORMATION GATHERING GUIDES

appendix 5: our case studies

Enclosed in this appendix are the case studies that we produced for the DOER as the project deliverables.