



WPI



IMPROVING ENVIRONMENTAL CONDITIONS AT THE RESTORE

An Interactive Qualifying Project

Submitted to the Faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science

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Abstract

The Habitat for Humanity Greater Worcester ReStore often reaches extreme temperatures during the summer months, creating a hazardous environment for its occupants. Our team surveyed ReStore customers, volunteers, and staff in order to evaluate the impact environmental conditions have on their experiences. By performing cooling load calculations, assessing ventilation and insulation options, and analyzing costs, the team provided the ReStore with a list of potential solutions and focused recommendations based on cost and effectiveness, most notably the AIRMAX ventilation system.

Executive Summary

Habitat for Humanity is a nonprofit organization founded in 1976 on the belief that any person should have a right to a simple, durable place to live, and that decent shelter in decent communities should be a matter of conscience and action to all. Since 1976, Habitat has grown to become one of the largest and most visible nonprofit organizations in the country, building or repairing hundreds of thousands of homes, and helping millions of people around the world.

Habitat for Humanity is supported by their local ReStores, retail stores dedicated to selling donated furniture, home accessories, and building materials. Instead of placing these donations directly in new homes, all profits from the ReStore sales are used to fund Habitat's local building projects. These ReStores are crucial to Habitat for Humanity as they provide its only reliable source of revenue. Habitat occasionally receives grant funds, but the pressure of funding a significant portion of their projects falls to the ReStores, and challenges them to resell as many goods as possible (Galvin, Arnone & Tate, 2014).

This project sought to propose an affordable energy solution to efficiently regulate the working environment for the customers, volunteers, and staff of the ReStore, and which would allow the facility to remain in operation during the summer months. Firstly, we identified the impact an environmental change will have on the ReStore's customers, volunteers, and staff. Our team conducted in-person customer questionnaire surveying in order to assess the effects of temperature on the experiences and interactions of customers at the ReStore. We ascertained from the data collected using the survey that a significant percentage of ReStore customers have experienced high temperatures while at the facility, which have led to negative experiences. An even larger percentage of the survey participants responded that environmental conditions with lower temperature levels would contribute to a more positive experience while shopping at the

ReStore. The other demographic that our team surveyed was ReStore volunteers and staff members. Individual interviews were conducted with volunteers and employees in order to understand the impact that current summer conditions have on their ability to do their work and their motivation while working. Analysis of the responses of the individual interviews showed that a majority of ReStore workers feel the summer temperatures inhibit their ability to work and their enthusiasm, which would be improved by maintaining a lower temperature in the warehouse. Notably, our team was also informed of the necessity of better air circulation and ventilation as several respondents indicated that it can become difficult to breathe while working within the ReStore in the summer.

Following data collection, we determined specific reasons the warehouse reaches high temperatures throughout the summer, and sought to correct these issues by conducting cooling load calculations and determining appropriate ventilation requirements. Our team began creating a ventilation solution by first seeking professional advice, analyzing which approach would best serve a warehouse of the ReStore's size, and then performing calculations using ASHRAE handbooks to determine which specifications our system would need.

The experts we reached out to included professors at WPI as well as practicing Professional Engineers in the field of heating, ventilation, and air conditioning (HVAC). The professionals we met with recommended that we implement a night flush system, a technique that uses large ventilation fans to pull cool air into the building during the night. For the system to be effective in a retail warehouse, the HVAC specialists suggested an industry standard of six to ten complete air changes per hour. This target far exceeds the calculated minimum ventilation rate required by ASHRAE Standard 62.1.

Selecting supply and exhaust fans required careful consideration of variables including static pressures, loudness, weight and cost, required power draw, and maintenance accessibility. In calculating the cubic feet per minute (CFM) necessary for each intake and exhaust fan to achieve at least six air changes per hour, we discovered problems with rain penetration across the louvers. Our team adjusted our target air changes per hour to reduce the speed at which air flowed into the warehouse to compensate for this issue. Problems also emerged regarding the structural integrity of the building and its ability to support the additional weight of large ventilation fans. Our team's leading concern however, was the fan's ability to circulate air effectively enough to provide significant temperature reduction.

Fortunately, during our research we came across an alternative industrial-sized ventilation system. AIRMAX International offers a ventilation system which utilizes a large outdoor air-handling unit to circulate air through a ceiling-mounted fabric ductwork. An outdoor fan unit is ideal as it avoids any excessive noise and weight problems created by wall mounted propeller fans. Strategically placed holes in the fabric duct ensure that the air is evenly distributed and will not disturb shopping customers. The system is designed to spread air throughout the warehouse rapidly, replacing all the air in the building every six minutes. Thus, this design eliminates the possibility of areas without air movement or circulation, known as dead-zones.

The AIRMAX team will fabricate and install a 30,000 CFM makeup air system that will deliver ten air changes per hour at the floor level of the warehouse. This system also utilizes the night flush method and will allow the building to be as much as 20 degrees cooler in the morning, making the warehouse significantly more comfortable for employees, volunteers, and customers.

The AIRMAX unit is a renowned ventilation system that has been installed in hundreds of warehouses nationwide with proven results. Our team is confident the AIRMAX system will be the most beneficial climate control system for the ReStore to establish a retail friendly environment. Deborah Maruca Hoak, the ReStore Director, mentioned that in her three years of research prior to this project she has not found a system of equivalent capability. Perhaps the most advantageous aspect of the AIRMAX system is that it can be transported, and thus will remain an asset of Habitat for Humanity should they relocate the ReStore.

The total cost for the system including delivery, installation, and electrical connection will be \$30,723.00. This price is comparable to the cost of supply and exhaust fans used in a traditional night flush; however, the AIRMAX system retains a verified track record of providing effective temperature reduction in large-scale warehouses.

Furthermore, the ReStore is required by their lease to insulate the walls of the warehouse, before the year 2017. We determined the optimal insulation option based on a cost analysis of materials and installation in order to provide the most economical solution to the ReStore. Insulation will not significantly reduce the temperature inside throughout the summer, but will reduce the heating costs for the ReStore by hundreds of dollars each month during the winter. The different insulation types our team considered for the ReStore were spray foam, rigid foam board, and blown-in. The Dow Chemical Company donates one inch rigid foam board to all Habitat for Humanity projects, leading to significantly reduced material costs. Rigid foam board can be difficult to install due to existing wiring and pipe work; however, volunteers are able to perform the installation, saving thousands in labor costs. Rigid foam board is the most logical choice based on cost effectiveness, thermal resistance, and installation application therefore was our recommendation to the ReStore.

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Chapter 1: Introduction

Habitat for Humanity is a nonprofit organization dedicated to building safe and affordable housing for those in inadequate or homeless living environments. Habitat was founded in 1976 on the conviction that every man, woman, and child should have a simple, durable place to live in dignity and safety and that decent shelter in decent communities should be a matter of conscience and action to all. At Habitat for Humanity their motto is “A hand *up*, not a hand *out*.” They are dedicated to building families *with* families not for them. They partner with families who earn between 25%-60% of the area’s median income and do not qualify for homeownership programs. These families pay for their homes through a monthly mortgage after putting in roughly 500-600 hours of “sweat equity” prior to becoming homeowners (Habitat for Humanity MetroWest/Greater Worcester, 2012). Since Habitat began its mission it has improved the quality of life for 750,000 families by helping them build their own homes and become homeowners (Dang, LaBove, Mastascusa & Milazzo, 2014).

Habitat for Humanity is supported by their local ReStores, a retail store dedicated to selling donated furniture, home accessories, and building materials. Instead of donating these additions directly to new homes, all the profits from the ReStore sales are used to fund Habitat’s local building projects. These ReStores are crucial to Habitat for Humanity as they are its only reliable source of revenue. Habitat occasionally receives grant funds, but the pressure of funding their many projects falls to the ReStore to accept and resell as many donations as possible (Galvin, Arnone & Tate, 2014).

The purpose of this Interactive Qualifying Project was to improve the environmental conditions at the MetroWest/Greater Worcester Habitat for Humanity ReStore. Deborah Maruca Hoak, the director of the ReStore, explained that the ReStore’s warehouse has little to no

insulation and ventilation, causing the warehouse to heat up to unworkable temperatures during the summertime. Our team undertook the task of finding a feasible solution to the temperature problem at the ReStore facility.

Our team's goal was to create a proposal for the ReStore that analyzes various solutions to the above stated problem. Within this proposal we make recommendations based on cost, available contracting from local installers, impact on customers and volunteers, and energy efficiency. Our report delivers options that provide strong investments towards solving the temperature problem, and furthering the purpose and initiatives of Habitat for Humanity as an organization.

Chapter 2: Literature Review

Throughout history our citizens have strived to improve the society in which they live. The desire to advance one's community is one of the reasons behind the success of nonprofit organizations such as Habitat for Humanity. Habitat expanded dramatically after being recognized by the former U.S. President, Jimmy Carter, and his wife. Carter helped to restore a six-story building in New York City that was able to house 19 families (Galvin, Arnone & Tate, 2014). Still, being a nonprofit organization presents an issue when taking on the gargantuan task of overcoming poverty and homelessness. For a recent alternative solution to such homelessness see Appendix B. The volunteers at the ReStore provide a service that allows Habitat to continue reaching the community.

2.1 Volunteer's Role in Nonprofit Organizations

Nonprofit organizations are a resource where many individual volunteers develop relationships among one another and connect over a common interest. Volunteers provide an invaluable service to nonprofits which allows for growth to serve even more of their community. "Volunteer hours in U.S. nonprofits were equivalent to 8.9 million full time employees in 2011. With competitive wages, the volunteer hours were worth \$296.2 billion which is roughly the same amount as donations (Blackwood, 2012)" (Dang, LaBove, Mastascusa, Milazzo, 2014, 24). Volunteers bring more than labor hours to the organizations; they bring personal, business, and government expertise to nonprofits that would not be able to have access to those resources. Problem solving, civic engagement, and fundraising are just a few of value assets volunteers bring every day to the millions of nonprofits throughout the United States. Volunteers bring enthusiasm to people in need and add significance to their lives (Boris, 2006). Volunteers are not

only the backbone of nonprofit organizations they are also the reason programs helping communities exist because the community itself begins with the people in it.

2.2 The Importance of Warehouse Climate Control

2.2.1 Environmental effects on employees and products

The environment of a work environment greatly impacts the employees, volunteers, and customers. An excessively hot and humid climate is detrimental to the individuals working there. Air-circulation is essential to ensure humidity level and temperature remain within reasonable standards. Workers exposed to excessive heat will negatively affect their performance and can be extremely dangerous at extreme levels. Workers exposed to high temperature environments are less efficient and are more prone to accidents; including heat stress if exposed for extended periods of time. (Allen, 2014) “Understanding the problems created by poor ventilation and temperature fluctuations, and the possible solutions, will help you maintain a better warehouse environment” (Allen, 2014, 1).

The ReStore warehouse has reported temperatures exceeding 100°F during the warmer summer months. “Applying a meta-analytic approach, Hancock *et al.* (2007) and Pilcher *et al.* (2002) found evidence that both heat and coldness have negative impacts on performance beyond certain thresholds. Both groups of researchers identified thresholds of about 10°C (50°F) or lower and 30°C (86°F) or higher, which lead to performance decrements. Between these thresholds, findings are inconsistent” (Kolb, Gockel, & Werth, 2012, 622). The temperature of the warehouse is clearly well above the acceptable threshold during the warm summer months, indicating a strong need for a new environment control system. The American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE), the industry standard, has

indicated an ideal outdoor environment comfort zone is between 20°C to 28°C (68°F to 82.4°F) under normal conditions and clothing (Kolb, Gockel, & Werth, 2012).

The humidity level can greatly influence the warehouse environment, and create problems with moisture and warping. Wood is very porous and absorbs moisture extremely well, causing it to expand and warp. Home improvement warehouses often carry large numbers of wooden products; therefore humidity control is essential for maintaining quality merchandise. In ferrous materials humidity also promotes the oxidation of the metal and creates rust (Allen, 2014). Air-Conditioning and circulation equipment are essential for creating a productive work environment and retaining product quality.

2.2.2 Effects of temperature on customer-employee interactions

The ReStore is a retail store, where interactions between employees and customers take place regularly throughout each day. Temperature can have an impact on interpersonal performance of employees and customer orientation. Research has shown that temperature does unconsciously impact the behavior of individuals including employees and customers and can influence social aspects of interactions (Kolb, Gockel, & Werth, 2012). “We found that participants in rooms with a low temperature [20.22°C (68.40°F)], compared to those in rooms with a high temperature [25.86°C (78.55°F)], generally showed more customer-oriented behavior. Specifically, they showed stronger customer-oriented helping behavior, scored higher on the SOCO Scale – a self-report questionnaire assessing customer orientation ... In Sum, our study shows that ambient temperature can impact social performance in service settings. One strength of this study is that it examined the effects of two kinds of temperatures that can and do occur in real-life service settings” (Kolb, Gockel, & Werth, 2012, 629). All aspects of the

ReStore will greatly benefit from a climate control solution that will provide a more comfortable environment for its employees, volunteers, and customers.

2.3 Warehouse Climate Control Systems

2.3.1 Ventilation Solutions for warehouses

Ventilation is a crucial and required component to any retail space. ASHRAE Standard 62.1-2013 provides the industry standard for ventilation that Professional HVAC Engineers use to create ventilation solutions in buildings. There are numerous options for the ventilation of warm air through exhaust fans located on the roof and side walls of a warehouse. Exhausting fans use a system of shutters and vents to move air throughout the building and ideally exhaust all of the warm air to the exterior in the summer months. Fans engineered to circulate air within in a building include ceiling fans, circulation fans, and portable fans. The Department of Energy produced a report in 1999 documenting the energy consumption of various HVAC system components. The report details the parasitic primary energy use of supply and return fans as well as exhaust fans because of the continuous operation of the equipment while the building is in use (Westphalen & Koszalinski, 1999). Ventilation systems have energy drawbacks and parasitic energy consumption; however, a comfortable work environment is a requirement. The additional energy consumption will far outweigh the costs of worker injuries caused by excessive heat and humidity.

2.4 Insulation

The insulation section is a compilation of data and methods from the United States Department of Energy (U.S. DOE) and the National Renewable Energy Lab, which can be found on U.S. DOE website, energy.gov. Insulation materials are compared based on the thermal resistance, which is the materials resistance to heat flow. Thermal resistance is also represented by the unit R; R is the surface area of the material multiplied by the temperature and divided by

the amount of energy. A higher R-value means that the material is better at retarding the amount of heat transfusing through the material.

2.4.1 Types of Insulation

Blanket: Batts and Rolls:

Blanket insulation is the most common type of insulation, known in industry as batt and roll insulation. Blanket insulation is usually made from fiberglass, mineral wool, plastic fibers or natural fibers. Manufacturers sometimes add facings to the batts or rolls; this type of blanket is often used when needing to attach the insulation to a wall or support. However, unfaced blankets are better when adding insulation over pre-existing insulation due to the continuity between the insulations. Blanket insulation is used in unfinished walls, foundation walls, floors and ceilings. Blanket insulation is advantageous when the wall is relatively free from obstructions, since it is suited for standard stud and joist spacing. (Energy.gov, 2015)

Rigid Foam Boards:

Rigid foam boards can insulate any part of a building, from the roof to the foundation. Rigid foam boards provide a good thermal resistance and can retard heat transfer through structural elements. The boards are made from either polystyrene, polyisocyanurate (polyiso), or polyurethane foam. Rigid foam board insulation is used in unfinished walls, foundation walls, floors, ceilings and unvented low-sloped roofs. The advantages of using rigid foam boards is that they have a high insulating value given the thickness of the material, and they can block thermal breaks if installed continuously over frames or joists. A thermal break occurs when the material is only installed between joists and this leaves a small gap between the material and joist that allows a free flow of heat within the wall. (Energy.gov, 2015)

Loose-Fill or Blown-In:

Loose-fill or blown-in insulations are small particles of fiber, foam, or other materials that are blown or poured into a wall. This method of insulation can be used in an enclosed existing wall, open new wall cavities, unfinished attic floors or other hard-to-reach places. The materials that are typically used for loose-fill insulation are cellulose, fiberglass, or mineral wool. Cellulose loose-fill insulation provides a thermal resistance between R-3.2 and R-3.8 per inch, fiberglass provides between R-2.2 and R-2.7, and rock wool provides between R-3.0 and R-3.3. (Energy.gov, 2015)

Radiant Barrier and Reflective System:

Radiant barriers and reflective systems are unlike most insulation systems. Instead of resisting conductive or convective heat flow, the radiant barriers and reflective systems reflect radiant heat away from the building. Studies have shown a five to ten percent lower cooling cost when installed in warm, sunny climates. Radiant barriers and reflective systems are usually created from foil-faced kraft paper, plastic film, polyethylene bubbles, or cardboard. The system is used in unfinished walls, ceilings and floors. Radiant barriers and reflective systems are suitable for framing at a standard spacing and are most effective at preventing a downward flow of heat. (U.S. Department of Energy, 2012)

Rigid Fibrous or Fiber Insulation:

Rigid fibrous insulation is primarily used for insulating air ducts in buildings, or used when the insulation can potentially reach high temperatures. Rigid fibrous or fiber insulation provides a thermal resistance of R-4 per inch. Rigid fibrous insulation is made from fiberglass, and mineral wool. The system is used for duct work insulation in unconditioned spaces and other areas that require insulation that can withstand high temperatures. (Energy.gov, 2015)

Sprayed Foam and Foamed-In-Place:

Spray foam insulation is also known as liquid foam insulation. Liquid foam materials can be sprayed, foamed-in-place, injected or poured. Common materials used for liquid foam insulation are polyisocyanurate and polyurethane. The thermal resistance of spray foam ranges between R-4 and R-8 per inch. (Energy.gov, 2015)

2.4.2 Material Categories

Fiberglass:

Fiberglass is currently produced as medium- and high-density insulation. The denser products are more useful when needing to insulate areas that have limited cavity space. Standard fiberglass' thermal resistance is between R-2.9 and R-3.8, while high-performance fiberglass is between R-3.7 and R-4.3. When installed, it has a density between 0.5 and 1.0 pounds per cubic foot. (U.S. Department of Energy, 2012)

Mineral Wool:

Mineral Wool consists of two types of wool, rock wool and slag wool. Rock wool is a man-made material that consists of natural materials like basalt or diabase. Slag wool is another man made material from the layer that forms on the surface of molten metal. “Mineral wool contains an average of 75% post-industrial recycled content”, and therefore does not need additional applications to become fire resistant (U.S. Department of Energy, 2012). Its thermal resistance is approximately R-3.7 per inch. When installed it has a density of 1.7 pounds per cubic foot.

