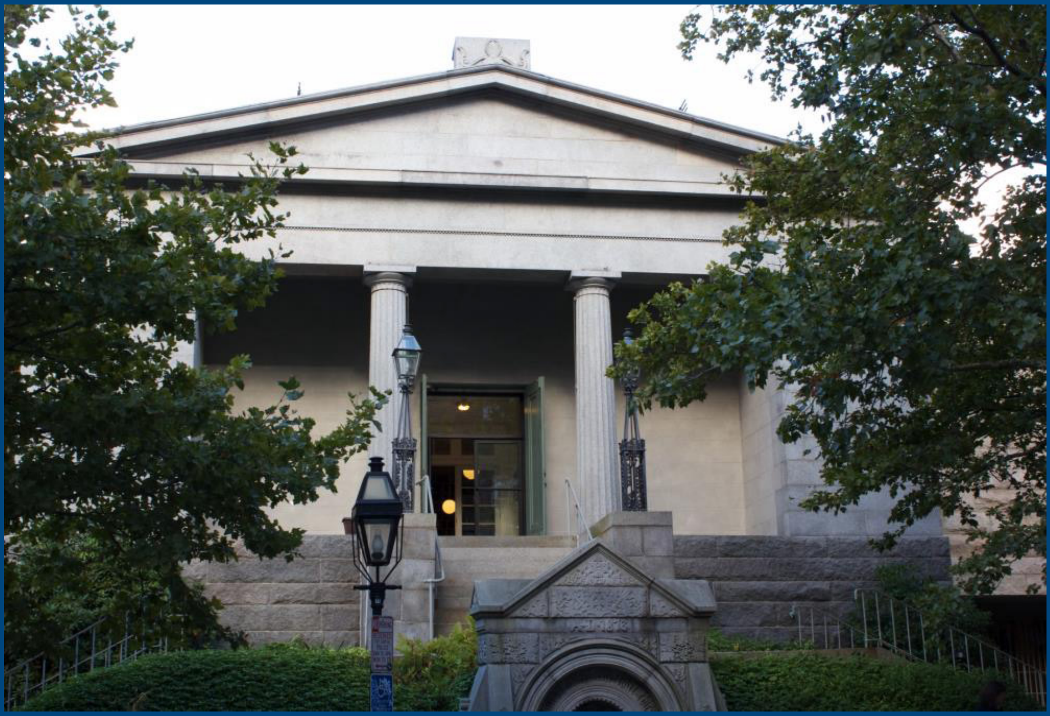
Community Partnerships Center
at Roger Williams University

# HVAC System Analysis and Energy Audit



Community Partner: *The Providence Athenaeum - Providence, RI*

Academic Partner: *School of Engineering, Computing & Construction Management*

*Fall 2013 & Spring 2014*

## The Roger Williams University Community Partnerships Center

The Roger Williams University (RWU) Community Partnerships Center (CPC) provides project based assistance to non-profit organizations, government agencies and low- and moderate-income communities in Rhode Island and Southeastern Massachusetts. Our mission is to undertake and complete projects that will benefit the local community while providing RWU students with experience in real-world projects that deepen their academic experiences.

CPC projects draw upon the skills and experience of students and faculty from RWU programs in areas such as:

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- Business
- Community Development
- Education
- Engineering and Construction Management
- Environmental Science and Sustainability
- Finance
- Graphic Design
- Historic Preservation
- History
- Justice Studies
- Law
- Marketing and Communications
- Political Science
- Psychology
- Public Administration
- Public Relations
- Sustainable Studies
- Visual Arts and Digital Media
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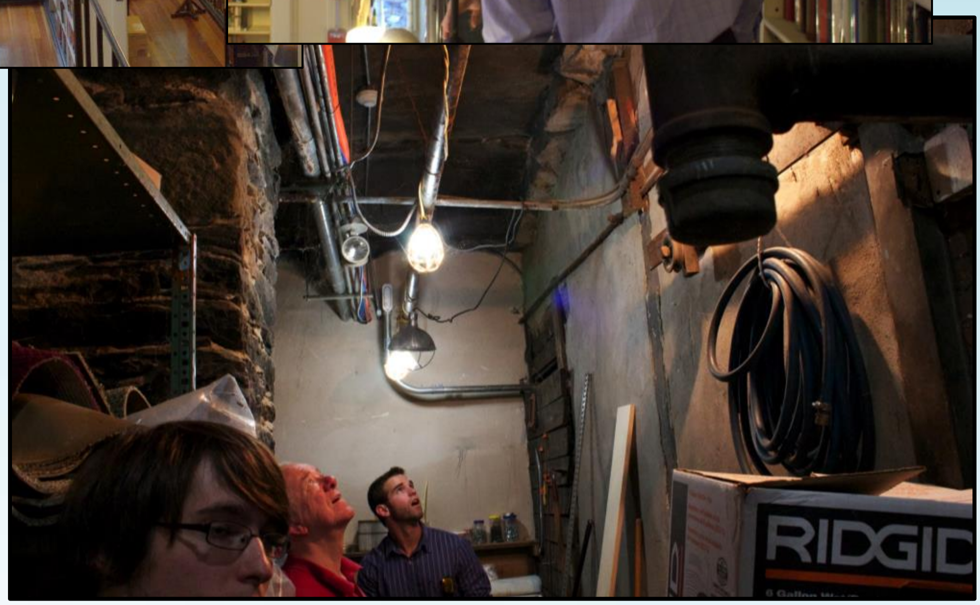
Community Partnerships Center
Roger Williams University
One Old Ferry Road
Bristol, RI 02809
cpc@rwu.edu
http://cpc.rwu.edu

# Historical Value Adding Consultants

## Providence Athenaeum Design Project

Academic Year
2013-2014

May
2014




Roger Williams
University

Team Members: Nicholas Farland, Trevor Larson, Justin Taylor, Cameron Wendler
Professional Client: The Providence Athenaeum
School of Engineering, Computing & Construction Management
Faculty Advisors: Dr. Anthony Ruocco and Dr. Janet Baldwin
Fall 2013 and Spring 2014

## Abstract

Opening its doors to the public over 175 years ago, the Providence Athenaeum is one of the oldest buildings in Providence, Rhode Island. The Athenaeum is an independent member-supported library that offers the public access to its rare books collection as well as sponsoring community-oriented programs. The facility's HVAC systems, however, are aged. A team of Roger Williams University engineering students was asked to accomplish the following tasks.

- Conduct an assessment of existing conditions of the Athenaeum's HVAC and related systems.
- Develop a conceptual preliminary HVAC design that meets the operation requirements of the facility as specified by the owner.
- Identify and investigate opportunities to incorporate more modern energy generating technologies into the facility.
- Provide the client with a general overall report and recommendations for moving forward.

An initial physical inspection of the Providence Athenaeum identified several key characteristics listed below which formed the basis for the assessment of the current conditions and the subsequent conceptual design of the HVAC system.

- The facility is heated by a single pipe, single boiler, gravity return steam system.
- The rare book archive of the building is air conditioned by a Liebert air conditioning unit that is maintaining a temperature of 68 ºF and a humidity level of 50% year round.
- The majority of the building is currently not air conditioned leading to uncomfortable working conditions for the staff and visitors.
- Window air conditioners are placed throughout the building to partially condition the occupied spaces.

To evaluate the impact of potential modifications to the HVAC system the Historical Value Adding Consultants developed a building energy model. The building energy model was constructed using a Microsoft Excel spreadsheet that utilizes typical meteorological year (TMY) data to determine the average energy usage of the Athenaeum for a typical year. The model has been validated against actual energy usage and is used to identify and quantify energy savings resulting from design alternatives.

The proposed renovation includes the removal of the current boiler and one-pipe distribution system and its replacement with a modern heating system that includes a single 375,000 Btu/hr high efficiency boiler and a slant fin radiator system. Accounting for the need to heat evenly, but also being able to reduce heat in unoccupied spaces, the team developed a series of zones. The zone

controller will allow for comfortable operating temperatures during different occupancy levels.