Cellulose:

82% - 85% of cellulose is made from recycled paper products. The cellulose has to be blended with either borate or ammonium sulfate to be fire and insect resistant. Cellulose also does not require a moisture retardant. When installed it has a density between 1.5 and 2 pounds

per cubic foot. Cellulose also has a thermal resistance between R-3.6 and R-3.8 per inch. (U.S. Department of Energy, 2012)

Plastic Fiber:

Plastic fiber is made from recycled plastic milk bottles, and is treated with a fire retardant. The thermal resistance varies with the batts' density, ranging from R-3.8 per inch at 1 pound per cubic foot to R-4.3 per inch at 3.0 pounds per cubic foot density. (U.S. Department of Energy, 2012)

Natural Fiber:

Natural Fiber consists of cotton, sheep's wool, straw and hemp. "Cotton insulation contains 85% recycled cotton and 15% plastic fibers, which have been treated with borate -- the same flame retardant and insect/rodent repellent used in cellulose insulation" (U.S. Department of Energy, 2012). Its thermal resistance is R-3.4 per inch. "Sheep's wool is treated with borate to resist pests, fire and mold" (U.S. Department of Energy, 2012). It also can hold large quantities of water. The thermal resistance is about R-3.5 per inch. Straw undergoes a process which it is fused together to create boards, without using adhesives. The panels are usually 2 to 4 inches thick and have a thermal resistance between R-1.4 and R-2. The boards do make effective sound-absorbing panels for interior divisions. (U.S. Department of Energy, 2012)

Polystyrene:

Polystyrene is a colorless and transparent thermoplastic commonly used in foam boards or bead board insulation, concrete block insulation and loose-fill insulation. The thermal resistance of polystyrene foam boards is between R-3.8 and R-5.0 per inch, while loose-fill is around R-2.3 per inch. (U.S. Department of Energy, 2012)

Polyisocyanurate (polyiso):

Polyisocyanurate is a thermosetting type of plastic, closed-cell foam that contains a low-conductivity and contains a hydro chlorofluorocarbon-free gas. Due to the gas the thermal resistance of the material is between R-5.6 and R-8 per inch. This material is available in a liquid, spray foam, and a rigid foam board. Due to the gas within the material, within the first two years after the product is made, the gas may escape and is therefore replaced by air; this process is called thermal drift. This process causes the thermal resistance to drop slightly, but remains the same afterwards, unless the foam is damaged. Panels that have an added foil facing have a more stabilized thermal resistance between R-7.1 and R-8.7 per inch. (U.S. Department of Energy, 2012)

Polyurethane:

Polyurethane is a foam insulation that contains a low-conductivity gas in its cells. The thermal resistance of this material is between R-5.5 and R-6.5 per inch. Due to the gas in the cells of the material, this material goes through a process called thermal drift and results in a slightly reduced thermal resistance. This material can be used in foam boards or as liquid spray foam. The liquid spray foam is not as thermally resistant as the boards, but it can mold itself into any cavity. Slow expanding foam is also available, which is intended for cavities in existing buildings. The foam will not expand quickly enough to damage the walls due to overexpansion. The foam is water vapor permeable, remains flexible and is resistant to wicking of moisture. The thermal resistance of the foam is about R-3.6 per inch. (U.S. Department of Energy, 2012)

Insulation Facings:

A facing is fastened to the insulation during manufacturing and protects the insulation's surface, holds the insulation together, and facilitates fastening to building components. Facing can sometimes act as an air barrier, radiant barrier and/or vapor retardant. Common materials

used for facings are kraft paper, white vinyl sheeting, and aluminum foil. (U.S. Department of Energy, 2012)

2.4.3 Installation of Insulation

Blanket: Batts and Rolls:

Blanket insulation requires unfinished walls, floors or ceilings in order to be installed. The insulation is sold in rolls with a variety of widths. The insulation then needs to be unrolled, cut and fitted between studs, joists or beams, if the wall has no obstacles. If the wall has obstacles, then the blanket needs to be cut to avoid the obstacles. Once the first layer is installed it is possible to add thermal resistance to the wall, floor or ceiling by adding second layer of insulation. The wall, floor or ceiling would then be sealed, keeping the insulation in place. (Energy.gov, 2015)

Foam Board or Rigid Foam:

Foam boards or rigid foam are sold as panels, and are used in unfinished walls, foundation walls, floors, ceilings, and low-slope roofs. When installing the insulation on the interior of the building, the insulating boards must be covered with a half-inch gypsum board, or another type of building-code approved material for fire safety. For Exterior applications, the boards must be covered with a weatherproof facing. (Energy.gov, 2015)

Loose-Fill and Blown-In:

Loose-fill and blown-in insulation are used for enclosed existing walls, new wall cavities, unfinished attic floors, and other hard-to-reach areas. The insulation is installed is by drilling holes into the finished walls, and with a special machine, the material is blown into the wall to a specific density. The material can also be poured into the wall, although this method of

installation is less common. After the addition of the new materials, the walls are patched up and refinished. (Energy.gov, 2015)

Radiant Barriers and Reflective System:

Radiant barriers and reflective systems are installed in unfinished walls, ceilings, and floors. Radiant barriers and reflective systems are usually installed on the interior side of the roof of a building, and is focused on reducing the radiant heat transfer from the roof into the attic. For this method to be effective the radiant barrier must face an air space. Newer technology has also allowed radiant roofing paint to begin to be used to reflect and emit solar radiation from the sun, and successfully reducing the internal temperature of buildings. (U.S. Department of Energy, 2012)

Rigid Fibrous or Fiber Insulation:

Rigid fibrous insulation is used to insulate air ducts in unconditioned spaces, and other places that require insulation that can withstand high temperatures. Rigid fibrous or fiber insulation is usually installed in air ducts by a heating, ventilation, and air conditioning (HVAC) contractor. The insulation can also be installed on the exterior of the ducts by impaling it on the duct with weld pins and securing it with speed clips or washers increasing the thermal resistance of the air ducts within unconditioned spaces where heat transfer between the duct and space is undesirable. (Energy.gov, 2015)

Sprayed Foam and Foamed-In-Place:

Spray foam insulation or liquid foam insulation is used in enclosed existing walls, new wall cavities, and unfinished attic floors. Liquid foam insulation is applied by either using small spray containers or in larger quantities with special machines, which is most likely pressure sprayed. Both types of installation expand and harden as they cure. Following the installation, a

fire retardant thermal barrier equal to a half-inch gypsum board must cover all of the foam materials. In addition, some building codes do not recognize sprayed insulation as a vapor retardant, so installation might require an additional vapor retarder. After the addition of the new materials, the walls are patched up and refinished. (Energy.gov, 2015)

2.4.4 Cost Implications

Insulation cost as well as the price to install the insulation varies greatly with type and placement. The three main placements for insulation are ceiling, underfloor, and wall. Along with the placement of the insulation there are various grades of insulation. Different “R” values of the insulation change the cost and installation price. Fiberglass insulation has been used for many years and is the most cost effective and common types of insulation for the walls and ceilings of a building.

The cost of the material itself is pretty similar for most types of insulation; the major cost is a product of the installation fees. Installation cost is going to vary greatly between companies because of competition. If contacted, companies will visit the site providing an estimate based off of their views and conclusions about the area. Another important detail to consider in the cost of installation is what type of installation is going to be installed. Typically, installing spray foam installation is going to cost significantly more than the installation of standard fiberglass roll insulation.

2.5 Technical Complications

The local MetroWest/Greater Worcester ReStore warehouse has many technical problems associated with it due to faulty construction methods used in the past, which do not pass modern building codes. Many methods of insulation and ventilation cannot be utilized within the ReStore’s warehouse due to structural loads within the building. The warehouse was built in the 1970’s and does not meet current building load regulations, so the addition of loads

on the roof will cause further complications for the building. It would be possible to add structural support to the building, so more weight could be added to the roof, but at this time that option is not feasible due to the budget of that project. The ReStore does not own the building it occupies, creating another obstacle for insulation and ventilation solutions that would be recommended under normal conditions. The ReStore is not seeking a solution involving a large capital investment; therefore, the recommendations presented need to be carefully tailored to current restrictions on the store.

Chapter 3: Methodology

The goal of this project was to propose an affordable solution which improves the ReStore warehouse infrastructure in order to efficiently regulate the shopping and working environment for the customers, volunteers, and staff. Achieving this goal required the following research objectives:

1. Identify the impact an environmental change will have on the ReStore's customers, volunteers, and staff.
2. Identify specific reasons the warehouse is reaching high temperatures throughout the summer, by conducting a cooling load calculation and determining appropriate ventilation requirements to reduce the warm air inside.
3. Determine the optimal insulation type and benefits of that selection based on industry standards, therefore reducing the energy consumption associated with lowering the environmental temperature during the warmest months.
4. Categorize the solutions based on cost analysis of materials and installation to provide the most economical resolution for the ReStore.

Throughout this chapter, we provide an in-depth explanation into how research, data, and specifications were collected, and how a thorough analysis was performed to develop recommendations for the improvement of the ReStore's working environment.

3.1 Objective 1

Identify the impact an environmental change will have on the ReStore's customers, volunteers, and staff.

The current environmental conditions within the ReStore warehouse, such as temperature and air circulation, have been identified by the project liaisons as issues that affect the ability of the ReStore to operate, with high temperatures in the summer sometimes forcing the warehouse to shut down. According to the American Society of Heating, Refrigerating, and Air-

Conditioning Engineers, the ideal environment comfort zone for people wearing typical clothing is 68 - 82.4 °F (20 – 28 °C) (ASHRAE 2010). In addition to reviewing the industry standards for comfort, our team sought to identify the impact that the ReStore’s environmental conditions has on customers, volunteers, and staff, and to gage their perception of how changes to the warehouse’s environment would affect their interactions as either customers or employees. This information would help us to confirm that improvements to the ReStore are significant for not only the operation of the warehouse, but also the success of the ReStore as a business.

3.1.1 Customer Surveying

In order to properly collect information on the impact of environmental change, our team focused on two population samples to survey, ReStore customers and ReStore volunteers or staff. In order to collect information from ReStore customers, a questionnaire survey method was used. Questionnaire surveying was identified as a favorable method for interacting with customers as it provides a means by which to capture responses from respondents in a standardized manner. Our method of delivery for the questionnaire survey was to approach customers as they entered the warehouse and ask if they would be willing to participate in a brief survey to improve the ReStore. The survey questions were administered and responses were recorded by a member of the project team. Each customer was informed that all answers would be confidential and anonymous, and that there would be no attempt to identify any respondent. Paper copies of the questionnaire survey were utilized, with clipboards as a surface to write on. By utilizing a structured questionnaire we were able to ask a standard set of questions to each customer from which the customer was able to select an answer from a given set of choices. The questions, and structured answers, from the questionnaire survey were as follows, in order.

1. Have you been to the ReStore before?
 - Yes
 - No(If respondent answers “No” to this question, skip directly to Question #6)

2. Would you say that you visit the ReStore...?
 - Less than once every month
 - Approximately once every month
 - Several times every month
 - Other: _____

3. Have you ever visited the ReStore during the summer months?
 - Yes
 - No(If respondent answers “No” to this question, skip directly to Question #6)

4. While you were visiting the ReStore in the summer, would you say that the temperature within the warehouse was comfortably hot?
 - Yes
 - No
 - Unsure(If respondent answers “No” or “Unsure” to this question, skip directly to Question #6)

5. How did the temperature of the warehouse during the summer impact your visit, did it...?
 - Contribute to a positive experience at the ReStore
 - Contribute to a negative experience at the ReStore
 - Not impact the customer’s experience at the ReStore

6. What is a temperature range in which you would personally begin to feel uncomfortably hot while visiting a facility such as the ReStore?
 - Below 70 °F
 - 70 – 80 °F
 - 80 – 90 °F
 - 90 – 100 °F
 - Above 100 °F

7. If the temperature within a facility such as the ReStore were to reach [insert customer’s answer to Question #6], or above, would you...?
 - Continue with your visit to the ReStore without an impact
 - Continue with your visit to the ReStore but have a more negative experience
 - Decide to leave the ReStore and come back another time
 - Decide to leave the ReStore and go to a different place of business to meet your needs

8. Do you think that you would have a more positive experience with your visit to the ReStore if the temperature within the facility was maintained to be lower than [insert customer’s answer to Question #6]?
 - Yes

- o No
- o Unsure

At the conclusion of the questionnaire survey, customers were thanked for their participation and reassured that their responses would help to contribute to a more positive ReStore experience.

The questions for the survey were carefully designed to provide the customer with the most comfortable experience while still collecting information relevant to their experiences with the ReStore. The questionnaire survey is structured, meaning that the respondent chooses their answer or gives a dichotomous response, rather than being put on the spot to generate their own answer. This structuring ensures that the customers do not feel pressured to come up with an intricate response, and allows for more effective aggregation and statistical analysis of results as all of the data is already categorized.

The questionnaire was designed to establish comfort with the participant by engaging them with simple and non-compromising questions like whether it was their first time at the ReStore. The questions then develop into more personal responses once a baseline was established. The questions were carefully worded so as to ensure that the meaning of the question is unambiguous, and that the customer is not made to feel uncomfortable. For example, variations of the word “visit” were used rather than “shopping” so as to avoid social desirability bias with respondents who are not comfortable utilizing a discount business. The questionnaire was set up so that the team member administering the survey is able to skip questions based on the respondents experiences with the ReStore, this ensured that customers were not asked questions which do not apply to their experiences or to which they lack the information needed to respond; additionally this helped to keep the length of time they were participating in the survey shorter, for their benefit. Certain questions, like the name of the participant were not

included so that the customer was not made to feel uncomfortable or concerned with their anonymity while being surveyed.

The design and administration of the questionnaire also helped to avoid certain types of bias. The questions eliminate most occurrences of social desirability bias, while sampling and non-response bias were reduced by asking customers who are physically at the ReStore if they were willing to participate in the survey before attempting to administer a questionnaire. The questionnaire survey was put through pre-testing by administering the survey to other students or WPI campus community members in order to ensure that questions did not present unforeseen challenges to the respondent, and that response options covered a majority of possible answers; changes were made to improve the survey based on feedback from pre-test respondents.

This questionnaire survey was structured to provide information on not only the experiences and interactions of customers with the ReStore and its environment, but also to gain insight into the perceived effects of environmental changes and improvement from the eyes of a customer. Once data was collected, the structured questions allowed for efficient compilation and analysis based on percentages of customers who chose each response option. The information collected through customer surveys was then utilized to argue a business oriented angle on the necessity of environmental condition improvements at the ReStore. If a majority of customers responded with negative feedback as to the effects of temperature ranges which were known to be present at the warehouse, conclusions were then drawn as to a negative effect on the aggregate business potential of the ReStore.

Anticipated challenges and limitations to conducting customer surveys were primarily focused on the willingness and responsiveness of ReStore customers. While there were not significant issues with low response rates, the team made preparations to include additional

incentivizing to increase participation numbers, for example chocolate may have been distributed for completing the survey questionnaire.

An online version of the customer questionnaire survey was also generated at the recommendation of the ReStore floor manager and social media supervisor. This survey was created using Google Forms and distributed over social media via the MetroWest / Greater Worcester ReStore Facebook page, which at the time of distribution had approximately 2,000 likes. An online version of the survey would theoretically allow for better sampling distribution of data as it allows for anyone with prior ReStore interactions to complete the survey at their will and does not target only customers who shop at the ReStore during March and April, as an onsite survey would. Additionally an online survey would removes many of the biases previously discussed for in-person surveying as it allows participants to take as much time to answer truthfully and with thought out answers as they need, and removes any pressures leading toward social desirability or similarly interaction-driven biases. The most notable limitation of online surveying is that participants are not able to ask questions related to the survey questions, though attempts were made to address common questions with the addition of clarifying subtext below questions that frequently yielded confusion from participants during in-person questionnaire surveying.

Techniques and strategies for the architecture and administration of the questionnaire survey utilized in this section are taken from *Social Science Research: Principles, Methods, and Practices* by Anol Bhattacharjee. All WPI Institutional Review Board policies and steps for human surveying were fulfilled and abided by during the completion and analysis of the questionnaire surveying.

3.1.2 Volunteer and Staff Surveying

In order to collect information from ReStore volunteers and staff members, our team determined that the most effective method would be group interviews, or focus groups. This technique is used when a small group of participants are interviewed in a single location simultaneously (Bhattacharjee 2012). In the case of our team, focus groups would be utilized to interview groups of ReStore volunteers and staff members. Focus group interviewing was identified as a favorable method for surveying as it allows for a deeper look at complex issues, and provides participants with an environment in which they can build off of the ideas of others. Interview surveys would be administered to the focus groups by a team member who was a designated interviewer and whose role was to facilitate discussion on the questions and ensure that a balance was maintained in which no one interviewee dominated the conversation and where more reluctant participants were given equal opportunities to voice their opinions or contribute to a discussion. An additional team member would be present in order to take diligent notes on the responses of the participants, and the role of this team member would be explained to the participants prior to the start of the interview, to ensure the comfort of the interviewees. Both team members would formally introduce themselves prior to the start of the focus group. Additionally, the interviewees would be ensured that their responses would be recorded anonymously as an aggregate group so that no one individual's points of discussion could be traced back to that individual. The discussion questions to be utilized during the focus group interviewing were as follows, in the order asked by the interview facilitator.

1. In the time you have worked/volunteered at the ReStore, have you ever felt that the temperature created an uncomfortably environment for you to work/volunteer in?
2. What sort of effects does the temperature or air flow in the warehouse have on your ability to do your work?

3. Have you ever noticed environmental conditions in the warehouse contributing to a customer having a negative experience while at the ReStore?
4. What range of temperatures would you consider to be uncomfortable for you while you are working in the warehouse? What range of temperature would you like to work in?
5. Do you think that if any environmental issues at the ReStore were resolved and an agreeable environment was maintained, it would benefit your enjoyment for what you do or contribute to your productivity as a staff member/volunteer?

At the conclusion of the focus group interview, volunteers and staff members were thanked for their participation and reassured that their responses would remain anonymous and would be used to try to help improve the overall ReStore experience.

The questions for the focus group interview were created to facilitate discussion based primarily on the personal experiences of the volunteers and staff members. The questions were ordered in a manner which would first allow for interviewees to establish a comfort level by answering a simple question regarding their name and how long they had been involved with Habitat or the ReStore. The questions scale up to more anecdotal experiences but provide important information on the effects of environmental conditions not only for the staff and volunteers, but also as an additional angle on the customer experience. The questions allowed the volunteers and staff members to express their opinions on how changes to the ReStore environment would affect the interactions of each party with the warehouse facility.

Despite determining that focus group surveying would be the best method to collect data from volunteers and staff on the environmental conditions at the ReStore, our team discovered that the logistics of focus group interviewing were not feasible based on the staffing limitations of the ReStore. The business operation of the ReStore would not be able to run if all volunteers and staff were pulled in for a group interview. As a result of this realization, and at the advising of our project liaison, our team spoke with the WPI Institutional Review Board and changed the nature of our volunteer and staff surveying to individual interviews, though the same questions

and processes were carried over to the individual interview with the exception that the role of the note taking investigator was removed to avoid a potentially intimidating surveying climate.

Although the format of the surveying was changed with the shift from focus group interviews to individual interviews, all data collection and analysis methods, like the questions and process, remained the same. The information that was generated through the individual interviewing was compiled by question and then sorted based on the types of feedback given since the question responses were unstructured. The information was then used to make conclusions on the necessity of environmental condition changes and the foreseen impacts they would yield on the staff members and volunteers at the ReStore, as well as the perceived effects on customers from the vantage of the employees.

Many potential issues in information collection and biasing that may have arisen during the group interviewing would have been covered by the actions of the interviewer, who had practiced probing techniques for eliciting developed responses from more reluctant participants, utilizing clarifying questions, and discussion management methods to avoid overly dominating personalities by controlling the flow of who is responding at a given time. However, these issues were largely dealt with by the switch to individual interviewing. Sampling and non-response bias were eliminated as the interviewing was a voluntary process with a consent form which was signed prior to the commencement of the interview. The interview questions were pre-tested using groups of WPI students and other campus community members in order to assure that questions did not present directed bias through wording, or cause unnecessary response overlap from question to question. These pre-test sessions were facilitated by team members as additional experiential practice facilitating the focus group interviews. These considerations and practiced skills all carried over during the transition to individual interviews.

Potential challenges and limitations of the focus group interviewing are that certain interviewees may succumb to a group mentality and may be less likely to contribute a different or new opinion; however these issues were also addressed by the switch to individual interviewing. The trade-off is that thoughts may have been less likely to develop fully or clearly in individual interviews than in the environment that a group interview would have established.

Techniques and strategies for the design and execution of the focus group interview surveying utilized in this section are taken from *Social Science Research: Principles, Methods, and Practices* by Anol Bhattacharjee. All WPI Institutional Review Board policies and steps for human surveying were fulfilled and abided by during the completion and analysis of the focus group interview surveying.

3.2 Objective 2

Identify the ventilation requirements of the warehouse and determine the rate of air circulation required to reduce the temperature during the warmer months.

3.2.1 Cooling Load Calculation Principles

The ReStore warehouse currently does not have any form of ventilation for 262,000 cubic feet of air contained within the building. The issue arising at the ReStore is the high costs related to installing, operating, and maintaining air conditioning equipment. Therefore the ReStores first priority is ventilation, which in turn will provide a method of cooling. “Cooling loads result from many conduction, convection, and radiation heat transfer processes through the building envelope and from internal sources and system components” (ASHRAE-Fundamentals, 2009, 18.1). Our team began building a ventilation solution by first seeking out professional advice, analyzing which approach would best suit a warehouse of this size, and then performing calculations using the ASHRAE handbooks to determine what specifications our system would need.

3.2.2 Professional Engineering Advice

The ventilation team pursued professional advice initially with its most available resource: WPI Professors. We contacted multiple Mechanical Engineering professors with a background in thermodynamics and heat transfer and on in particular who specialized in HVAC ventilation. Though perhaps not able to provide us a structural audit of the warehouse, we hoped our campus Professors could offer their expertise and point us in the right direction.

For a structural examination of the warehouse, we turned to local Engineering Firms with a plan to find a Practicing Engineer who could give our group a formal permit to implement a ventilation system. One of the nearby firms that our teamed planned to contact was Bolton & DiMartino. Our team also contacted the City of Worcester Building and Zoning Office to try and obtain the original building plans of the warehouse to assist in a structural assessment.

Seeking further consultation, the ventilation team contacted companies previously used by the ReStore and our group members. Our hope was to schedule an interview with a Mechanical Systems Professional to ask some of our more technical questions such as, ‘will large exhaust fans provide practical temperature reduction?’ and, ‘what will the buildings electrical system be compatible with fans of this size?’ as well as questions relating to cost-effectiveness.

3.2.3 Ventilation requirements based on ASHRAE Standards 62.1.2013

ASHRAE standard 62.1 is used to determine the required ventilation and indoor air quality for buildings, including the various methods used to achieve acceptable indoor air quality (ASHRAE-Fundamentals, 2009) ASHRAE *Standard 55* specified the conditions in which 80% of the occupants in the environment deem it thermally acceptable. Our team familiarized itself

with some of the basic concepts and terminology of Ventilation and Infiltration such as Forced-Air Distribution, Outside Air Fraction, Air Exchange Rate, Age of Air and noted relevant topics such as Perfect Mixing and Underfloor air distribution. Further Research made it clear that Mechanical Ventilation had the greatest potential for air exchange when the system was properly designed, installed and followed the requirements outlined in ASHRAE 62.1.2013.

Using table 6.2.2.1 our team found minimum ventilation rates allowed in warehouses and retail spaces. From the given air rate values our team calculated the cubic feet per minute per person, estimating that roughly fifty people would be in the warehouse at its busiest hours. We also calculated the cubic feet per minute per feet squared using the area outdoor air rate values and 16,000 as the square footage of the warehouse retail space. By adding both of these values together we came up with an absolute minimum CFM requirement for a ventilation system in the warehouse.

3.3 Objective 3

Determine insulation options based on material properties, cost and installation and payback time in order to deliver one optimal option.

Firstly, our team set out to learn about insulation types and materials that would be the most effective solution to adequately maintain the environment of the warehouse. To learn about the types of insulation and materials that could be used in the warehouse, we researched various articles, reports and studies obtained from sources such as the United States Department of Energy. The data researched gave us insights into R-values, installation methods, and types of materials that could be utilized in the warehouse. We also researched new technology that could be used to potentially help reduce the temperature during the summer.