Chilled beams in parallel with a dedicated outdoor air system (DOAS) will provide the cooling and ventilation for the Athenaeum. Eight active beams are to be placed in the main room of the Athenaeum to meet the areas cooling needs. They will be placed perpendicular to the exterior walls in order to promote the best circulation of air.

To offset energy costs and to introduce renewable energy sources, the team has proposed the installation of photovoltaic panels on the roof of the Athenaeum. Utilizing the energy usage and cost over the past three years of the Providence Athenaeum an analysis of different photovoltaic panel configurations was performed to identify the best configuration to optimize the return on investment.

As part of the overall effort, the team identified numerous areas for energy conservation actions that are readily addressable and which can provide near term savings. Such things as installing insulation in open attic space, re-glazing windows and weather-stripping of doors and window frames will provide real savings for little expense.

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# I. Introduction

The Providence Athenaeum is considered on of the oldest buildings in Providence Rhode Island, having opening its doors to the public over 175 years ago. The Athenaeum is an independent member-supported library that offers the public access to its rare books collection as well as sponsoring community-oriented programs. The facility's HVAC systems, however, are aged. A team of Roger Williams University engineering students was asked to accomplish the following tasks.

- Conduct an assessment of existing conditions of the Athenaeum's HVAC and related systems.
- Develop a conceptual preliminary HVAC design that meets the operation requirements of the facility as specified by the owner.
- Identify and investigate opportunities to incorporate more modern energy generating technologies into the facility.
- Provide the client with a general overall report and recommendations for moving forward.

## II. General Approach

This project originated from the Community Partnerships Center (CPC) at Roger Williams University. This project was initially assigned to an architecture student to construct a building information model, but was revised for the ENGR 492 Senior Design course. Once the students were assigned to this project, the next step was to set up the initial meeting with the client. The initial meeting with the client was to introduce the project team and identify the objectives of this project. The team was given a tour of the Providence Athenaeum to examine the exiting conditions of the building and its HVAC related systems. After the physical inspection, the Athenaeum's financial data were analyzed to determine the energy usage of the building. To properly study the energy usage of the Athenaeum the Historical Value Adding Consultants created a building energy model. The building energy model was used to evaluate the cost and efficiency of the new boiler system. The proposed renovation to the system includes a single 375,000 Btu/hr high efficiency boiler and a slant fin radiator system. To offset energy costs, the team has proposed the installation of photovoltaic panels on the roof of the Athenaeum. As part of the overall effort, the team identified numerous areas that are readily addressable for energy conservation improvements and can provide near term savings. Chilled beams in parallel with a dedicated outdoor air system (DOAS) will provide the cooling and ventilation for the Athenaeum. The clients at the Providence Athenaeum may choose to use this report to develop a consensus for future improvements of the facility.

## III. Results and Discussion

### Analysis of roof loads

In order to see if the photovoltaic panels can be placed on the roof of the Athenaeum, the maximum roof load before failure needed to be found. The current load that is being applied to the roof was found first. There is an equation of load combination that was used with the most common loads (dead load, snow load, wind load). The first load that was found was the snow load. There is a map of the United States, in Ram S. Gupta's *Principles of Structural Design*, that has snow load factors that cover all of the regions. A load factor is a factor that accounts for deviations of the actual load from the nominal load. These load factors can be used in an equation to find the actual load and are also unit less. For the Rhode Island region, the snow load factor is 25. Since the area of the roof selected for PV panel installation is flat, no other factor has to be incorporated and the snow load of the roof remains 25.

The wind load factor was found by using the same book that the snow load came from. When designing this load, a couple sub factors were taken into consideration. These sub factors are the location of the PA, importance factor, and height of the building. The importance factor can be broken down into four occupancy categories; low hazard to human life structure, normal structures, high occupancy structures, and essential structures. Each category has two factors that could be used to find the wind load factor, winds less than or equal to 100 mph and greater than 100 mph. Providence fits in the high occupancy structure and less than 100 mph. with all these considerations taken in, the wind factor that was used was 8.

Next the dead load was found. This load is another factor like the snow and wind loads, but this is based on what the roof is already supporting (i.e. the Liebert system and the gravel). Each object/ material's weight is converted into their dead loads and then added together. By figuring out what is exactly on the roof, a dead load of 15 was calculated. Using these load factors, they can be entered into equation 1 to get what the roof load currently is (64.4 psf). Furthermore, the bending moment for the current structure was calculated. Equation 2 was used and solved for the bending moment (Wu). After Wu was found, it was multiplied by 12 to get our bending moment, which is 1536 psf.

To find what the maximum load can be before failure, an assumption was made. The type of wood used in the beam is not known so southern pine was chosen. This type of wood has a reference design value in bending of 2050 psi. Using this number, the adjusted reference design value (Fb') was calculated with equation 3. $C_f$ is the repetitive member factor and $k_f$ is the format conversion factor which can be found (pg. 100, *Principles of Structural Design*). Equation 4, with d representing the dressed depth of the section of beam was used to find $C_f$. After entering $C_f$ and $k_f$ into the equation, Fb' was found to be 4339.44 psi. Next the trial load was found by using equation 5; the number came out to be 94.53 psi. After determining the trial load, the adjusted reference design was multiplied by the trial load to get an adjusted bending moment, which came out to be 410207.26 psi. Now taking this moment and the current bending moment and set them into equation 6 and solve for Wu. This number came out to be 267.06 psi. Finally, the max load of the beam was found by taking the new Wu and dividing it by 5 to get 89.02 psf.

**Eq. 1**

$$1.2D + 1.6S + 0.8W$$

**Eq. 2**

$$\frac{WuL^2}{8}$$

**Eq. 3**

$$FB' = 2050C_f k_f$$

**Eq. 4**

$$C_f = (\frac{12}{d})^{\frac{1}{9}}$$

**Eq. 5**

$$S = \frac{1}{6}wh^2$$

**Eq. 6**

$$1536Wu = 410207.26$$

Please turn to Appendix A for the complete calculations.

## Heating system (redesign)

The initial approach to the redesign of the boiler system for the Providence Athenaeum was to assess the current system that is being utilized. The current system is based off of a single natural gas-fueled hydronic boiler located on the basement floor next to a utility closet on the western side of the Athenaeum. The hot steam then exits the boiler to a single 7" cast iron pipe that leads to one controllable zone of heating throughout the building which then gravity feeds back to the boiler through the same cast iron pipe. Paired with the hydronic boiler as a separate system a modern Liebert unit is located in the Archive room of the basement, which controls the heating, cooling and humidity ratio for the Archive room as well as the Philbrick Rare Book room.

The new heating apparatus proposed by our team is a multiple zone controlled single boiler hydronic system that dissipates heat by way of fin tube baseboard radiators. The first step in the redesign of the heating apparatus was to calculate the total heating load of the areas that will be addressed by new system which includes the entire building void of the two rooms controlled by the Liebert unit. Historical Value Adding Consultants collaborated with a graduate student attending Roger Williams University who shared a 3D Revit model of the Providence Athenaeum which was used to model and size the new heating system that is being proposed. Using the Revit model the square footage of each area throughout the Athenaeum was calculated. Using a heating load of 30 Btu/hr per square foot which is generally associated with low insulated buildings containing many perimeter windows the total heating load needed for each room was found and added together to generate a total heating load for the building. The total heating load was then multiplied by a pickup factor of 1.15 to calculate the final heating load of approximately 320,000 Btu/hr that the new boiler would have to satisfy. The square footage and heating load by room as well as the final heating load can be found in Table B.1 located in Appendix B of this report.

Using the final heating load calculated in Appendix B a boiler then had to be selected to meet required specifications. The boiler recommended by our team is the LAARS NeoTherm 399MBH High Efficiency Hydronic Boiler or equivalent. This boiler operates with a 375,000 Btu/hr output with up to 96.5 thermal efficiency %. Three specifications that the NeoTherm boiler meets that are ideal for our system are that it is floor mounted, with zero clearance for tight installation making it suitable to be utilized in the same room as the old boiler and it accepts external modulation signals which will be paired with a wireless control system. The specifications sheet for the LAARS NeoTherm boiler selected can be found in Appendix C of this report.