Secondly, we identified three insulation providers and installation contractors whom agreed to give us base estimates. All of the estimates given to us were subject to change pending

further complications discovered at the site. We then compiled the data collected from various sources and providers into a cost analysis report. We also gave an option for each type of insulation with a final cost for materials and installation.

Lastly, we calculated the payback time for each option. This was done by calculating the annual savings for each option based on the total thermal resistance value. Then, we divided the total cost of the insulation by the calculated annual savings. The optimal insulation option was selected based on the material's thermal resistance, total cost, and payback time.

Chapter 4: Results and Analysis

Objective 4.1:

Identify the impact an environmental change will have on the ReStore's customers, volunteers, and staff.

4.1.1 Customer Surveying

Over the course of one week our team conducted questionnaire surveying of 50 ReStore customers onsite at the Habitat for Humanity facility. The visual analytics of the customer surveying can be found graphically in Appendix C in the form of pie charts which break down the response rate for each question and are accompanied by legends which show the number of responses, percentage of each answer out of the total number of participants, and for questions which may have been skipped as a part of the surveying procedure, include a second percentage value which shows the percentage of each answer from the number of responses for that specific question.

Our team created an online version of the customer survey using Google Forms which was distributed through the Habitat for Humanity MetroWest/Greater Worcester ReStore Facebook page in order to collect additional data from a more widespread population. Unfortunately the response rate of the online survey was very low, with only seven responses, one of which was from a ReStore employee. As such the data from the online surveying was discarded as it did not embody a large enough sample size to draw conclusions from; below we analyze and draw conclusions from the data analytics of the in-person customer questionnaire surveying.

From the first question of the survey we determine that 90% of survey participants have been to the ReStore before, and from the second question we see that almost half of those that have been to the ReStore previously are customers who visit several times a month. This initial

data serves to qualify the population of the respondents, and we can see that our data will be reliable as they have significant personal experience with the ReStore.

Looking more closely at the break down of questions that focus on previous customer interactions with the ReStore during the summer, we see that 74% of all surveyed customers have been to the ReStore during the summer, 82% if analysis is based only on customers with previous ReStore experience. This data not only signals that we have a large population to draw information on summer interactions from, but also that a majority of the overall surveyed population has been associated with the ReStore for a minimum of at least eight months, since the end of last summer, which signifies reliable data on the basis of situationally specific knowledge. Of those that had been to the ReStore over the summer, 54% reported that the temperature was uncomfortably hot, with a large 30% answering that they were unsure. The large percentage of uncertain respondents is primarily attributed to the long span of time between their summer visit and their participation in the survey, and was potentially reinforced by having them answer the survey within the ReStore while it was cool, in the early spring. Regardless of potential skews in uncertain data, only 16% of customers claimed that they were comfortable from a temperature standpoint during the summer. This data may also be impacted by a range of factors, for example inconsistent personal opinions of which months classify as summer, as in a case where a respondent may consider their experience in May to be within the summer or the social desirability factor of admitting that you are uncomfortable in a hot environment, which is particularly impactful for male respondents. Finally for the section on summer experiences, 85% of respondents felt that the temperature in the summer negatively impacted their experience at the ReStore.

The final three questions of the survey focus on a general participant's opinions on the impact of environmental conditions on their customer experience, regardless of specific interactions with the ReStore. Appendix C displays the distribution breakdown for responses on temperature ranges in which customer participants start to feel uncomfortably hot, with the data forming a bell curve centered on the range of 80-90°F. When asked on the impact of shopping in temperatures within a range where they felt uncomfortable, 56% of participants reported they would have a more negative experience, with an additional 22% claiming they would leave the ReStore as soon as they entered the uncomfortably hot environment. Overall 90% of participants reported that maintaining environment conditions in the ReStore at a temperature below the range which they would begin to be uncomfortably hot would provide them with a more positive experience at the ReStore.

The analysis of our customer survey findings support the hypotheses of our project liaison that the current environmental conditions at the ReStore during the summer months contribute to overall more negative experiences for a majority of customers, and that improvements to these conditions would provide customers with a more positive retail experience. The surveying responses signify that lower temperatures within the facility would improve customer experiences, which would contribute to more successful business operation and stronger reputation as a retail option, which is particularly important for locations like the ReStore.

4.1.2: Volunteer and Staff Surveying

Volunteer and staff surveying was conducted in the form of individual interviews which were conducted one on one with a student investigator interviewing individual ReStore volunteers who have been volunteering at the MetroWest / Greater Worcester ReStore since at

least the summer of 2014 or earlier, and with ReStore staff who work in the warehouse portion of the facility. Interviews were conducted voluntarily and in a private location, only after each volunteer or staff member was allowed to read and sign a consent form for participation in the survey. Overall nine interviews were conducted with volunteers and staff members. Candidates were determined based on staff members who work in the warehouse area, which is six, and volunteers who are currently involved with the ReStore and have been volunteering there for at least one summer, which is three.

The individual interviews were conducted using a standard set of questions for each participant, as outlined in the methodology section of this report, and the responses of all participants were combined into one database, and sorted by question, in order to ensure confidentiality and anonymity. From the combined responses that our team collected through the individual interviews, we were able to draw several conclusions about the experiences our volunteers and employees at the ReStore, and what types of changes would have the largest impacts on improving the environment for the people who make the ReStore run. A majority of volunteers and staff members noted that the temperature does sometimes reach uncomfortably high levels, but also remarked that those days when it is unworkable from temperature alone are infrequent. The largest feedback that the team received through the individual interviews which was not identified during other forms of surveying was that one of the most debilitating environmental factors for volunteers and staff in the ReStore is the lack of air movement and circulation. One interviewee noted that, especially when moving heavy objects, it can be very difficult to breathe in the ReStore during the summer due to the hot, stagnant air, which is frequently filled with dust or other particulates which accumulate on the merchandise in the

facility. These difficulties were noted by several of the interviewees and support the importance of a solution which emphasizes a ventilation improvement to the ReStore.

Objective 4.2

Identify the ventilation requirements of the warehouse and determine the rate of air circulation required to reduce the temperature during the warmer months.

Our team began pursuing solutions to ventilate the building by reaching out to experts in the field of heating, ventilation, and air conditioning (HVAC). These experts included professors at WPI as well as practicing Professional Engineers. Appendix D contains notes and commentary from the interviews we conducted. The following ventilation report is separated into sections including: building structure, ventilation calculations, and proposed ventilation solutions.

4.2.1 Building Structure Analysis

First, we sought the advice of a Structural Engineer to address the concerns brought forth by the ReStore director and determine if improvements were essentially possible for the warehouse due to the structural limitations and modern building codes. Our team contacted a local engineering firm and an engineer agreed to meet with our project team. He provided us a starting point to launch a structural investigation into the integrity of the building with ventilation modifications in place.

4.2.1.1 Structural Engineering Consultation

The structural engineer that we met with explained that the warehouse was a prefabricated metal building designed and constructed in the 1970's to save as much steel as possible while also meeting the building code at the time. The building code has since changed to increased tolerances for snow loads. The Professional Engineer (PE) stated the current snow loads in Worcester, MA is 35 pounds per square foot, but he believed the building was designed

to 30 pounds per square foot. This information confirmed the issues with the ceiling limitations. The PE also explained why adding insulation to the ceiling is not viable. The insulation would shield the roof from the outside heat during the summertime, but it would also increase the amount of heat retained inside the building leading to less heat transfer through the roof and as a result the snow will melt more slowly. This will increase the amount of snow resting on the roof in the winter and could lead to a serious structural deficiency and possible a collapse of the building. The PE also suggested that as long as the new fans do not exceed the weight of the old fans the new ventilation fans should not compromise the structural integrity of the building. He advised us to research fans that will fit in the locations of the previous system of fans and louvers so that there will not be an additional weak point added to the buildings envelope.

4.2.1.2 Building Plans

The structural engineer also recommended we locate the original building plans for the warehouse. The ReStore did not have the original building plans, so we began searching through the City of Worcester's public records. The first step was to locate the construction date for the building through Worcester City Hall. It was determined the building was constructed in 1965. The City of Worcester Division of Building and Zoning located at 25 Meade Street, Worcester, MA 01609 has record books for buildings within city limits. We located the permit number from the 1967 record book under the 45 Glennie Street address. The permit number was found to be 938, and was applied for on October 8th, 1968. The Division of Building and Zoning staff were able to locate the blue prints when we presented the permit number to them. A printed copy of the blue prints was created for future use of our team and the ReStore.

4.2.1.3: Structural Engineer Professional Opinion

Construction could not begin until a Professional Engineer completed an assessment of the building's structure and confirmed that our proposed ventilation and insulation solutions would meet code. We contacted the structural engineering firm Bolton & Di Martino for a quote to perform the required assessment and approve our team's proposal. On April 15, 2015 our team met with Christopher J. Tutlis, P.E. at the ReStore to perform a building walk through showing exactly what our team is proposing for a ventilation solution. Throughout the building tour, we asked Chris to address any concerns he saw with our plan but he saw no major flaws. The following section contains a document Chris furnished providing his professional opinion stating the ventilation proposal drafted is an acceptable change to the building, and will not cause any structural deficiencies. In Chris's opinion, the AIRMAX complete ventilation system would be the most structurally sound because it only involves a thin walled HVAC duct running through the wall and the load associated with it will be much lower than that of an exhaust fan.

4.2.1.4 Structural Engineer Written Document

BDI BOLTON & DIMARTINO, INC.
CONSULTING STRUCTURAL ENGINEERS
100 Grove Street Worcester, MA 01605
Tel 508-756-8972 Fax 508-757-9750

May 1, 2015

Ms. Deborah Maruca Hoak
Habitat for Humanity
11 Distributor Road
Worcester, MA 01609

Re: Mechanical Review
ReStore Building
Worcester, MA

Dear Ms. Hoak,

We have been asked to review the structural impact of upgrading the ventilation system of the ReStore Habitat for Humanity facility as part of a Worcester Polytechnic Institute IQP project, with student Kyle LeBorgne. We understand the upgrade includes installing two mechanical fan systems, outside the building, and ducting through the exterior walls at previous ventilation openings. Our review is limited to the Building Code impact of installing the ventilation system.

Observations:

We visited the building on April 15, 2015 to view the structure, and discuss the project scope with the WPI team. A couple of weeks prior to visiting the site, we were able to view the original Construction Documents, in our office. The original documents showed the foundations and general building layout, but did not indicate the design loads or framing member sizes.

The building structure is a single-story, pre-engineered, metal building with an attached office area. The building structure includes:

- Pile foundations
- Concrete grade beams
- Concrete structural slab-on-grade
- Steel bents with a center column to form a low slope gable roof
- Steel roof purlins
- Steel girts
- Metal roofing over insulation
- Metal siding panels
- Diagonal rod bracing at walls and roof
- CMU knee walls in the warehouse, with a few full-height CMU walls

The existing wall framing has rough framing for four openings for a previous ventilation system (fans & louvers). The previous system has been removed and siding has been installed over the openings. Two openings are on the North wall and two openings are on the East wall. It is our understanding that framed openings will be reused for the new ventilations system, limiting the work required at the new penetrations.

The new ventilation systems will include two mechanical units located on-grade outside the building, with ducts penetrating the exterior walls at two previous openings. Inside the building, lightweight ducts will be

hung from the roof structure. It is our understanding that the ducts will weigh approximately 1 pound per linear foot.

Structural Review:

Our opinions are based on visual observations, and review of the Massachusetts State Building Code, 8th Edition, we did not performed calculations to verify adequacy of existing members, since we do not have the member sizes.

Installation of new mechanical ducts has been reviewed in accordance with the 2009 International Existing Building Code, as modified by the Massachusetts State Building Code.

Classification of Structural Work for this project: Level 1 (IEBC Section 405)

Structural Requirements associate with Level 1 Work:

Level 1 Structural Requirements:

606.2 Addition or replacement of roofing or replacement of equipment: Where addition or replacement of equipment results in additional dead loads, structural components supporting such reroofing or equipment shall comply with the gravity load requirements of the International Building Code.

- There will not be any re-roofing work associated with the ventilation work, but there will be additional dead load associated with the new ductwork. Based on a weight of 1 lb/ft of ductwork, the net stress increase of the roof framing will be approximately 2% at the roof purlins and even less at the column frames. Provided the increase in stress is less than 5% in a member, the additional load is acceptable. Louvers may be placed in previous wall openings, provided the louvers weight does not exceed 5 psf (approximate weight of existing siding and insulation). Otherwise, review of the framing for the new louvers shall be required.

606.2.1 Wall anchors for concrete and masonry buildings: Where a permit is issued for reroofing more than 25 percent of the roof area of a building assigned to Seismic Design Category B, C, D, E or F with a structural system consisting of concrete or reinforced masonry walls with a flexible roof diaphragm or unreinforced masonry walls with any type of roof diaphragms, the work shall include installation of wall anchors at the roof line to resist the reduced International Building Code level seismic forces as specified in the IEBC.

- Permit for reroofing is not part of the scope of work.

606.3.1 Bracing for unreinforced masonry bearing wall parapets: Where a permit is issued for reroofing for more than 25 percent of the roof area of a building that is assigned to Seismic Design Category B, C, D, E or F that has parapets constructed of unreinforced masonry, the work shall include the installation of parapet bracing to resist the reduced International Building Code seismic forces specified.

- Permit for reroofing is not part of the scope of work.

Conclusion:

It is our opinion that installing the proposed ductwork conforms to the Structural requirements Massachusetts State Building Code, Eighth Edition.

If you have any questions, please call.

Very truly yours,

BOLTON & DIMARTINO INC



Christopher Tutlis

Bolton & DiMartino, Inc.
Consulting Structural Engineers

4.2.2 Ventilation Recommendations

4.2.2.1 Ventilation requirements based on ASHRAE Standard 62.1.2013

Our team also worked on preliminary calculations that we knew would be beneficial to us moving forward, all of which can be found in Appendix E. Using the square footage of the warehouse, customer population and airflow rate values specified in ASHRAE 62.1.2013 we calculated the absolute minimum ventilation rates that would be required in the warehouse to provide breathable air. We found the minimum outdoor airflow required at the ReStore to be 2295 CFM (cubic feet per minute of air). We also calculated minimum exhaust rates required for a functional ventilation system in a warehouse of this size. The minimum exhaust rate was calculated to be 8,000 CFM for the warehouse. In addition to these airflow rate calculations, our team also began estimating the daily cost of high CFM exhaust fans and how many air changes per hour they could produce.

4.2.2.2 Additional Recommendations from HVAC Experts

There are many aspects of the warehouse that require improvement to assist the proposed ventilation system in cooling the warehouse. The twelve skylights in the ceiling are made from a thin sheet of opaque plastic and during the summertime heat is entering through these leaky openings. The professionals we met with advised our team to address these areas with a replacement skylight, a professional air sealing procedure, or covering the openings completely. Three openable vents in the ceiling also exist which can aid the ventilation of warm air through the roof. Improvement opportunities are being addressed for these vents as well.

Painting the roof was also recommended, and so we performed calculations to determine the solar reflectance index (SRI), which we used to determine whether or not the paint will have an impact on the temperature inside the building. Appendix J contains complete calculations

determining radiant roof paint is not a cost effective method to reduce the temperature within the warehouse. Radiant paint will only reduce the temperature by on average two degrees throughout July, and with a cost of over ten thousand dollars makes painting of the roof an irrelevant method of cooling.

Within the Warehouse, there are 12 three foot by ten foot skylights, which during the year let in light and radiant energy. The total 360 square foot area of the skylights compared to the 22,000 square foot roof, would not affect the temperature of the ReStore. Overall the temperature difference from removing the skylights, does not add up to the cost of replacing them with roofing metal. To replace the Corrugated Steel Panels, material costs and installation costs come into factor. For the material costs, a three foot by ten foot corrugated steel panel costs \$30 per panel, and with 12 panels, the total cost would be \$360. Installation would be more costly than the roofing materials, due to the need to remove the existing skylights and install the roofing materials to be continuous with the rest of the roof. The exact pricing of install is not known, due to the inability of our team to access the roof and examine the state of the skylights; however, to install corrugated steel panels would cost a minimum of five dollars per square foot. The minimum cost to remove the skylights and install the roof would be \$1,800; for a minimum total cost of \$2,160.

4.2.3 Proposed Ventilation Solution: AIRMAX Complete Ventilation System

Our team conducted extensive research into viable ventilation solutions. AIRMAX International offers a complete ventilation system that has been proven to work across the country. Their system uses a large air-handling unit that is placed outside of the building and the fresh outdoor air is pumped through fabric ductwork inside to properly ventilate the space. “For every cubic foot of air that you exhaust, you must not only replace that air, you must force it

back into the building. Overheating will no longer be a problem. It is a proven fact that you can accomplish five times more with matching amounts of makeup air and exhaust than just exhaust. You must pressurize the building from the center out” (AIRMAX quote located in Appendix F). The benefits to pressurizing the building in this way will force all of the warm air towards the exterior walls and out of the building through the exhaust fans and large garage doors when open.

The AIRMAX team will fabricate and install a 30,000 cfm makeup air system that will deliver 10 air changes per hour at the floor level of the warehouse. The total cost for delivery and installation for this quote is \$42,888.00; however, AIRMAX has made a \$20,000.00 donation bringing the total cost for Habitat to \$22,888.000. The system will run throughout the evening, introducing cool nighttime air and removing warm air within the warehouse, allowing the building to be as much as 20 degrees cooler in the morning ensuring the warehouse is a significantly more comfortable environment for employees, volunteers, and customers. This system is designed to move the warm air from the floor level to the ceiling and use the exhaust fans to remove the warm air from the building, specifically during the afternoon when the temperature inside the warehouse is soaring.

The fabric duct uses strategically placed holes every foot to ensure the air is distributed evenly and will not disturb shopping customers. The system is designed to distribute air efficiently, completely replacing all the air in the building every six minutes. Thus this design eliminates the possibility of dead-zones, areas without air movement or circulation. The photo below shows an AIRMAX system that has been installed in the Worcester area, and will provide you with a visual representation of the small holes in the fabric duct.



Figure 1: AIRMAX Ventilation System installed at Saint Gobain Ceramics Plant

The system incorporates one large outdoor air handling unit and two exhaust units instead of large propeller ventilation fans. An outdoor fan unit offers a major added benefit as it solves any excessive noise problems associated with wall mounted fans. The outdoor intake fan, shown in Figure 2 below, has a seven and one half horsepower motor capable of moving 30,000 cubic feet per minute (CFM) of air. The motor will use a variable frequency controller, allowing the fan to be turned down when 30,000 CFM of air is not required on cooler days during the summer. The unit has re-usable Merv8 filters that will eliminate pollen and other particulates from that air providing a safer and healthier work environment. It will be placed outside the north corner of the warehouse, providing fresh cool air from the shaded side of the building in the warm summer afternoons. The re-usable filters provide a non-additional operating cost option for the ReStore, which is a huge benefit to the non-profit.



Figure 2: AIRMAX Outdoor Air Handling Ventilation Unit

The 18,000 CFM exhaust units will be placed on the floor of the warehouse, adding minimal additional weight to the structure of the building, and will be ducted through the wall where the previous fans were positioned. The combination exhaust and heat recovery air filtration units will operate throughout the entire year, effectively recirculating air during the winter months. Throughout the winter, the combination air filtration units will create a constant temperature from floor to ceiling across the entire warehouse space. “The end result will be less heat lost through the roof. Heat from the heating units is no longer stratified at the ceiling, it is forced back to floor level. The ReStore’s heating bill will be significantly reduced. In most cases it will be cut in half” (AIRMAX Quote located in Appendix F). During the summer, the air filtration units will allow for the utilization of the night flush method, which is discussed in detail in the following section. Figure 3 displays what these units will look like installed in the ReStore.



Figure 3: Combination Exhaust & Heat Recovery Air Filtration Units

The AIRMAX International team visited the ReStore to determine the possible locations for air handling units. The drawing in Figure 4, gives a complete view of the warehouse and provides a schematic of the entire AIRMAX system.

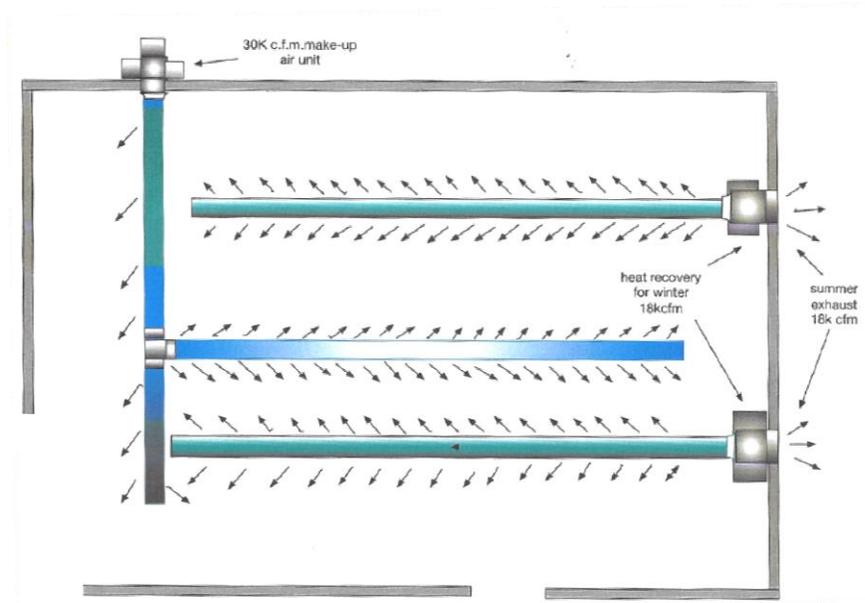


Figure 4: AIRMAX International Drawing for the ReStore

The AIRMAX system is a quality solution that will have a positive, long-term impact for the Habitat for Humanity ReStore. Perhaps the most attractive aspect of the AIRMAX system is

that this system shall remain the property of Habitat for Humanity should they move the ReStore to a new location. The ReStore currently has a contract to lease the warehouse building through the year 2017 after which additional five-year contracts are an option. Unlike typical sheet metal ducts, which are often fabricated to a specific location, the AIRMAX system is relatively transportable because it uses a standalone air handling unit and a relatively light fabric duct.

The AIRMAX unit is a renowned ventilation system that has been installed in hundreds of warehouses with proven results. The AIRMAX team will install the complete system with no added cost, providing the restore with an economical and time-efficient method of installation. To ensure the AIRMAX units' authenticity and reliability our team, along with the ReStore Director Deborah Maruca Hoak, made a site visit on April 23, 2015 to the Saint Gobain factory to see the system first hand. The factory building had two AIRMAX units running throughout the visit, one of the units was installed 37 years ago and has only needed a small section of fabric duct replaced. The other unit was installed three years ago and has been running non-stop since installation. The employees of the factory mentioned the impact the system has had lowering the temperature to a more work friendly environment. We concluded the system and receiving positive feedback from employees, the AIRMAX system is the most logical choice for the ReStore.

Operational costs associated with the AIRMAX system are shown below. The cost to run the intake and exhaust units at full power for 24 hours a day is \$38.56. In practical use the AIRMAX units would not be running at full power for 24 hours each day, they would only be running at their maximum when it is very warm inside the warehouse. In the evening the units can run at a reduced speed, still effectively cooling using the night flush method, but saving money on electricity in the process. In the following calculations we compared the AIRMAX

system to the operational costs for the current floor ventilation fans used at the ReStore and projected air conditioning costs.

The AIRMAX unit and the dual combination exhaust/heat recovery fans:

$$\begin{aligned}(7\frac{1}{2}\text{hp} + 3\text{hp} + 3\text{hp}) \times 746 \text{ watts} &= 10,071 \text{ watts} = 10 \text{ kw} \\ 10 \text{ kw} \times 24\text{h} &= 241 \text{ kw/day} \\ .16\text{¢} &= \text{cost per kilowatt per day} \\ .16\text{¢} \times 241 \text{ kw} &= \mathbf{\$38.56}\end{aligned}$$

The ReStore currently has eight floor fans it uses as a temporary cooling solution during the summer, but they have little impact and frustrate customers:

$$\begin{aligned}3.32\text{A} \times 208\text{v} \times 8\text{h} &= 5524.48 \text{ watts/day} = 5.5 \text{ kw/day} \\ .16\text{¢} &= \text{cost per kilowatt per day} \\ .16\text{¢} \times 5.5 \text{ kw} &= \mathbf{\$0.88 \text{ day/fan}} \\ &= \$0.88 \text{ day} * 8 \text{ fans} \\ &= \mathbf{\$7.04 \text{ per day}}\end{aligned}$$

Thus the ReStore is essentially wasting \$7 a day to run these inefficient fans.

To run an industrial sized 50-ton air conditioning unit during the stores normal operating hours the cost would be as follows:

$$\begin{aligned}50 \text{ tons} &= 175,200 \text{ watts} \\ &= 175,200 \text{ watts} \times 8 \text{ hours} \\ &= 1,401,600 \text{ watts/hour} \\ .16\text{¢} &= \text{cost per kilowatt per day} \\ .16\text{¢} \times 1,401 \text{ kw} &= \mathbf{\$224.16 \text{ per day}}\end{aligned}$$

The AIRMAX team will complete the installation of the fan units, ductwork, and control system within a three day period. The ReStore is closed on Sunday and Monday each week, allowing for a majority of the installation to be completed without interruption of normal

operation of the retail store. The only portion the installation team will not complete is the electrical hookup of the fans themselves. Our team received a quote from a LidCo Electrical Contractors, Inc. for the amount of \$7,385.00 to connect the three fan motors to three phase power. A complete quote can be found in Appendix F.

4.2.4 Alternative Ventilation Solution: Night flush using supply and exhaust fans

4.2.4.1 *The Night Flush Concept*

A night flush is a common practice method to cool a space without air conditioning. The method uses large exhaust fans to ventilate the warm air inside of the building and replace the warm air with cooler nighttime air. Our team is recommending a climate control system that will use an indoor and outdoor thermometer to regulate when the fans are in operation. The control system will turn the fans on before sunrise, which will draw cool air into the building until sunrise when the fans will be shut down. The fans will remain off until the inside thermometer indicates a warmer temperature inside than the outside thermometer. The fans will then proceed to run throughout the rest of the work day, effectively circulating air and lower the indoor temperature, until 5:00 pm when the ReStore closes. The Professional Engineers we spoke with are hopeful this system will drastically improve indoor breathing conditions and reduce the temperature with the warehouse to provide a more inviting environment for customers and a safer workplace for volunteers and employees.

4.2.4.2 *Night Flush Calculations*

CFM per Fan Needed

(ACH) Air Changes per Hour

(CFH) Cubic Feet per Hour

(CFM) Cubic Feet per Minute

$$262,000 \text{ ft}^3 \times 6 \text{ ACH} = 1,572,000 \text{ CFH}$$

$$1,572,000 \text{ CFH} / 60 \text{ min} = 26,200 \text{ CFM}$$

$$26,000 \text{ CFM} \Rightarrow \text{Two fans} = \mathbf{13,000 \text{ CFM} / \text{fan}}$$

Maximum Louvre Intake = 500 ~ 750 FPM (feet/minute)

Wall Opening - 4 ft.

$$4 \text{ ft} \times 4 \text{ ft} = 16 \text{ ft}^2$$

$$13,000 \text{ CFM} / 16 \text{ ft}^2 = 812.5 \text{ FPM}$$

$$\mathbf{500 \sim 750 < 812.5 \text{ FPM}}$$

625 FPM – Reverse Calculation

$$625 \times 16 \text{ ft}^2 = 10,000 \text{ CFM}$$

$$10,000 \text{ CFM} \times 2 = 20,000 \text{ CFM}$$

$$20,000 \text{ CFM} \times 60 \text{ min} = 1,200,000 \text{ CFH}$$

$$1,200,000 \text{ CFH} / 262,000 \text{ ft}^3 = \mathbf{4.58 \text{ ACH}}$$

4.2.4.3 Night Flush Supply and Exhaust Fan Specifications

Our team performed calculations and used guidelines to size the proper fan based on several factors including: size, weight, cfm, noise, and amperage. Using the formulas in the previous section we targeted a 36 inch fan that could produce 10,000 cfm of air movement. Greenheck is an industry leader in energy efficient fans and was recommended by the professional HVAC engineer we spoke with, thus we began our research with this fan manufacturer. Greenheck produces a guide named *Fan Fundamentals*, which was instrumental in accurately calculating fan requirements.

The first step to determine the cfm output of a supply and exhaust fan is to determine the static pressure inside the building. Using the guide in Figure 3, we determined the static pressure

of the building to be a range between 0.13 and 0.28 inches. The static pressure significantly affects how effective the fan can move air, thus as the static pressure increases the cfm of the fan decreases. Our team sized fans based on the design requirements of 10,000 cfm at a static pressure of 0.125.

STATIC PRESSURE GUIDELINES	
Nonducted	0.05 in. to 0.20 in.
Ducted	0.2 in. to 0.40 in. per 100 feet of duct (assuming duct air velocity falls within 1000-1800 feet per minute)
Fittings	0.08 in. per fitting (elbow, register, grill, damper, etc.)
Kitchen Hood Exhaust	0.625 in. to 1.50 in.
IMPORTANT!	Static pressure requirements are significantly affected by the amount of make-up air supplied to an area. Insufficient make-up air will increase static pressure and reduce the amount of air that will be exhausted. Remember, for each cubic foot of air exhausted, one cubic foot of air must be supplied.

Figure 5: Greenheck Fan Fundamentals Static Pressure Guidelines

The second step for determining a fan for a retail space is noise created by the fan. Propeller fans create low frequency noise similar to that of a small scale helicopter. The chart represented by Figure 4 shows the suggested limits for room loudness. Our target room loudness limit was based on the Hotel kitchen and laundries, supermarkets category with a DBA range of 56-72 or 7-21 Sones.

SUGGESTED LIMITS FOR ROOM LOUDNESS		
Sones	DBA	
1.3-4	32-48	Private homes (rural and suburban)
1.7-5	36-51	Conference rooms
2-6	38-54	Hotel rooms, libraries, movie theatres, executive offices
2.5-8	41-58	Schools and classrooms, hospital wards, and operating rooms
3-9	44-60	Courtrooms, museums, apartments, private homes (urban)
4-12	48-64	Restaurants, lobbies, general open offices, banks
5-15	51-67	Corridors and halls, cocktail lounges, washrooms and toilets
7-21	56-72	Hotel kitchens and laundries, supermarkets
12-36	64-80	Light machinery, assembly lines
15-50	67-84	Machine shops
25-60	74-87	Heavy machinery

From AMCA Publication 302 (Application of Sone Ratings for Non Ducted Air Moving Devices with Room-Sone-dBA correlations).

Figure 6: Greenheck Fan Fundamentals Loudness Limits

The last main component factoring into fan selection on this project was the weight and power draw. The amperage or amount of power the fan requires to operate is fairly consistent among all fan models and manufacturers. The fans in our design specification use one half horsepower motors and all models were between six and eight amps. There are two main types of propeller fans, belt driven fans and direct drive fans. The difference between the two is how the motor is connected to propeller. In a belt driven fan, the motor sits directly below the propeller and a belt connects the two together. In a direct drive fan, the motor is directly connected to the propeller, therefore the center of gravity will be shifted on a direct drive fan. After examining the ReStore’s previous ventilation fan mounting brackets with the structural engineer, he determined the maximum fan weight the brackets can support is 100-150 pounds. The belt driven fans weighed less than the direct drive fans by a factor of 2. The Greenheck belt driven fan we sized weighs 110 pounds and the Greenheck direct drive fan weighs 230 pounds. The direct drive fans do have lower maintenance costs because there is not a system of belts and pulleys that need to be replaced when the belts were down. He stated if the fans weigh more than that, additional support running to the floor would be required. Additional support will also be required if the fan’s center of gravity is not directly over the mounting brackets. An example of

how the center of gravity would not be directly over the mounting brackets is how the motor is positioned on a direct drive fan shifting the center of gravity outward off of the wall.

4.2.4.4 Night Flush Fan Quotes

After utilizing Greenheck to research fan requirements and choose specifications, we contacted their sales team and requested an official quote of the model SBE-1L36-10 sidewall belt drive exhaust fan with accessories. The quote contained loudness information, construction features, assembly drawings of included components and minimum and maximum performance curves for our selected fan.

David, our Greenheck sales coordinator, provided us with options to choose from. He included 90-degree and 40-degree weather hoods with pre-punched mounting holes and 0.5 inch welded wire bird screens along with short wall and long wall housings containing flanges that overlap with the weather hoods to keep rain out. Both vertical mount intake and vertical mount exhaust damper specs were added as well as the ReStore director had used shutter-mounted louvers before and specifically requested mechanical louver options instead. In an email, David included a “budget” cost of \$11,705.00 for the whole package, standard lead-time from the factory being 6 weeks plus shipping.

The full quote along with all of the technical details can be found in Appendix G.

4.2.5 Alternative Ventilation Solutions:

In addition to the night flush system our team also researched other cooling and ventilation solutions. Chillers are often a popular choice for those attempting to cool large areas. Centrifugal chillers are the most efficient mechanical compression chillers for large-scale applications. One issue that emerges immediately due to the ReStores financial limitations is that

condensers are required in cooling systems. Cheaper air-cooled condensers are primarily used for small-scale operations while the far more expensive water-cooled condensers are seen in large-scale operations like the warehouse (Climate Tech Wiki). Additionally water-cooled condensers require cooling towers that are often located on the rooftops of buildings, which we know already, is not a viable option. Yet, we know that chiller systems are effective; however, costly, deeming this solution impractical.

Objective 4.3

Determine insulation options based on material properties, cost and installation and payback time in order to deliver one optimal option.

From the knowledge we gathered through our research about the different uses and installation methods of the various insulations, we narrowed down the options to five types of insulation. These five options consisted of blown-in, rigid foam board, closed cell spray foam, open cell spray foam, and a radiant barrier system. Other types of insulation could not be added to the ReStore's existing structure, and would require new construction or on large scale reconstruction projects. We contacted All in One & Moore Building Systems for professional advice on installation methods and materials, who informed us that the insulation currently within the warehouse has a thermal resistance value of R-4. The insulation used in the warehouse is one inch vinyl covered fiberglass, which is used as a vapor retardant, with a moisture transmission rate, or permeability, of 0.2. The existing insulation was installed on three of the four walls in the ReStore, as seen in Figure 7. Our team sought to determine whether adding to the existing insulation in the warehouse would cause moisture to build up within the wall, before deciding the optimal insulation.

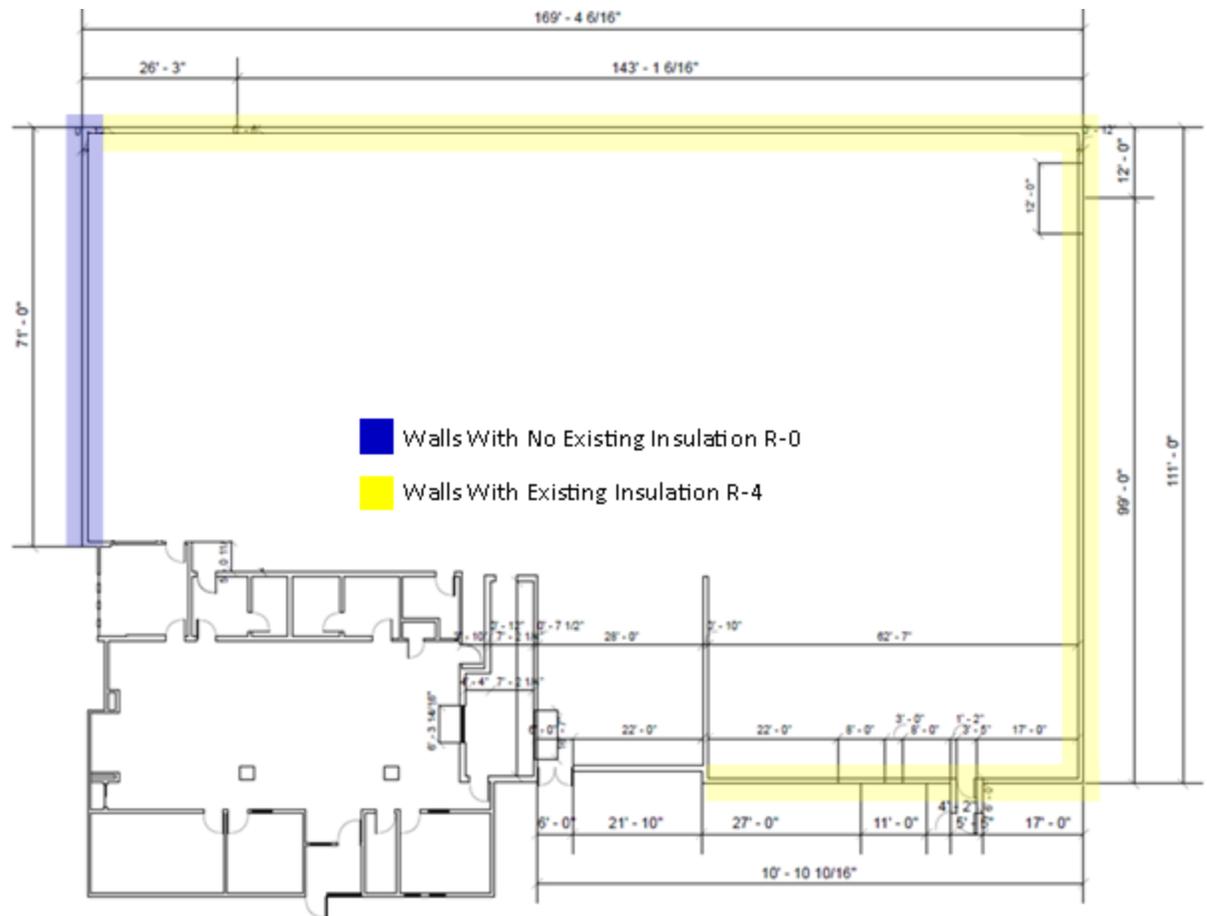


Figure 7: Current Insulation at the ReStore

4.3.1 Insulation Types

Vapor retardants are installed differently based on the building’s climate, because moisture travels from hot to cold areas. The purpose of the vapor barrier is to prevent moisture from reaching the metal wall of the warehouse and condensing. During the winter months, moisture from the air within the building may reach the interior metal wall, condense, and cause water damage. “In general, in cold climates, air barriers and vapor retarders are installed on the interior of building assemblies, and building assemblies are allowed to dry to the exterior by installing permeable sheathings and building papers/housewraps towards the exterior” (Lstiburek, 2004). According to Lstiburek, the best way to create a vapor barrier is to install it behind drywall, through the installation of foil faced drywall, plastic wrap, or vapor retarder

latex paint. The permeability of foil faced dry wall and plastic wrap are each less than 0.1 perms, while vapor retarder latex paint is less than one perm.

Eight potential insulation products were identified by contacting manufacturers and suppliers, the product specifications can be found in Appendix H. The total square footage of wall that needs to be insulated is 5,630 square feet. The building has an air gap of 6 ¾ inches between the metal exterior wall and where the drywall would begin. Filling the air gap with blown-in insulation the R-value would be a minimum of 20 with AttiCat's Expanding Blown-In Fiberglass, and a maximum of 28 with OPTIMA's Fiberglass Blowing Insulation. DOW Chemical Company's rigid foam board would achieve an R-value of 34. Closed cell spray foam from Certaspray offers an R-value of 43, while open cell spray foam from Certaspray offers an R-value of 25.

Additionally, our team explored the feasibility of installing a radiant barrier or radiant paint. A radiant barrier would be applied to the underside of the warehouse roof. This barrier repels 94% of the radiant energy the warehouse gains from the sun. This radiant barrier material is lightweight and could be applied to the roof without concern for the excess weight. One square foot of material weighs 0.47 ounces meaning it would only be an additional 413 pounds across the entire 14,000 square foot roof. On the other hand, the radiant paint would be applied to the exterior of the roof reflecting 80% of the radiant energy from the sun and would emit 90% of the energy that is absorbed by the paint. Radiant paint only requires a thin coating across the roof, which is low weight as well. We determined radiant paint to be more effective than a radiant barrier. Our calculations were based on the current conditions of the warehouse compared to the conditions if radiant paint was applied. After application, the maximum heat reduction within the

warehouse would be two degrees during the month of July. The specifications for radiant barriers can be found in Appendix H, while the calculations can be found in Appendix J.

4.3.2 Insulation and Installation Costs

All options require existing vinyl insulation to be removed before any additional insulation is installed. Each option also requires a drywall face, which costs \$1,900 without the vapor retardant. The Restore can utilize volunteers for installation, thus eliminating labor costs.

For the vapor retardant, there are three different options. The first option is a vapor barrier latex paint, which would be applied to backside of the drywall. This option would cost around \$400 and could be applied prior to the installation of the drywall. The next option is polyethylene sheeting; this would cover the insulation from roof to floor and provide a continuous vapor retardant. Polyethylene sheeting would need to be installed prior to the installation of the drywall to keep the moisture from reaching the insulation. The price for polyethylene sheeting is 5.2 cents per square foot, for a total price of \$294. The final option is foil back gypsum board, which would be installed instead of normal drywall at a cost of \$5,348.

The cost of blown-in insulation ranges from \$1,400 for GreenFiber's Blown-In Cellulose to \$6,400 for OPTIMA's Fiberglass Blowing Insulation, with an additional cost to rent a machine to blow-in the material. The machine costs \$50 a day, with a projected total cost of \$250 if used eight hours a day for five days. The total cost to install blown-in insulation is \$1,650 to \$6,650. The installation process of blown-in insulation requires drywall to be installed on each wall. Holes are then cut in the drywall, and insulation is blown-in until the entire cavity is filled. Repairing the holes after installation of the materials finalizes the process. Blown-in results in a continuous layer of insulation and reduces the chances of a thermal break, which is a flow of air around or through insulation that significantly reduces the effectiveness of the material.

Rigid foam board is donated to the ReStore from DOW Chemical Company and does not require any special machinery to install the boards. Rigid foam boards need to be taped and glued together to make sure a continuous seam is created. Drywall is then installed to keep the rigid foam boards in place. For more information on how to install rigid foam board, refer to section 3.02 on DOW's Rigid Foam Board Insulation For Engineered Buildings website (DOW Chemical Company, 2015).

Closed cell and open cell spray foam from Certaspray require professional installation, but with a significant difference in price due to safety requirements. Closed cell spray foam is hazardous and requires gas masks, ventilation, the building to be shut down during the installation process and the proceeding 24 hours. The cost of insulation materials for the warehouse using closed cell spray foam is \$37,993, while open cell spray foam is \$24,710. Anchor Insulation Company estimated the installation cost for closed cell spray foam to be \$23,100, or open cell spray foam for \$10,250. The total price for closed cell would be \$63,243, or \$37,149 for open cell. Installation would need to be completed in sections, taking months to complete since installation can only take place on Sundays and Mondays, as those are the only days the ReStore is closed.