The next step of design was to select the individual comfort zones that would be addressed throughout the Athenaeum as well as the control systems associated with each zone. Six heating control zones were implemented for a more comfort oriented design. The zone layout is depicted in Figure D.1 which can be found in Appendix D of this report. The zones were designed to utilize the current baseboard chaseways that at the moment house the 7" cast iron pipe from the old boiler system so as to maintain the current historical aesthetics of the building. Each zone will include a Honeywell Wireless Thermostat which will communicate with a TACO ZVC-404 6 zone valve controller. The TACO zone valve controller will then signal to TACO Zone Sentry zone valves located before the pumps in each zone loop, when a zone requires a heating load the valves will open allowing hot water to flow throughout said zone. The specifications sheets for each of these components can be found in Appendix E of this report.

The baseboard heating was next to be selected and sized for each zone. After looking into leading manufacturers in baseboard heating out team choose Slant/Fin Bare Elements fin and tube C-440 as the best choice for the system. The specifications sheet for the Slant/Fin C-440 can be found in Appendix F of this report. To then find the equivalent length of baseboard heating for each zone a supply temperature from the boiler had to be selected which for our system was 180°F. This supply temperature was used in conjunction with the specifications sheet for the Slant/Fin C-440 to determine that the baseboard hot water rating would output 1166 Btu/hr per foot length. Using the equation located directly below the total equivalent length of Slant/Fin baseboard was calculated for each zone.

**Eq. 7**

$$Ft\ of\ SlantFin = \frac{Needed\ Heating\ Load\ [\frac{Btu}{hr}]}{1166\ [\frac{Btu}{hr}]/ft}$$

The values for each zone can be found in the table included in Appendix G of this report. Once the length of baseboard heating for each zone was calculated the layout of the piping system could be designed. The piping system runs from the boiler through the causeways housing the 7" cast iron pipe of the current heating system to the baseboard heating in each zone, and then flows back to a single return pipe to the boiler. The schematics for the baseboard heating and piping can be depicted in Appendix H of this report.

Once the piping and baseboard heating schematics were set the pumps for each zone loop were sized to overcome frictional losses through the pipe while meeting the minimum return temperature of 150°F. The first step in sizing the pumps was to solve for the flow rate in GPM of each zone, this was done by solving the two simultaneous equations located directly below.

**Eq. 8**

$$T_{return} = T_{supply} - \frac{Zone\ Btu/hr}{500 \times Flow\ Rate[GPM]}$$
$$Flow\ Rate = 2.45 \times Velocity[fps] \times (Pipe\ Diameter)^2$$

The only variable that could be changed for the system was the velocity of the water through the pipe as the pipe diameter is set at 1" by the physical characteristics of the baseboard fin and tube. The velocities were modified until each loop had a return temperature greater than 150°F, the minimum velocity was set at 3fps as the Slant/Fin baseboard heaters were specified to that velocity. These calculations were performed and can be seen in the table located in Appendix G of this report. Now that set flow rates are established the pressure drop due to friction for each loop could be calculated. Next each loop was broken down into pipe runs to simplify the calculations. Each pipe run length was quantified and pipe fittings associated with the run was counted. Then using Table (3.15) located in Appendix I of this report the equivalent length of the fittings were calculated and added to the run length to find the total frictional run length. Using the flow rate calculated prior for the loop a pipe size for each run was selected to meet acceptable velocity range of 3-8fps using the equation located directly below.

**Eq. 9**

$$Velocity = \frac{Flow\ rate\ [GPM]}{2.45 \times (Pipe\ diameter)^2}$$

Using Figure (3.34) located in Appendix I of this report the pressure drop [psi] per 100 ft of pipe was calculated. By multiplying the total frictional run length by the pressure drop per 100ft the total pressure drop in psi was calculated for each run and summed together to produce the overall pressure drop of the entire loop in Head Ft. The equation used can be found directly below.