There are two options for a radiant barrier system. A single bubble radiant barrier from Reflectix would cost \$5,000 to cover the entire roof. Due to the complexity to apply the material to the metal roof beams, the cost to install a radiant barrier could not be determined. Radiant roof paint requires a primer coat followed by two top coats. The primer and each top coat would cost \$3,100 and \$8,275 respectively, for a total cost of \$19,650 to coat the entire roof.

4.3.3 Insulation Analysis

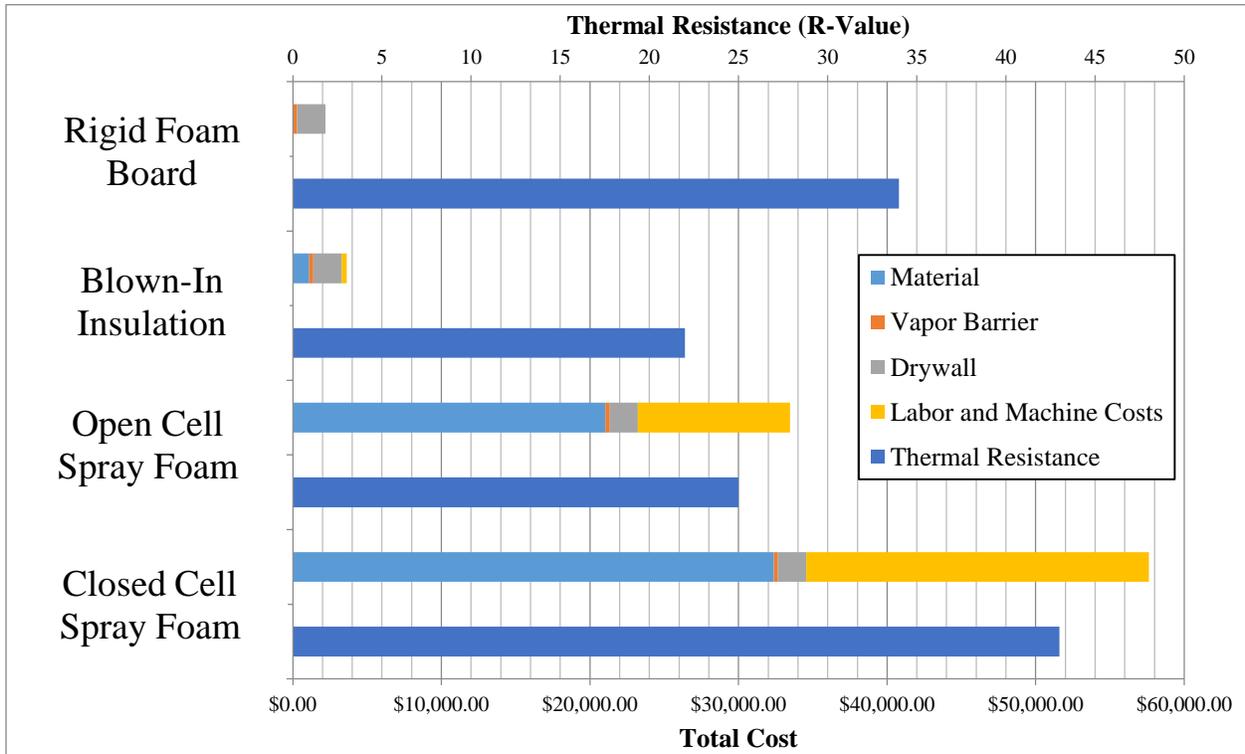


Figure 8: Insulation Comparison Graph

In order to determine the optimal insulation based on cost and thermal resistance, our team believed that the best comparison method was to calculate payback time, which can be found in Appendix K. The payback method is calculated by taking the total cost of insulation and dividing it by the annual heat savings. The four options compared can be found in Appendix I.

To calculate the total cost of the insulation, we had to first decide on which type of vapor barrier would be ideal. Latex vapor barrier primer and polyethylene sheeting have similar costs, both of which are over \$2,000 cheaper than foil back gypsum board. However, polyethylene is \$100 less expensive than latex vapor barrier paint and is 90% more effective, making it the best vapor barrier choice.

For insulation selections, the best option available is the rigid foam board, which is option one in Appendix I. Rigid foam board is optimal due to its low cost, high thermal resistance and ability to be installed using volunteers. The payback time for rigid foam board is 2.85 years. The next best option is blown-in insulation; however it would take 5.37 years for the ReStore to recoup the money invested into the insulation. The final two options are open and closed cell spray foam. These options have an extended payback time of over 50 years, making both unreasonable.

Finally, we looked at the total cost and temperature reduction to determine whether a radiant barrier system would be effective in the ReStore. The capital investment of a radiant barrier system would not see a reasonable return. The maximum average temperature drop during the day in July is just two degrees. It is not worth the investment for the ReStore to install a radiant barrier or apply radiant roof paint.

Chapter 5: Conclusions and Recommendations

5.1 Ventilation Recommendations

Our team is confident the AIRMAX system will be the most beneficial climate control system for the ReStore to establish a work and customer friendly environment. Extensive research into ventilation systems currently being installed around the country led to the AIRMAX system's selection. The ReStore Director, mentioned her three years of research prior to this project had not yielded a system of equivalent capability. The system will effectively perform a pressurized night flush, reducing the temperature throughout the building's structure, leaving the warehouse cooler in the morning. This system offers the ability for it to remain an asset of Habitat for Humanity, unlike other systems that would remain property of the warehouse. When Habitat's lease ends, if the ReStore decides to move, the AIRMAX system can be loaded onto a truck and moved to the new location with only new installation costs incurred.

The total cost for the system including delivery, installation, and electrical connection will be \$30,723.00. This price is comparable to the cost of supply and exhaust fans used in a traditional night flush; however, the AIRMAX system offers a proven track record of effectively cooling warehouses nationwide.

5.2 Insulation Recommendations

Rigid foam board is the optimal insulation option for the ReStore, due to its low cost and high thermal resistance. The insulation would not only retain heat in the building during the cold winter months, but in conjunction with the night flush method, the insulation would also repel heat during the summer months, allowing the warehouse to remain cooler for longer durations. The payback is less than three years, which is in the scope of the ReStore's potential lease agreement. If the ReStore chooses to install the insulation in 2016 and remains at the location for an additional six years, they would see a total savings of \$4,608 over the span.

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Appendix A: Timeline for IQP

Assignments	Timeline						
	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Work alongside of volunteers and develop relationships	Active	Active	Active	Active	Active		
Survey staff, volunteers, and customers		Active	Active	Active			
Evaluation of current warehouse environment		Active	Active				
Sizing of systems based on calculations			Active	Active			
Contact local installers and gather pricing information				Active	Active		
Create preliminary proposal for HFH					Active	Active	
Prepare report and revisions to proposal						Active	Active

Appendix B: Comparison of the Utah Homelessness Solution to the Habitat for Humanity Approach

Habitat for Humanity is one of the most visible non-profit organization in the world, an organization founded on the conviction that everyone should have a reasonable place to live in dignity, and that decent shelter within a decent community should be a matter of action to all. One could argue that, simply put, the mission of Habitat is to build a world without homelessness, and in the Beehive State of Utah, a state government initiative called “Housing First” is working to do just that.

Habitat’s process is a simple one. Funds are generated through donation and other philanthropic means, as well as by the revenue from Habitat’s local discount home accessory and building material retail stores, aptly named ReStores. These funds are then used to support building projects in which Habitat partners with families that earn between 25-60% of their area’s median income, but do not qualify for homeownership programs. Habitat for Humanity is dedicated to building families with families, not for them; their motto is “A hand up, not a hand out”, and as such families pay for their homes through a monthly mortgage after putting in roughly 500-600 hours of “sweat equity”.

In 2005, under the leadership of then Governor Jon Huntsman, the state of Utah began to address a problem which faces nearly every city and state government, homelessness. In Utah, the average homeless person costs the state between \$15,000-20,000 each year through the operational costs of running shelters and soup kitchens, and the expenses associated with hospital bills and jail visits. The “Housing First” initiative was developed to combat the massive expenditures related to dealing with homelessness, dollars that many taxpayers argue are being thrown away. The Housing First program is particularly focused on addressing the needs of a

specific group of homeless people, those that are identified by the state as being “chronically homeless”.

The distinction between identifications of homeless individuals or families is made based on their circumstances. In many cases, homelessness is a temporary issue for individuals or low-income families, who find themselves without a place to live in between jobs or housing options, but are able to make things work within a number of weeks or months, find residence and employment, and getting back on their feet. The other classification is chronic homelessness, those who live on the streets, sometimes for years, decades, or in some cases, most of their lives. In Utah, about 14% of the homeless population is considered to be chronic homeless, but this demographic costs the state a significant majority of the total amount spent each year on dealing with homelessness. Upon investigation, many shelters reported that upwards of 60% of their beds were occupied on a nightly basis by chronically homeless people; and in some cases, individuals who fall under the chronic homelessness umbrella can rack up emergency room or hospital bills totaling in the hundreds of thousands of dollars.

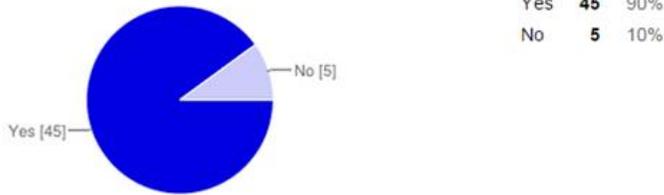
The Housing First initiative was constructed to reduce the chronic homeless population by building housing for the chronically homeless or homeless families with difficult circumstances, and giving them a place to call their own, essentially for free. To many the plan initially sounds ludicrous, but the total expenses of building permanent housing and social worker case management are just under \$8,000, while shy of the annual average of \$18,000 for an individual on the streets. In the long run, the state is able to save itself tens of thousands of dollars on an individual basis, with overall savings being in the millions. By giving the homeless a permanent home to call their own, the operational expenditures associated with homelessness drop exponentially, so it is no surprise that Utah has been building permanent housing and

converting motels as rapidly as it can for the past few years. Individuals or families who participate in the Housing First program are only expected to pay \$50 or 30% of their monthly income, whichever is greater, abide by lease agreements, and work regularly with a social worker, in order to keep their residency.

As the decade long initiative begins to draw to a close, Housing First has helped Utah to reduce its chronic homelessness by more than 70%. By providing homes for the homeless, Utah has turned the traditional model on its head and proven that one needs a place to live in order to find a job, become sober, or achieve stability, and not the other way around. In many ways the Utah solution is very similar to the Habitat approach; both seek to work with their respective parties in order to help them improve their own circumstances. While Housing First and Habitat address two very different populations, perhaps Habitat for Humanity can mirror the Utah model and begin to partner more with local and state government in order to assist the homeless or low-income populations in creating their own housing, housing in which they can take personal ownership and pride, and which can anchor them as they begin the journey to building themselves brighter lives.

Appendix C: Customer Surveying Analytics

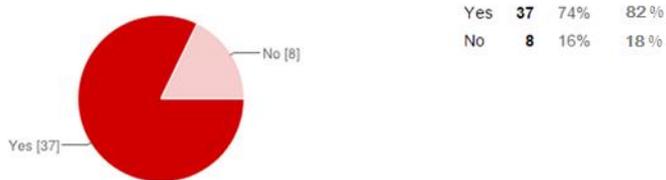
Have you been to the ReStore more than once?



How often do you visit the ReStore?



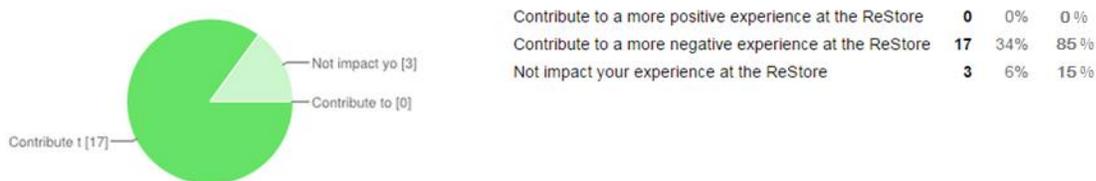
Have you been to the ReStore during the summer?



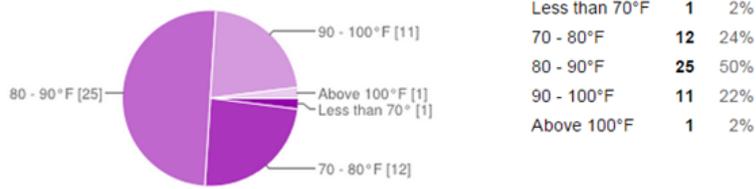
Was the temperature uncomfortably hot?



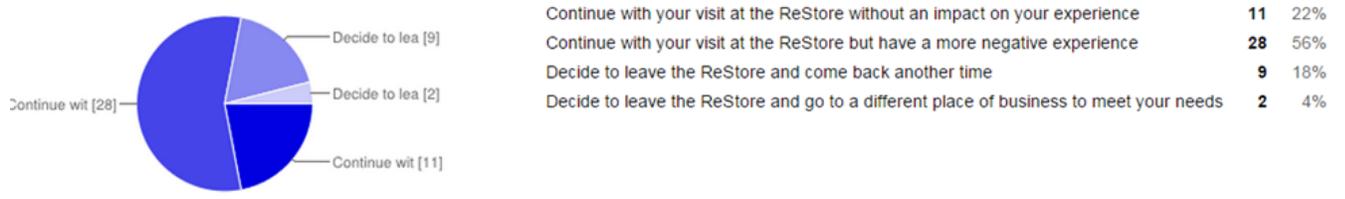
Did the temperature during the summer...



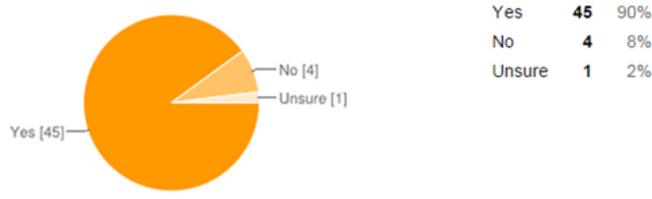
What is a temperature range where you as a customer would start to feel uncomfortably hot?



If the temperature was in or above that range, would you...



Would a temperature below that range contribute to a more positive experience as a customer?



Appendix D: Ventilation Engineering Discussions

HVAC Expert Meeting

Present: Professor Elovitz, Kyle LeBorgne, Robert Wood

Friday, March 27, 2015 1:00 pm

Project Goals: Reduce the temperature of the warehouse to a reasonable temperature throughout the summer using ventilation.

- How would large exhaust fans affect the temperature?
 - Would it reduce the temperature of the building to outside temperature if the ACH is high enough?
 - 6-10 air changes per hour is “common practice”
 - Exhaust 85-90% of intake air, this will pressurize the building
 - Recommends performing a “night flush”, this will pre-cool the building.
 - Temperature control unit (Climate control systems), this will allow the fans to come on when the inside temperature is higher than the outside temperature, and stay off when the inside temperature is lower than the outside. This will allow for pre-cooling in the morning, then the fans will turn off as the outside air heats up. The exhaust fans will then kick on in the late morning or early afternoon when the temperature in the building increases to higher than outside. This will essentially allow the fans to lag a few hours behind the sun heating.
 - What would the maximum recommending CFM into the 16,000 sq. ft. building be?
 - 50-60 fpm air velocity is acceptable, will not affect customers
 - Based on ACH
 - A ½ HP 36” 6500 CFM exhaust fan costs around \$3 per day to operate
 - Need to look into breaker space, possible adding a subpanel. Put consideration into power, 1 phase or 3 phase electric, and the costs associated with 3-phase power.
- Interior circulation using fans located on the 6 steel support columns in the center of the warehouse. The distance they are separated is 24 feet.
 - There main concerns are noise and having air flow affect customers
 - Look into ASHRAE Standard 55 – The balance between airflow and comfort
 - Pole fans are very load and the air velocity will be too high for customer comfort.
 - HVLS – High Volume Low Speed – highly recommended
- Is there an alternative to Air Conditioning that is more operational cost friendly?
 - Air Conditioning is the most effective way to cool a building currently.

- Fan-Jet
- Habitat is required by their contract to insulate the walls; however, the ceiling cannot be touched, is it worth it to only insulate the walls?
 - Run an energy model
- There are 12 skylights that are about 9' by 3' and are made of clear corrugated Plexiglas (R 0.86), how much heat is lost in the winter and added in the summer? Should this be something we look into?
 - Consider replacing with insulated skylights
 - Wasco and Kalwall are two well-known manufactures
- There are openable vents in the ceiling which are approximately 2' by 10' and open around the perimeter about 6 inches, are these useful?
 - Possibly used in the past for specific warehouse machinery
- Is it possible to have isolated cooling? i.e. cool the area where the cash register is.
 - There is no need to do this, the employee break room is air conditioned and breaks can be taken in there to cool down when it is extremely warm inside
- Ice bath waterfall methods, humidity is a concern?
 - Yes

HVAC Professional Engineer Conference Call

Present: Sonia Barrantes, Kyle LeBorgne, Robert Wood

Sunday, March 29, 2015 7:00 pm

Project Goals: Reduce the temperature of the warehouse to a reasonable temperature throughout the summer using ventilation.

- How would large exhaust fans affect the temperature?
 - Would it reduce the temperature of the building to outside temperature if the ACH is high enough?
 - 6-10 air changes is extremely high, that is used for venting a warehouse with a combustion engine running
 - 1-2 ACH is reasonable
 - Need to have a structural engineer analyze the building to determine what possible. First-step in project is to see what is actually possible from a structural perspective.
 - Night Flush is the best option.
 - Variable speed fans to reduce operating costs when demands are low
 - Watch out for operating costs and look into energy efficient fans - Greentech
 - What would the maximum recommending CFM into the 16,000 sq. ft. building be?
 - ASHRAE requires 2295 CFM according to 62.1

- Research table 6.5 minimum exhaust rates instead of outside air requirements
 - A ½ HP 36” 6500 CFM exhaust fan costs around \$3 per day to operate
- Interior circulation using fans located on the 6 steel support columns in the center of the warehouse. The distance they are separated is 24 feet.
 - There main concerns are noise and having air flow affect customers
- Is there an alternative to Air Conditioning that is more operational cost friendly?
 - Paint roof white – look into calculations
- Habitat is required by their contract to insulate the walls; however, the ceiling cannot be touched, is it worth it to only insulate the walls?
 - Run an energy model of existing conditions, with just the walls, and with both the ceiling and the walls.
- There are 12 skylights that are about 9’ by 3’ and are made of clear corrugated Plexiglas (R 0.86), how much heat is lost in the winter and added in the summer? Should this be something we look into?
 - Look into air sealing the perimeter of each skylight
- There are openable vents in the ceiling which are approximately 2’ by 10’ and open around the perimeter about 6 inches, are these useful?
 - Send pictures to her for an opinion
- Is it possible to have isolated cooling? i.e. cool the area where the cash register is.
 - Why would you want to
- Ice bath waterfall methods, humidity is a concern?
 - Didn’t ask due to information collected from Professor Elovitz.
- How will insulation during the summer affect the temperature if the air changes per hour create an environment where the inside temp is the same as the outside temp.
 - Really need run the energy models

Structural Professional Engineer Meeting

Present: Chris Tutlis, Kyle LeBorgne, Robert Wood

Thursday, April 2nd, 2015 10:00 am

Project Goals: Reduce the temperature of the warehouse to a reasonable temperature throughout the summer using ventilation.

- ❖ Is adding ventilation fans to the old support structures that housed the old fans feasible?

Yes. If the existing structures supported the old fans than there should be no issue with replacing them with the same size fans. The structural integrity of the walls should be fine.
- ❖ The consultant Engineer that looked at the ReStore pointed out issues with the load capacity of the ceiling, is this going to apply to the walls as well?

Not necessarily. The load capacity issue with the ceiling exists primarily because of snow loads and the fact that the roof is almost flat. The walls don’t have this problem and were able to support the old fans. Therefore we should be in the clear to simply replace the old fans. If we consider adding more

fans than were previously there however, we should consider investigating how much extra load the walls could withstand.

- If so, is there something we can do to add support or make adding ventilation fans possible?
Probably not. This type of warehouse is called a Prefabricated Metal building and was built to save money and use as little steel as possible. Therefore the structure is already at the bare minimum requirements for load capacity, so strengthening it becomes difficult.
- ❖ What is your opinion on the structural integrity of the ceiling?
 - How much weight if any could be added?
Probably very little if any, especially if we're talking about large fans. Insulation wouldn't be much of a problem except for the snow load issue.
 - Is the problem with the snow loads?
Yes. Without insulation the snow on the roof is melted through natural convection from the heat inside the warehouse. If the roof is insulated it will stop the heat from passing through the ceiling and melting the snow therefore allowing more snow to build up throughout the winter. This is an issue especially in Worcester as the amount of snow we get could add a significant amount of extra weight to an insulated roof.
- ❖ Adding additional support structures in the warehouse to support fans?
 - Location of support structures?
Same issue, the building is a Prefabricated Metal building and it would very difficult to add an additional support structure anywhere in the building.

Appendix E: Ventilation Formulas

Minimum Ventilation Rates in Breathing Zone

$$V_{bz} = R_p \times P_z + R_a \times A_z$$

Where

A_z = zone floor area, the net occupiable floor area of the ventilation zone, ft² (m)

P_z = zone population, number of people in the ventilation zone during typical usage

R_p = outdoor airflow rate required per person as determined from Table 6.2.2.1

R_a = outdoor airflow rate required per unit area as determined from Table 6.2.2.1

V_{bz} = the breathing zone outdoor airflow (CFM)

With values

$$R_p \times P_z + R_a \times A_z = V_{bz}$$

$$7.5 \times 50 + .12 \times 16,000 = \mathbf{2295 \text{ CFM}}$$

Minimum Exhaust Rate

E_a = minimum exhaust airflow rate required as determined from Table 6.5

$$E_a \times A_z =$$

$$.5 \times 16,000 = \mathbf{8,000 \text{ CFM}}$$

Dollar/day of Exhaust Fan

CFM 6480 36in 115v 6.4A 1/2hp 825rpm

$$6.4A \times 115v \times 24h = 17,664 \text{ watts/day}$$

$$= 18 \text{ kw/day}$$

Cost per day

$$.16\text{¢} = \text{cost per kilowatt per day}$$

$$.16\text{¢} \times 18 \text{ kw} = \mathbf{\$2.88 \text{ day/fan}}$$

Air Changes per Hour

$$4 \text{ fans} \times 6480 \text{ CFM} = 25,920 \text{ CFM}$$

$$25,920 \text{ CFM} \times 60 = 1,555,200 \text{ CFH}$$

$$\text{Warehouse} = 262,095 \text{ ft}^3$$

$$1,555,200 / 262,095 = \mathbf{5.93375 \text{ ACH}}$$

Appendix F: AIRMAX Ventilation System Quote

AIRMAX INTERNATIONAL INC.
PO BOX 5206
MANCHESTER, NH 03108
800-247-6291

April 25, 2015

Debbie Maruca Hoak
Habitat for Humanity

ReStore

11 Distributor Road
Worcester, MA 01605

Quotation #1504251

Airmax A1: Airmax will fabricate and install one (1) 30,000cfm makeup air system to consist of the following:

- Inlet Filtration Module
- Re-useable Merv8 filters
- Lunair Lander
- 6" x 6" x 8' Pressure treated sleepers
- Motorized shutter
- 7 ½ HP direct drive fan module
- Variable frequency controller for 7 ½ HP motor
- 36" elbows as needed
- Sheet metal ductwork as needed
- Airmax air distribution ducting with specifically located air discharge ports

Cost Delivered and Installed \$22,888.00

Price includes lift rentals, travel, per-diem, final measurements, freight, car rental and housing.

NOT INCLUDED: Electrical controls and hookups.

Airmax CEX1 & CEX2: Airmax will fabricate and install two (2) 18,000cfm Combination Exhaust / Heat Recovery / Air Filtration Units. Each unit to consist of the following:

- 3 HP direct drive fan module
- Variable frequency controller for 3HP motor
- (2) Motorized shutters
- Sheet metal ductwork as needed
- Weather hood
- Airmax air distribution ducting with specifically located air discharge ports
- Inlet Filtration Module
- Re-useable Merv8 filters

Cost Delivered and Installed \$20,000.00

Price includes lift rentals, travel, per-diem, final measurements, freight, car rental and housing.

NOT INCLUDED: Electrical controls and hookups.

Outside doors can now be closed for added security and your employees will be working in a cleaner, safer environment.

Summer Mode:

The makeup air and exhaust units will run 24 hours per day. The exhausts will be dumping the BTU's out of the building while the makeup air units introduce cool outside air directly into the center of the building. Even cooler night air will travel to every nook and cranny. In the morning the building will be as **much as 20 degrees or more cooler.**

The air discharge ports will be specifically located to provide the **maximum amount of cooling . Dust, pollen, and bugs will be prevented from entering the facility** with State of the Art Merv8, **re-useable** filters. Even **cement dust residue** will be significantly reduced.

For every cubic foot of air that you exhaust, you must not only replace that air, you must force it back into the building. Overheating will no longer be a problem. It is a proven fact that you can **accomplish (5) times more with matching amounts of makeup air and exhaust than just exhaust. You must pressurize the building from the center out. This system will provide 20 air changes per hour with discharge holes located 9' 3" off the floor.**

Cold Weather:

The CEX units will run in the recirculation mode. This will provide Heat Recovery and air filtration. Cold air will be taken into the unit at floor level and filtered. Clean, filtered, cold air will be discharge up into the ceiling thru small holes specifically designed for your individual application. A blanket of cold air will now be created at ceiling level on top of the hot stratified air (that normally leaks out the roof as heat loss.) As the cold air sinks it mixes with and forces the hot air back to floor level. The operation continues 24/7. In a matter of minutes the temperature from floor to ceiling is homogenized.

The end result is less heat loss thru the roof, free BTU's are utilized to the maximum. Heat from the heating units is no longer stratified at the ceiling it is forced back to floor level. Your heating bill will be significantly reduced. In most cases it will be cut in 1/2.

Even the reflector plate on your radiant heat get very hot and hot air wants to rise. All of that wasted stratified heat will no longer stay at ceiling, it will be forced back to floor level. Even your gas fires unit heater or heaters will now function the same way. You can use both systems at the same time to provide quick recovery when you come in first thing in the morning.

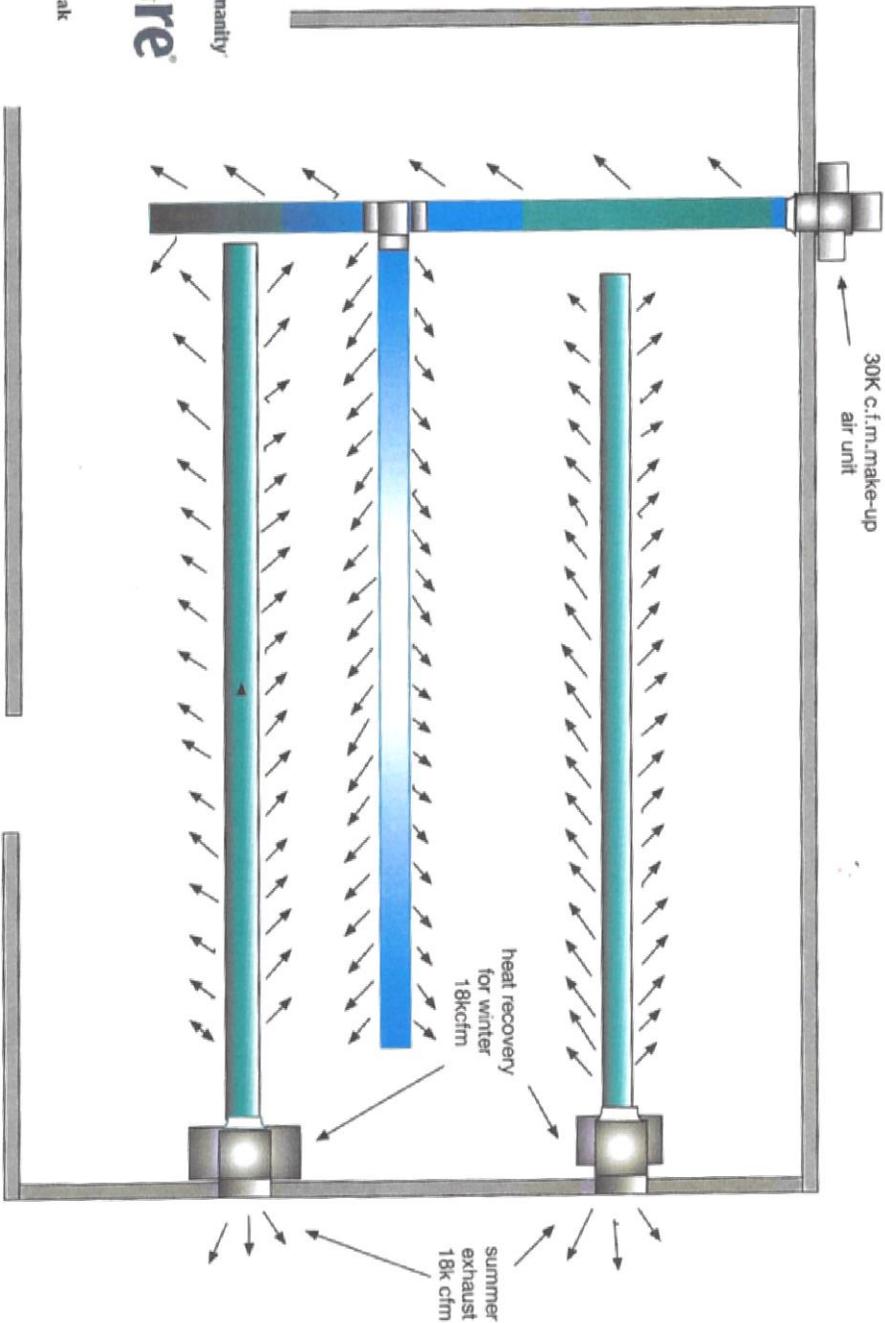
NOTE: From our experience we have found that a night time thermostat set back should not be lower than 55 degrees. The temperature in the mass of the building (cement floor, steel pallet racking etc.) gets too cold and radiates that cold. When the thermostat is raised to you work temperature the air temperature is soon satisfied. However the radiating cold from the mass soon is calling for more heat and the thermostat calls for more heat. The Airmax system will create a constant temperature wall to wall and ceiling to floor with clean filtered air. Every nook and cranny will constantly be getting an air change. There will no longer be any dead air stagnant locations.

Total System cost less electrical hook-ups	\$42,888.00
Airmax Donation	\$20,000.00
Your Cost	\$22,888.00

TERMS: 45% with Order - 35% Upon Delivery - 20% Upon Installation
State / Local Taxes - Permits & Permit Acquisition Costs are Not Included

Thank You for the opportunity to serve the needs of Habitat for Humanity

Sincerely,
Jack Balon
Cell 603-548-7402



Habitat for Humanity
 Restoring Communities Worldwide
Restore

Debbie Maruca Hoak
 Restore Director

Store Hours
 Tuesday - Saturday: 10am - 5pm

11 Distributor Road at
 Gold Star Blvd.
 Worcester, MA 01605
 Phone: 508-439-7655 ext. 123
 www.habitatmgw.org/restore
 debbie.marucahoak@habitatmgw.org

AIRMAX INTERNATIONAL
 PO BOX 5206
 MANCHESTER, NH 03108
 800-247-6291
 Drawing #1504251









Electrical Proposal

Electrical Contractors, Inc.

452 MAIN STREET
HOLDEN, MA 01520

TELEPHONE 508-829-6226
FAX 508 829-9327

B2351

ATTENTION: **Debbie Maruca Hoak**
Habitat for Humanity - Restore
11 Distributor Road
Worcester, MA 03108

DATE: **May 1, 2015**

PROJECT: **Airmax System Installation**

LidCo Electric is pleased to provide the following proposal for the work required to install electrical feeds as needed for new AirMax System being installed in the Restore.

Work Included:

The below price includes the labor and material necessary to

1. Exhaust / Heat Recovery Units:

- o From electrical panel located on the column in the Restore we will install (1) ¾" e.m.t conduit along the ceiling joist to the location of the (2) exhaust fan units.
- o Each unit will be provided with a 20 amp, 208 volt, 3-phase circuit that will be used to power the V.F.D..
- o Each unit will have (1) single pole switch that will activate the louvers, The louver end switch will be used to turn of the V.F.D..
- o Each V.F.D. is required to have a 3-phase service switch located at the unit.
- o Lidco Electric will mount and wire the V.F.D.'s that are being supplied by Airmax.

2. Make-Up Air Unit:

- o From electrical panel that is located in hallway adjacent to main office we will install (1) 3.4" e.m.t conduit along the ceiling joist to the location of the (1) make up air unit.
- o This unit will be provided with a 50 amp, 208 volt, 3-phase circuit that will be used to power the V.F.D..
- o This unit will also have (1) single pole switch that will activate the louvers. The louver end switch will be used to turn on the V.F.D.
- o Each V.F.D. is required to have a 3-phase service switch located at the unit.
- o Lidco Electrical will mount and wire the VFD that is being supplied by Airmax.
- Electrical permit allowance included = \$ 200.00.
- This scope of work will require the use of and electric scissor platform lift to get the electrical feeds installed along the ceiling area. Allowance included is \$600.00

Project Notes:

1. **Please note that there is no scope of work covered for an fire alarm system monitoring that maybe required for this system.**
2. **All work is to be performed during normal business hours 7 a.m. – 3:30 P.M. Monday to Friday.**
3. **Some of the merchandise in the store may need to be relocated to allow us the**

access we need to install our electrical feeds.

Our cost for the proposed scope of work is: \$7,385.00

General Notes:

1. This proposal and the attached scope of work are the result of a design service performed by LidCo Electrical Contractors Inc. The design and installation concepts included in this proposal are the property of LidCo Electrical Contractors Inc and shall not be transmitted to any other parties without the prior written consent of LidCo Electrical Contractors Inc.
2. This proposal expires (30) days from the date indicated above.
3. Our price is based on the work being performed during normal business hours.
4. Our cost is based on the trenching being done in a neat and professional manor (straight runs with 90 degree turns, no snakes requiring pipe bending etc)
5. The costs included in this proposal do not include amounts for changes in the sequence of work, disruptions, interferences and/ or impact costs. The right is expressly reserved to make claims for any and all of these related items of cost prior to any final settlement of this contract.
6. Payment terms: Net 10 from invoice date. A finance charge of 1 ½% per month (18% per annum) will be charged to all balances over 10 days.

Please call me if you have any questions regarding the above.

Sincerely,

Peter Liddy II
LidCo Electrical Contractors Inc.
P:508.829.6226
F:508.829.9327
Pete@lidcoelectric.com

Acceptance of Proposal:** _____ **Date:** _____
Signature**

Name: _____ **Title:** _____

Purchase Order #: _____

Please return signed proposal via email or fax to 508-829-9327

** By signing here, you certify that you:

- Are authorized representative of the above indicated company or organization.
- You accept the above specifications and conditions.
- LidCo Electrical Contractors Inc is hereby released to begin the proposed work .
- You agree to the payment terms indicated.

Appendix G: Quotes Associated with the Night Flush Solution Greenheck Supply and Exhaust Quote

From: Archibald, David [<mailto:darchibald@buckleyonline.com>]
Sent: Monday, April 13, 2015 2:07 PM
To: kyle@wpi.edu
Subject: Habitat for Humanity

Kyle, please see attached. Your "budget" cost for attached would be \$11,705.00. Standard lead time from the factory is 6 weeks plus shipping. Note the fans are not available with a VFD compatible motor and 2 speed.

Thanks

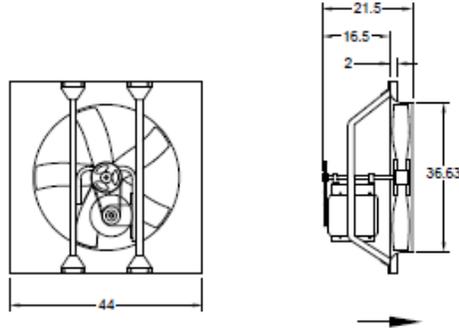
Regards,

David Archibald
Inside Sales Coordinator

Direct: (781) 681-3266
Cell: (781) 248-4068
Fax: (781) 871-9435

Buckley Associates, Inc. | 385 King Street | Hanover, MA | 02339
www.buckleyonline.com

Model: SBE-1L36-10
Sidewall Belt Drive Exhaust Fan

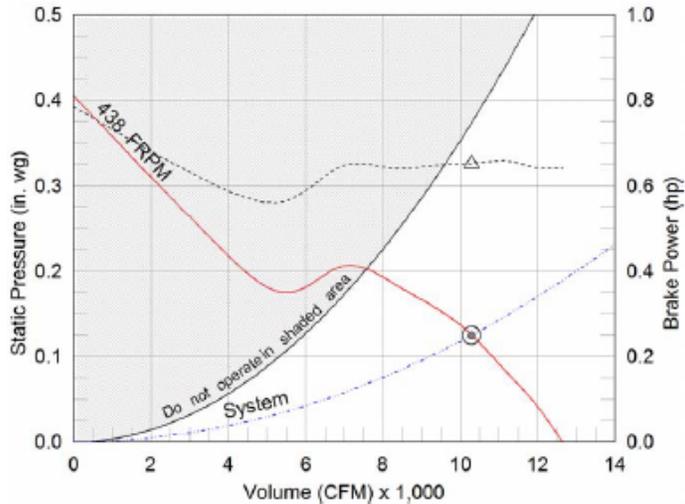


Dimensional	
Quantity	2
Weight w/o Acc's (lb)	119
Weight w/ Acc's (lb)	365
Max T Motor Frame Size	184
Optional Damper (in.)	38 x 38
Wall Opening (in.)	45.75 x 45.75

Performance	
Requested Volume (CFM)	10,290
Actual Volume (CFM)	10,290
External SP (in. wg)	0.125
Total SP (in. wg)	0.125
Fan RPM	438
Operating Power (hp)	0.65
Elevation (ft)	30
Airstream Temp. (F)	70
Air Density (#/3)	0.075
Drive Loss (%)	7.4
Tip Speed (ft/min)	4,129
Static Eff. (%)	34

Motor	
Motor Mounted	Yes
Size (hp)	1
V/C/P	460/60/3
Enclosure	ODP
Motor RPM	1725_860
Windings	2

See the Assembly Drawing For Selected Accessories



- △ Operating Bhp point
- Operating point at Total SP
- Operating point at External SP
- Fan curve
- System curve
- Brake horsepower curve

Sound Power by Octave Band

Sound Data	62.5	125	250	500	1000	2000	4000	8000	LwA	dBA	Sones
Inlet	78	83	74	71	69	65	62	58	75	63	13.5

Notes:

All dimensions shown are in units of in.
*FLA - based on tables 150 or 148 of National Electrical Code 2002. Actual motor FLA may vary, for sizing thermal overload, consult factory.
LwA - A weighted sound power level, based on ANSI S1.4
dBA - A weighted sound pressure level, based on 11.5 dB attenuation per Octave band at 5 ft - dBA levels are not licensed by AMCA International
Sones - calculated using AMCA 301 at 5 ft



Model: SBE-1L36-10

Sidewall Belt Drive Exhaust Fan

Standard Construction Features:

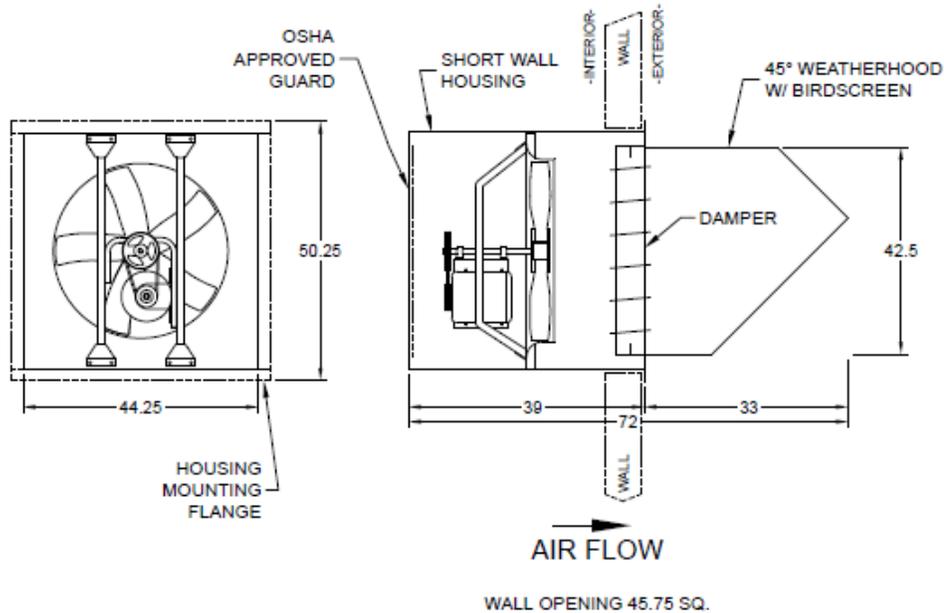
- Galvanized steel fan panel - Die formed, galvanized steel drive frame assembly
- Fabricated steel propeller for Levels 1 and 2, welded and painted steel for Level 3
- Adjustable motor pulley - Ball bearing motors - Fan shaft mounted in ball bearing pillow blocks - Static resistant belts - Corrosion resistant fasteners

Selected Options & Accessories:

- Damper Mounted, WD-320-PB-38X38, Gravity Operated, Not Coated
- Short Wall Hsg, Flush Ext., (1A-Exh), w/ OSHA Grd.
- Weatherhood, Galvanized 45 deg. with Bird Screen
- Unit Warranty: 1 Yr (Standard)

Assembly Drawing

Type: Sidewall Belt Drive Exhaust Fan

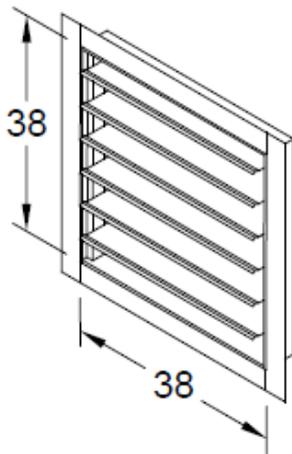


Vertical Mount Exhaust Damper

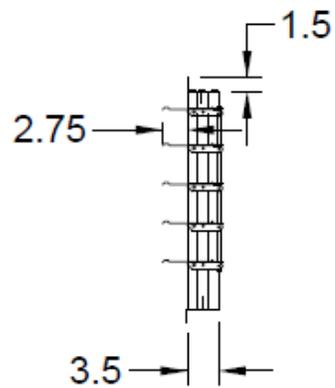
Model: WD-320

Standard Construction Features:

- Model WD-320 is a vertical mount exhaust damper and is constructed of 18 ga galvanized steel with pre-punched mounting holes and a flanged frame - Damper blades are 0.025 in. roll formed aluminum with vinyl seals on the closing edge - Steel axles are 0.188 in. diameter zinc plated mounted steel in acetal bushings - Synthetic axle bearings



DAMPER

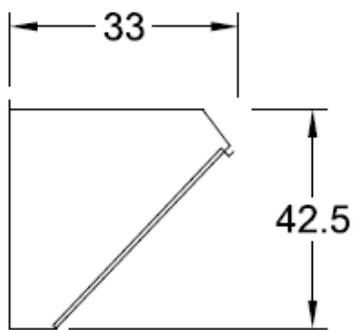


TYP. SECTION VIEW

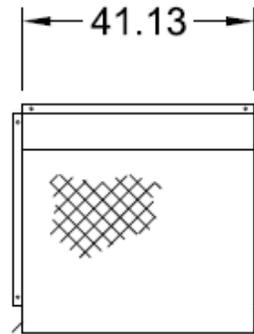
45 Degree Weatherhood

Standard Construction Features:

Galvanized Steel or aluminum construction. 0.5 welded wire birdscreen. Prepunched mounting holes. Field assembled.



SIDE VIEW

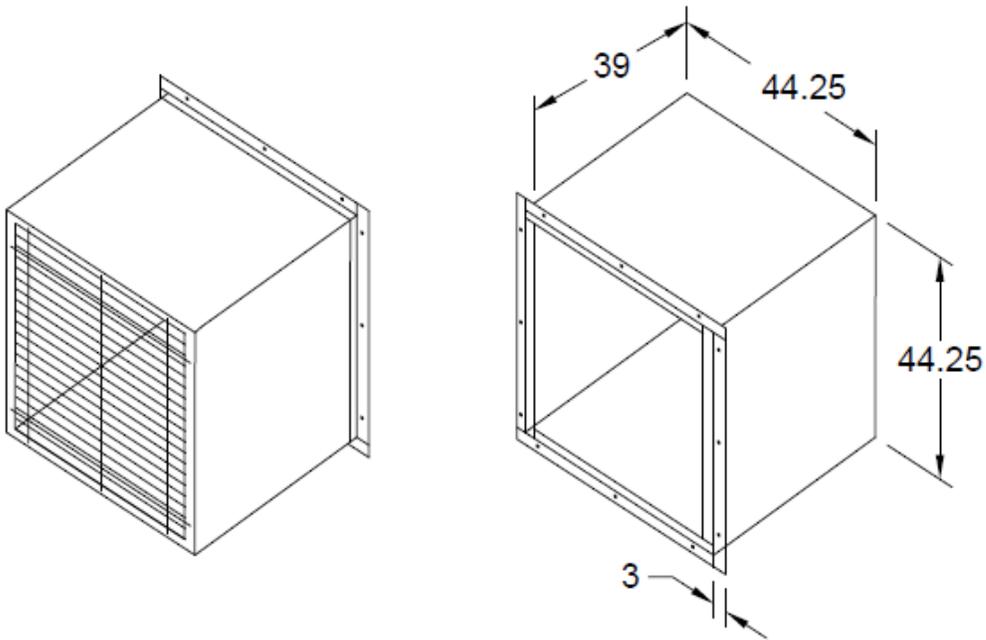


ELEVATION VIEW

Short Wall Housing

Standard Construction Features:

- Galvanized steel construction - Heavy gauge mounting flanges - Pre-punched mounting holes - Inside flanges allow damper to be mounted - Overlapping weatherhood flange keeps rain out - OSHA Protective guard of welded steel wire completely protects the drive side of the wall housing.

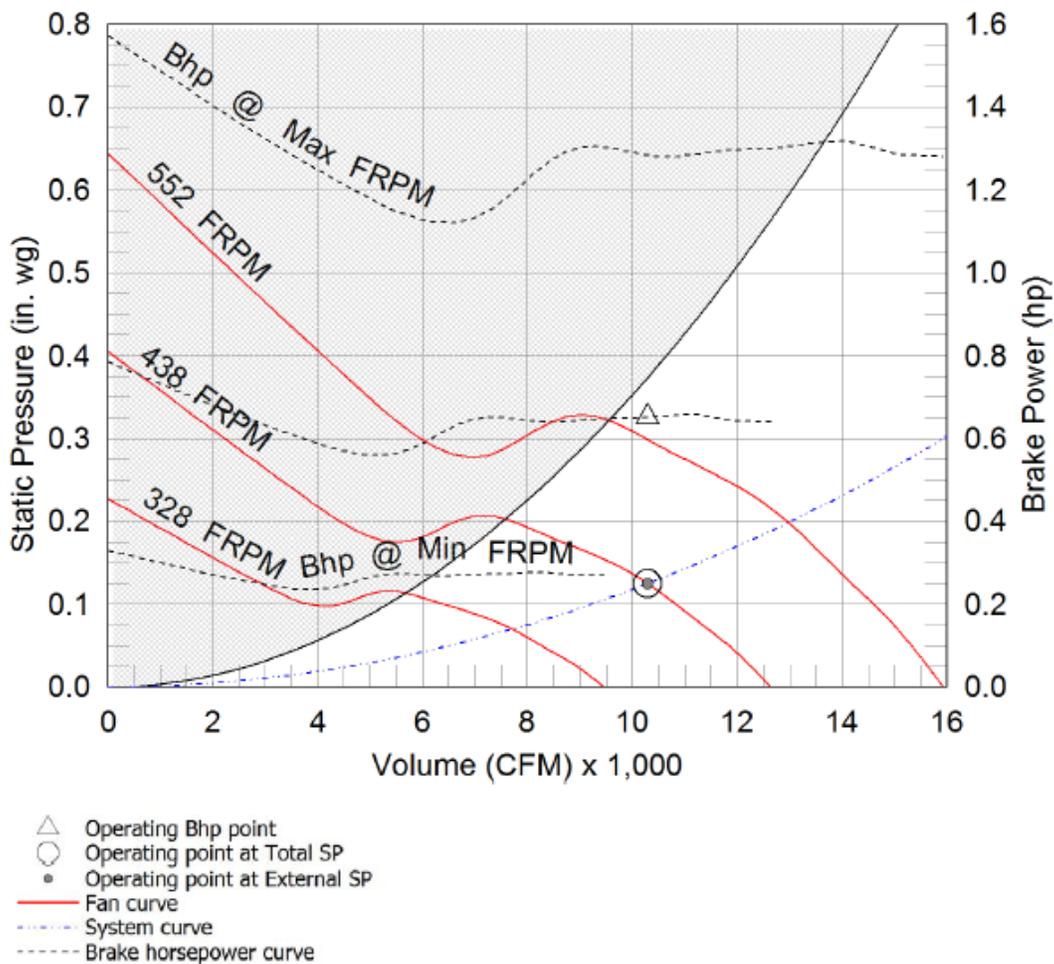


SBE-1L36-10

Min/Max Fan Curve

Performance

Requested Volume (CFM)	Actual Volume (CFM)	External SP (in. wg)	Total SP (in. wg)	Fan RPM	Operating Power (hp)
10,290	10,290	0.125	0.125	438	0.65



AMCA



AMCA Licensed for Sound and Air Performance. Power rating (BHP/kW) includes transmission losses.

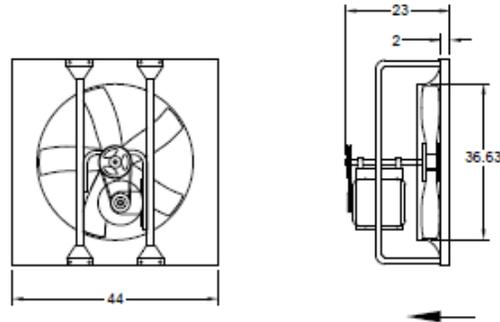
Greenheck Fan Corporation certifies that the model shown herein is licensed to bear the AMCA Seal. The ratings shown are based on tests and procedures performed in accordance with AMCA Publication 211 and AMCA Publication 311 and comply with the requirements of the AMCA Certified Ratings Program. Performance certified is for installation type A: Free inlet, Free outlet. Power rating (BHP/kW) includes transmission losses. Performance ratings do not include the effects of appurtenances (accessories). The sound ratings shown are loudness values in fan sones at 5 ft. (1.5 m) in a hemispherical free field calculated per AMCA Standard 301. Values shown are for installation type A: free inlet hemispherical sone levels. dBA levels are not licensed by AMCA International. The AMCA Certified Ratings Seal applies to sone ratings only.

Model: SBS-1L36-10
Sidewall Belt Drive Supply Fan

Dimensional	
Quantity	2
Weight w/o Acc's (lb)	119
Weight w/ Acc's (lb)	431
Max T Motor Frame Size	184
Optional Damper (in.)	38 x 38
Wall Opening (in.)	45.75 x 45.75

Performance	
Requested Volume (CFM)	10,290
Actual Volume (CFM)	10,290
External SP (in. wg)	0.125
Total SP (in. wg)	0.125
Fan RPM	438
Operating Power (hp)	0.65
Elevation (ft)	30
Airstream Temp.(F)	70
Air Density (ft3)	0.075
Drive Loss (%)	7.4
Tip Speed (ft/min)	4,129
Static Eff. (%)	34

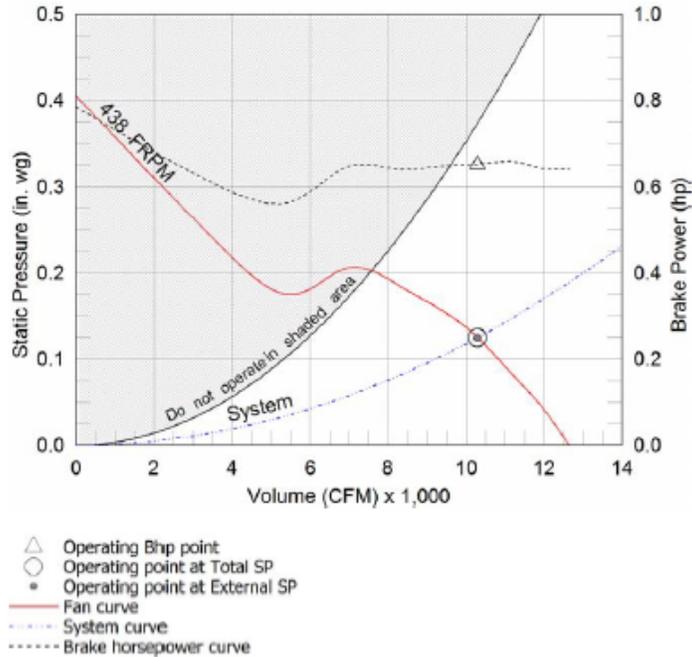
Motor	
Motor Mounted	Yes
Size (hp)	1
V/C/P	460/60/3
Enclosure	ODP
Motor RPM	1725_860
Windings	2



SUPPLY FANS CAN CARRY RAIN OR SNOW INTO THE BUILDING

AIR FLOW

See the Assembly Drawing For Selected Accessories



Sound Power by Octave Band

Sound Data	62.5	125	250	500	1000	2000	4000	8000	LwA	dBA	Sones
Inlet	78	83	74	71	69	65	62	58	75	63	13.5

Notes:

All dimensions shown are in units of in.
*FLA - based on tables 150 or 148 of National Electrical Code 2002. Actual motor FLA may vary, for sizing thermal overload, consult factory.
LWA - A weighted sound power level, based on ANSI S1.4
dBA - A weighted sound pressure level, based on 11.5 dB attenuation per Octave band at 5 ft - dBA levels are not licensed by AMCA International
Sones - calculated using AMCA 301 at 5 ft



Model: SBS-1L36-10

Sidewall Belt Drive Supply Fan

Standard Construction Features:

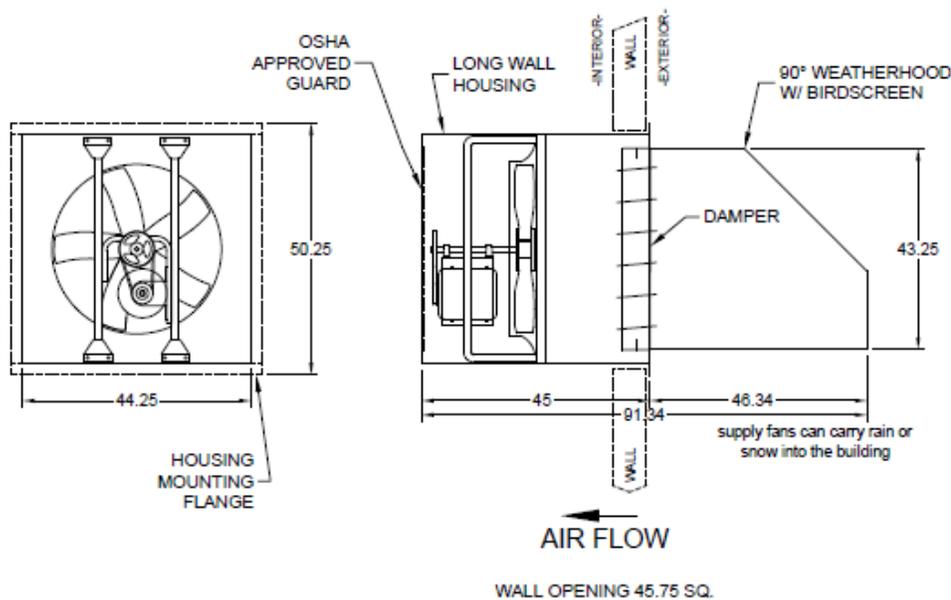
- Galvanized steel fan panel - Die formed, galvanized steel drive frame assembly
- Fabricated steel propeller for Levels 1 and 2, welded and painted steel for Level 3
- Adjustable motor pulley - Ball bearing motors - Fan shaft mounted in ball bearing pillow blocks - Static resistant belts - Corrosion resistant fasteners

Selected Options & Accessories:

- Damper Mounted, WD-220-PB-38X38, Not Coated
- Damper Actuator (MP-210), 24 VAC Actuated
- Long Wall Hsg, Flush Ext, (1B-Sup), w/ OSHA Grd.
- Weatherhood, Galvanized 90 deg. with Bird Screen
- Unit Warranty: 1 Yr (Standard)

Assembly Drawing

Type: Sidewall Belt Drive Supply Fan



Vertical Mount Intake Damper

Model: WD-220

Standard Construction Features:

- Model WD-220 is an electrically motorized backdraft damper that opens when energized and spring returns closed when de-energized. It is designed for vertical mounting to prevent undesirable reverse air flow when installed with roof or sidewall supply (intake) fans -- Galvanized frame with a flange opposite the motor side of damper - Steel axle material - Synthetic axle bearings
- Maximum temperature of 180 F - Electric motor pack is shipped separately and requires installation in field.

Damper Configuration:

Actuator Type: 24 VAC

End Switch: No

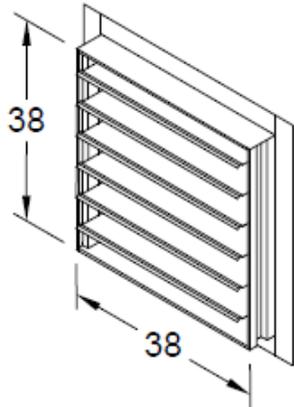
Actuator Configuration:

Manufacturer: Greenheck Jackshaft Quantity: 0

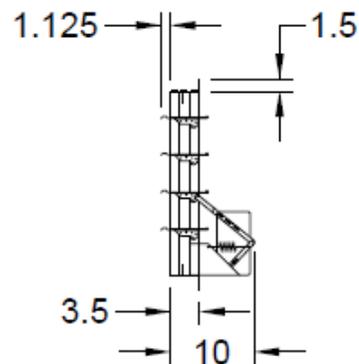
Model: MP-210

Mounting: None

Quantity: 1



DAMPER

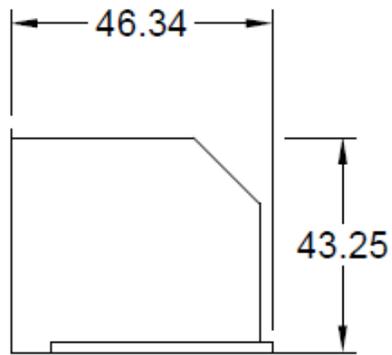


TYP. SECTION VIEW

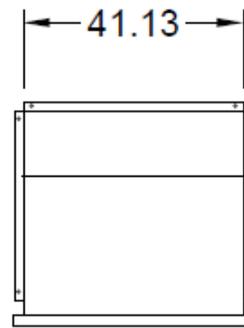
90 Degree Weatherhood

Standard Construction Features:

Galvanized Steel or aluminum construction. 0.5 welded wire birdscreen. Prepunched mounting holes. Field assembled.



SIDE VIEW

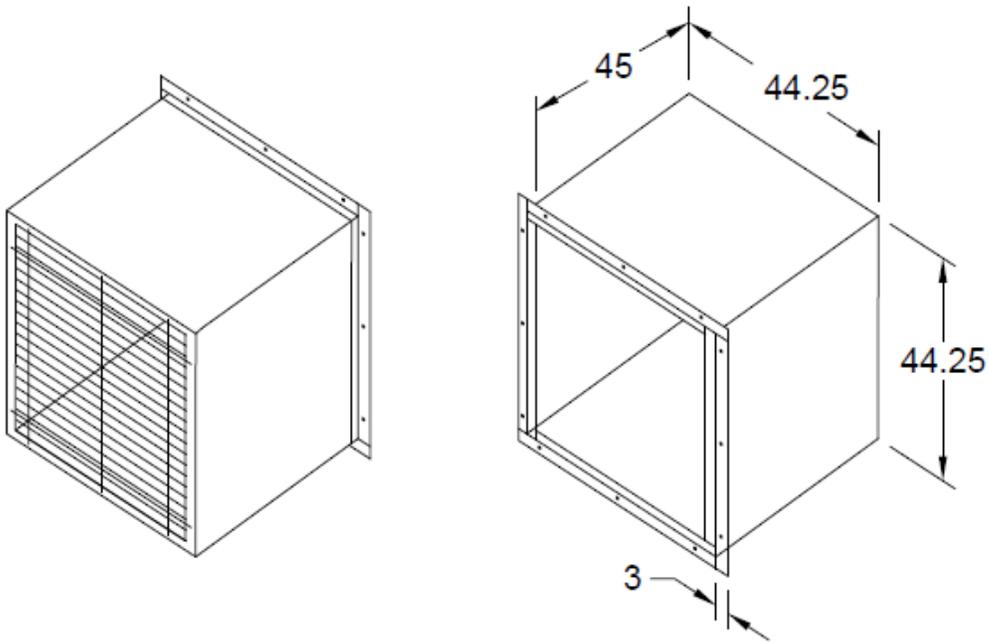


ELEVATION VIEW

Long Wall Housing

Standard Construction Features:

- Galvanized steel construction - Heavy gauge mounting flanges - Pre-punched mounting holes - Inside flanges allow damper to be mounted - Overlapping weatherhood flange keeps rain out - OSHA Protective guard of welded steel wire completely protects the drive side of the wall housing.

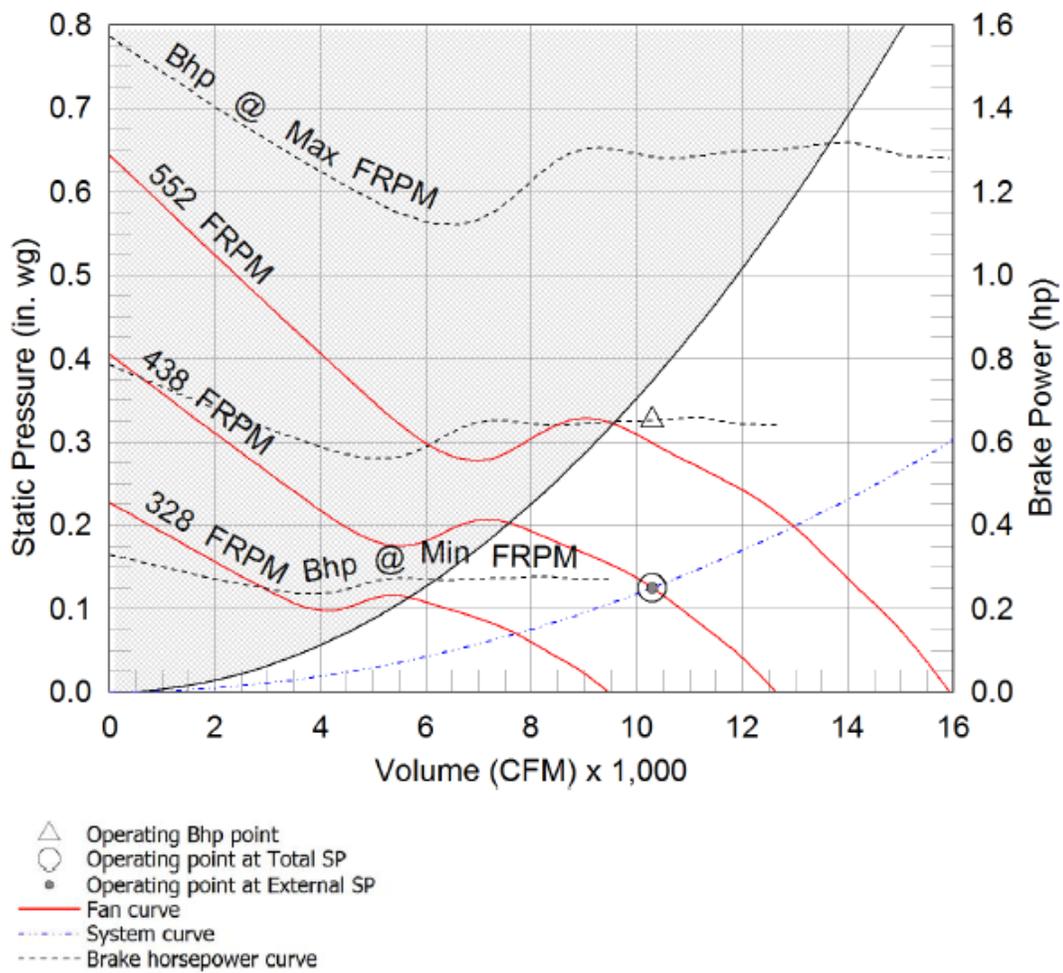


SBS-1L36-10

Min/Max Fan Curve

Performance

Requested Volume (CFM)	Actual Volume (CFM)	External SP (in. wg)	Total SP (in. wg)	Fan RPM	Operating Power (hp)
10,290	10,290	0.125	0.125	438	0.65



AMCA



AMCA Licensed for Sound and Air Performance. Power rating (BHP/kW) includes transmission losses.

Greenheck Fan Corporation certifies that the model shown herein is licensed to bear the AMCA Seal. The ratings shown are based on tests and procedures performed in accordance with AMCA Publication 211 and AMCA Publication 311 and comply with the requirements of the AMCA Certified Ratings Program. Performance certified is for installation type A: Free inlet, Free outlet. Power rating (BHP/kW) includes transmission losses. Performance ratings do not include the effects of appurtenances (accessories). The sound ratings shown are loudness values in fan sones at 5 ft. (1.5 m) in a hemispherical free field calculated per AMCA Standard 301. Values shown are for installation type A: free inlet hemispherical sone levels. dBA levels are not licensed by AMCA International. The AMCA Certified Ratings Seal applies to sone ratings only.

KE Fibertec Quote

From: Mike Carr [<mailto:mcarr@nas-hvac.com>]

Sent: Wednesday, April 15, 2015 4:29 PM

To: kyle@WPI.EDU

Subject: Habitat for Humanity Textile Duct

Hi, Kyle.

Attached is technical data for the fabric duct.

Two 150 Foot duct runs with hanging hardware.

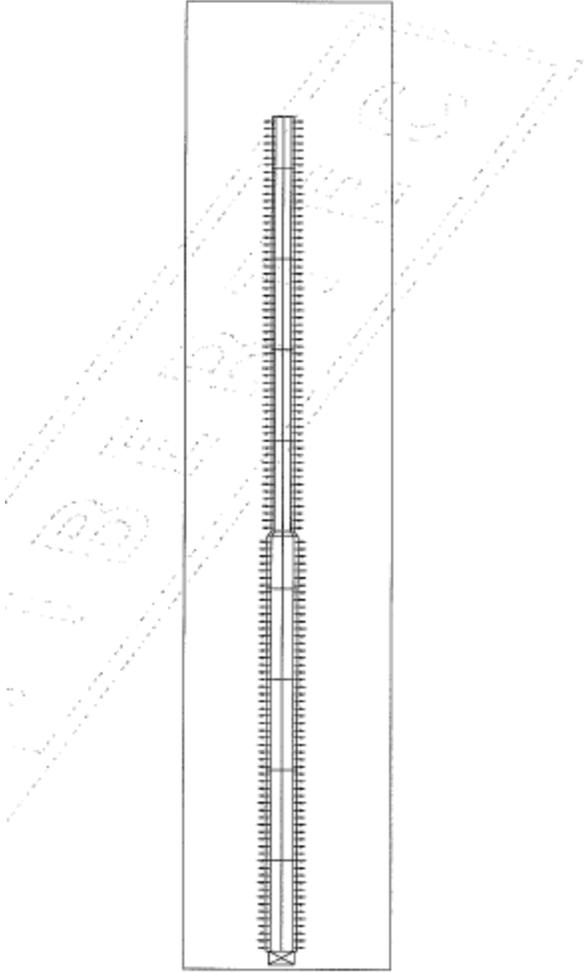
Cost: \$10,000.

Plan on 1# per linear foot for duct and suspension hardware.

Please contact me if you have any questions.

Thank you,
Mike

Michael Carr
Northeast Air Solutions, Inc.
140 Wood Road
Braintree, MA 02184
781.535.6800



Plan view

a Reinhold Group

Customer:		KE FIBERTEC	
NORTHEAST AIR SOLUTIONS		KE Fibertec AG	
Name: Habitat for Humanity		9991 Isakdahl Road	
Date: 4/16/2015		Fellsmo, MN 55021	
Part:		Tel: +1 256 665 7100/256 668	
Description:		Draw no: 15306-0-1	
Habitat for Humanity			

"Part" refers to quotation item no.

Quotation nr.: 15906-0/NAKD

Page No : 2

Room.....: Habitat for Humanity
System no.: 1

Item: 10 2 ps. KE-Inject XL
With Start piece and external zip
Dimension : Ø35.98 In X 75.00 ft
KE-material : 025430-5 LDC -FR
Colour : Traffic-red(RAL nr. : 3020)
No. of zippers : 4 6 mm standard
With 2 row KE-Clips - Length =19.57 In
Clamps 1 (Ø35.98 In)
With 1x5 Inject XL holes 135° / 1x5 Inject XL holes -135°
Total No. of XL holes 228

Item: 20 2 ps. KE-Inject XL
With internal zip(2010) and bottom
Dimension : Ø25.98 In X 76.00 ft
With conical piece
1 ps. Ø 35.98 In To Ø 25.98 In ,L=1.00 ft
Flat Edge on topWith internal zip(2010)
KE-material : 025430-5 LDC -FR
Colour : Traffic-red(RAL nr. : 3020)
No. of zippers : 5 6 mm standard
With 2 row KE-Clips - Length =14.57 In
With 1x5 Inject XL holes 135° / 1x5 Inject XL holes -135°
Total No. of XL holes 228

Item: 30 KE-Suspension set, Wire
No. of ft wire 678.74 ft
Wire 78.7 in strap-up 48
No. of turnbuckles 16
No. of wire locknuts 16
Wire=nylon sheathed wire

TECHNICAL INFORMATION

Total air quantity KE-System	10,000	CFM
Temperature difference(cooling)	18	°F
Temperature difference(heating)	18	°F
Total dimensioning pressure loss (Pt)	0.65	inWG
External static pressure loss (ESP)	0.53	inWG
Min. static pressure (centre duct)	0.62	inWG
Stated throw(min)	20.00	ft
Max. air velocity (cooling)	58.6	FPM
Max. air velocity (heating)	55.8	FPM

According to drawing no. :15906-0-1

Appendix H: Insulation Cost Breakdown

Drywall		(The Home Depot, 2015)	
Size	Price	Number of Sheets	Total Price
5/8"x4'x8'	\$11.98	176	\$2,108.48
1/2"x4'x8'	\$10.78	176	\$1,897.28
3/8"x4'x8'	\$10.78	176	\$1,897.28
1/4"x4'x8'	\$11.78	176	\$2,073.28

Blown-In Cellulose (Green Fiber)			(The Home Depot, 2015)	
Amount per Bag (sqft)	Price	Bags Needed	Total Price	R-Value for 6.75" Thick
49.5	\$12.15	94	\$1,382.08	22

Expanding Blown-In Fiberglass (AttiCat)			(The Home Depot, 2015)	
Amount per Bag (sqft)	Price	Bags Needed	Total Price	R-Value for 6.75" Thick
102	\$30.00	55	\$1,649.60	20

Fiberglass Blowing Insulation (InsulSafe)			(CertainTeed, 2015)	
Amount per Bag (sqft)	Price	Bags Needed	Total Price	R-Value for 6.75" Thick
34.4	\$32.00	164	\$5,231.40	27

Fiberglass Blowing Insulation (OPTIMA)			(CertainTeed, 2015)	
Amount per Bag (sqft)	Price	Bags Needed	Total Price	R-Value for 6.75" Thick
27.6	\$31.36	204	\$6,390.25	28
Fiberglass Blown-In Insulation (JM Spider)			(JM Spider, 2015)	

Amount per Bag (sqft)	Price	Bags Needed	Total Price	R-Value for 6.75" Thick
37.0	\$30.00	152	\$4,559.17	23

Rigid Foam Board			(Dow Chemical Company)		
Size per Sheet	Price	Total Sheets	Total Price	R-Value for 6.75" Thick	
1"x4'x8'	\$0.00	1,188	\$0.00	34	

Closed Cell Spray Foam (Certaspray)			(CertainTeed, 2015)			
Size	High Price per Sqft	Low Price per Sqft	Total Sqft	High Price	Low Price	R-Value for 6.75" Thick
5.75"	\$5.75	\$4.03	5628.6	\$32,364.45	\$22,683.26	43

Open Cell Spray Foam (Certaspray)			(CertainTeed, 2015)			
Size	High Price per Sqft	Low Price per Sqft	Total Sqft	High Price	Low Price	R-Value for 6.75" Thick
5.75"	\$3.74	\$2.53	5628.6	\$21,036.89	\$14,240.36	25

Radiant Barrier						
Single Bubble (metalized one side)			0.47 oz/sq ft		(The Home Depot, 2015)	
Size (sqft)	Price	Total Rolls	Price	Total Weight (oz)	Total Weight (lb)	
400	\$139.00	36	\$5,004.00	6605.2	412.83	

Single Bubble (metalized both sides)			0.53 oz/sq ft		(The Home Depot, 2015)	
Size (sqft)	Price	Total Rolls	Price	Total Weight (oz)	Total Weight (lb)	
400	\$129.00	36	\$4,644.00	7448.4	465.53	

Radiant Roof Paint (Insul Cool-Coat #2000)			(Hy-Tech Thermal Solutions, 2015)			
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Reflectivity	Emissivity	Spread Rate of Top Coat (sq.ft)	Spread Rate of Primer (sq.ft)	Top Coat Price/5 Gallon	Primer Price/ 5 Gallon	Max Price of Top Coat	Max Price of Primer	Total Price
80%	90%	100-150	200-250	\$192.50	\$142.50	\$16,555.00	\$3,063.75	\$19,618.75

Vapor Barrier					
UltraTech Interior Latex Vapor Barrier Primer/Sealer			< 1.0 perm	(Sherwin Williams, 2016)	
One Gallon Spread (Sq.Ft)	Price per 5 gallons	Total Sq.Ft	Price Per Sq.Ft	Price	Price with Drywall
250	\$80.00	5628.6	\$0.071	\$400.00	\$2,297.28

Black 6 mil Polyethylene Sheeting			< 0.1 perm	(The Home Depot, 2015)	
Size	Price	Total Sq.Ft	Price Per Sq.Ft	Price	Price with Drywall
20' x 100'	\$98.00	5628.6	\$0.052	\$294.00	\$2,191.28

Gold Bond Foil Back Gypsum Board			< 0.1 perm	(National Gypsum, 2015)	
Size	Price Per Sq.Ft	Total Sq.Ft	Total Price		
4' x 8'	0.95	5628.6	\$5,347.17		

Spray Foam Installation Pricing			
Anchor Insulation Company		(Anchor Insulation, 2014)	
Type	Cost per Board Foot (1' x 1' x 1")	Total Board Feet	Total
Closed Cell	\$0.90	25,620.4	\$23,058.36
Open Cell	\$0.40	25,620.4	\$10,248.16
Anderson Insulation		(Anderson Insulation, 2012)	

Type	Cost per Board Foot (1' x 1' x 1")	Total Board Feet	Total
Closed Cell	\$1.15	25,620.4	\$29,463.46
Open Cell	\$0.57	25,620.4	\$14,603.63

March & March Incorporated		(March & March Insulation, 2015)	
Type	Cost per Board Foot (1' x 1' x 1")	Total Board Feet	Total
Closed Cell	\$1.17	25,620.4	\$29,975.87
Open Cell	\$0.77	25,620.4	\$19,727.71

Safco Foam		(Safco Foam, 2012)	
Type	Cost per Board Foot (1' x 1' x 1")	Total Board Feet	Total
Closed Cell	\$1.10	25,620.4	\$28,182.44
Open Cell	\$0.40	25,620.4	\$10,248.16

Appendix I: Insulation Options

Option 1: Rigid Foam Board

- DOW Rigid Foam Board - \$0.00
- Polyethylene Sheet Vapor Barrier - \$294
- Drywall - \$1,897.28
- DIY Labor and Machine Costs - \$0.00
- Thermal Resistance - 34
- Payback - 2.9 Years
- **Total Cost - \$2,191.28**

Option 2: Blown-In Insulation

- Green Fiber Blown-In Cellulose - \$1,382.08
- Polyethylene Sheet Vapor Barrier - \$294
- Drywall - \$1,897.28
- DIY Labor and Machine Costs - \$50 a day for 5 days- \$250
- Thermal Resistance - 22
- Payback – 5.4 Years
- **Total Cost - \$3,823.36**

Option 3: Open Cell Spray Foam

- CertaSpray Open Cell Spray Foam - \$24,709.56
- Polyethylene Sheet Vapor Barrier - \$294
- Drywall - \$1,897.28
- Anchor Insulation Company Labor and Machine Costs - \$10,248.16
- Thermal Resistance - 25
- Payback - 50.8 Years
- **Total Cost - \$37,149.00**

Option 4: Closed Cell Spray Foam

- CertaSpray Closed Cell Spray Foam - \$37,993.05
- Polyethylene Sheet Vapor Barrier - \$294
- Drywall - \$1,897.28
- Anchor Insulation Company Labor and Machine Costs - \$23,058.36
- Thermal Resistance - 37
- Payback – 81.4 Years
- **Total Cost - \$63,242.69**

Appendix J: Radiant Roof Paint Calculations

Utilizing a Commercial Roof Savings Calculator (RSC) provided by the United States Department of Energy (DoE), we were able to get a rough estimate of how many kilowatt hours are gained through the roof currently and the potential savings due to painting the roof with radiant roof paint (United States Department of Energy, 2014). To estimate the values we needed to estimate the color of the metal roof, which gives us a solar reflectance (20%) and thermal emittance (20%); we can compare that to the solar reflectance (80%) and thermal emittance (90%) of the paint that we would use to cover the roof. The results can be found in the chart below.

Existing Roof													
kWh Gain	J	F	M	A	M	J	J	A	S	O	N	D	Total
	0	0	26.1	824.6	4964.9	9563.8	12339.6	10681.7	6218.1	1071.1	5.4	0	45695.3
Existing Roof with Radiant Roof Paint													
kWh Gain	J	F	M	A	M	J	J	A	S	O	N	D	Total
	0	0	11.6	681.5	4659	8638.8	10984	9723.6	5647	979.4	1.8	0	41326.7
Monthly kWh Savings													
kWh Saved	J	F	M	A	M	J	J	A	S	O	N	D	Total
	0	0	14.5	143.1	305.9	925	1355.6	958.1	571.1	91.7	3.6	0	4368.6

From the kilowatt hours we obtained from the simulation, we could convert them to BTUs. From our research we found that one kilowatt hour is equal to 3,412 BTUs; therefore giving us the values for the next chart. With painting the roof with radiant roof paint, the ReStore could save approximately 14,905,600 BTUs annually.

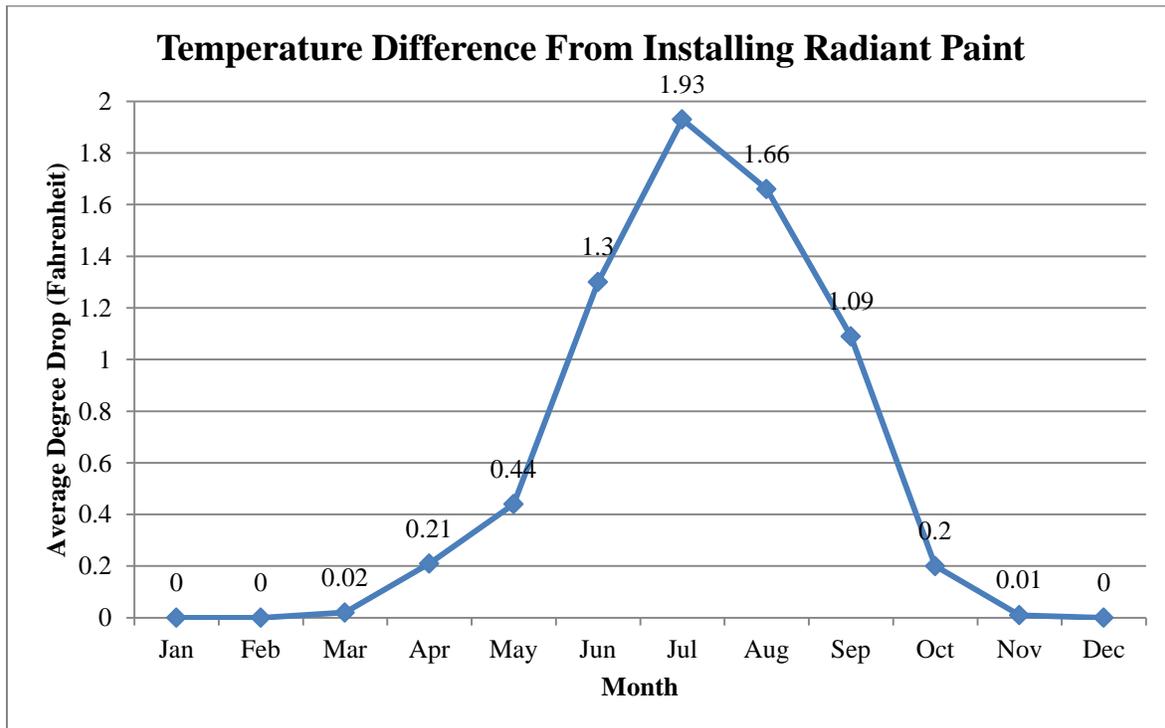
Existing Roof													
1000x BTU Gain	J	F	M	A	M	J	J	A	S	O	N	D	Total
	0	0	89	2,813.5	16,940.2	32,631.6	42,102.7	36,445.9	21,216.1	3,654.6	18.4	0	155,912.3
Existing Roof with Radiant Roof Paint													
1000x BTU Gain	J	F	M	A	M	J	J	A	S	O	N	D	Total
	0	0	39.5	2,325.2	15,896.5	29,475.6	37,477.4	33,176.9	19,267.5	3,341.7	6.1	0	141,006.7
Monthly BTU Savings													
1000x BTU Saved	J	F	M	A	M	J	J	A	S	O	N	D	Total
	0	0	49.4	488.2	1,043.7	3,156.1	4,625.3	3,269	1,948.6	312.9	12.2	0	14,905.6

Since we have the amount of BTUs saved per month, we needed to calculate the average daylight hours for each month and to do this we averaged the hours of sunlight for each month.

Average Daylight Hours Per Month											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
294.50	294.00	372.00	405.00	449.50	450.00	465.00	457.25	375.00	341.00	300.00	279.00

Now that we have the BTUs gained during daylight hours each month and the daylight hours per month, we could figure out the BTUs per hour. From our research we discovered that 0.02 BTUs are required to raise the temperature of one cubic foot of air, and with 262,095 cubic feet it requires 5,241.9 BTUs to raise the entire warehouse one degree Fahrenheit. Therefore, by dividing the BTUs saved each month from the BTUs to raise the entire warehouse one degree, and then divided again by average daylight hours, we achieve the average degree drop of the warehouse during the day.

Temperature Difference											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	0	0.02	0.21	0.44	1.3	1.93	1.66	1.09	0.2	0.01	0



Appendix K: Insulation Payback Calculations

The data in this spread sheet was obtain through a proposal from All in One & Moore Building Systems.

Existing R-Value	4	Energy Cost (Gas) per Therm	\$0.37
New R-Value	22.68-36.8	Heating Degree Days (HDD65)	6,969
Wall Area (sq.ft.)	5,629	Cooling Degree Days (CDD50)	676

To calculate the annual energy loss in kilowatt hours, we utilized the formula below.

$$\text{Annual Energy Loss (Kwh)} = \text{Area} * \frac{\left(\frac{1}{\text{R-Value}}\right) * \text{HDD65} * 24 + \left(\frac{1}{\text{R-Value}}\right) * \text{CDD50} * 24}{3,413}$$

To calculate the annual energy cost for heating, we utilized the formula below.

$$\text{Annual Energy Cost} = \frac{\left(\frac{1}{\text{R-Value}}\right) * \text{Area} * \text{HDD65} * 24}{100,000} * \text{Energy Cost (Gas)}$$

Current State	Walls	Roof	Total
Annual Energy Loss (Kwh)	75,647	188,877	264,524
Annual Energy Cost	\$871	\$2,175	\$3,046

Saving values are obtained from subtracting the state of the warehouse after insulation is installed from the current state of the warehouse. The payback was calculated by taking the total cost of the insulation and dividing by the annual energy savings.

Rigid Foam Board: R-34

New State	Total
Annual Energy Loss (Kwh)	197,777
Annual Energy Savings (Kwh)	66,748
Annual Energy Cost	\$2,277
Annual Energy Savings	\$768
Total Cost	\$2,191.28
Payback (Years)	2.85

Blown-In Insulation: R-22

New State	Total
Annual Energy Loss (Kwh)	202,631
Annual Energy Savings (Kwh)	61,893
Annual Energy Cost	\$2,333
Annual Energy Savings	\$712
Total Cost	\$3,823.36
Payback (Years)	5.37

Open Cell Spray Foam: R-25

New State	Total
Annual Energy Loss (Kwh)	200,981
Annual Energy Savings (Kwh)	63,544
Annual Energy Cost	\$2,314
Annual Energy Savings	\$731
Total Cost	\$37,149
Payback (Years)	50.79

Closed Cell Spray Foam: R-37

New State	Total
Annual Energy Loss (Kwh)	197,055
Annual Energy Savings (Kwh)	67,469
Annual Energy Cost	\$2,268
Annual Energy Savings	\$777
Total Cost	\$63,242.69
Payback (Years)	81.43