**Eq. 10**

$$Pres\ Drop\ [Head\ Ft] = \left(\sum (Length\ Ft \times \frac{Pressure\ Drop}{100\ Ft}\right) \times 2.3$$

All calculations were performed and can be seen in the tables located in Appendix J of this report. For our system our team decided to use TACO inline circulation pumps for each loop. The pumps were sized using the TACO-HVAC Pump Selection App located on TACO's website by inputting the flow rate [GPM] and pressure drop [Head Ft] for each loop. The TACO App would give a list of recommended pumps that meet the requirements of the loop, and then using the pump performance curves the pump best fitting our needs was selected. All TACO pump specifications as well as corresponding pump performance curves can be found in Appendix K of this report.

Now that the piping diagrams are laid out and pipe sizes have been chosen the expansion tank could be selected based upon the overall volume of the system. The total length of each pipe size used throughout the system was calculated. Then using the equation for volume of a pipe located directly below the volume of water was calculated for each pipe size and added together to find the overall volume of the system which was converted into Gallons of water.

**Eq. 11**

$$Volume = \pi(\frac{Pipe\ Diameter}{2})^2 \times Pipe\ Length$$

These calculations were performed in the Table 1 located directly below.

**Table 1. Expansion Tank Sizing**

| Expansion Tank Sizing | | | | | |
|---|---|---|---|---|---|
| Pipe Size [in] | Pipe Size [ft] | Total Length [ft] | Volume [ft^3] | Volume [m^3] | Gallons |
| 0.75 | 0.0625 | 158 | 0.485 | 0.014 | 3.626 |
| 1 | 0.083333333 | 678.9 | 3.703 | 0.105 | 27.699 |
| 1.25 | 0.104166667 | 99 | 0.844 | 0.024 | 6.311 |
| 1.5 | 0.125 | 12 | 0.147 | 0.004 | 1.102 |
| 2 | 0.166666667 | 8 | 0.175 | 0.005 | 1.306 |
| Total | | | | | 40.04 |

Our team decided on recommending an AMTROL Hydronic Expansion Tank after researching different brands. Using AMTROL's sizing apparatus inputting the total volume of our system, the minimum operating temperature, maximum operating temperature and pressure range the AMTROL AX-20V expansion tank was chosen to best fit the needs of our system. The specification sheet for the AMTROL AX-20V can be found in Appendix L of this report.

The last step in designing the system was to draw the schematics for the boiler system. A meeting was held with William McCarthy the Manager of Mechanical and Electrical Systems for Roger Williams University to consult on the designing of the boiler system schematics. He took it upon himself to educate us on standard procedures and provided examples of similar system schematics. After the meeting, using Revit the schematic for our personalized system was created and can be found in Appendix M of this report.

Once the system design was completed a cost analysis of the system was performed. A list of all components in the system and the quantity of each was constructed. Using an "RSMeans Building Construction Cost Data 2012 Ed" book the labor cost and hours for demolition of the old system as well as installation of the new system was calculated. By adding the total labor costs as well as component cost a complete estimate was created for the implementation of the new system. The estimation table for the new heating system can be found in Appendix N of this report. In conclusion the proposed new heating system implementation is estimated to cost approximately $85,000.

## Cooling and ventilation system

***Windows and Determination of maximum cooling load:***
The determination of the maximum cooling load was the big factor in determining the appropriate equipment for the Athenaeum. The cooling load included both the sensible cooling load and the latent load. The factors that have an effect on the sensible cooling load are:

- Doors
- Exterior Walls
- Rooftop
- Skylights
- Solar Gains on External Surfaces
- Lighting gains
- Heat Gains from Occupants

The factors that affect the latent cooling load are the factors that introduce moisture to the building such as:

- People
- Infiltration
- Forced Air

Utilizing a modified Building Energy model the maximum cooling load was determined for the Providence Athenaeum. The modified building energy model is available via the digital appendix. The modified building energy model is similar to what was presented in the fall of 2013, however this time cooling load was determined rather than heating. The factors that went into this building model consist of everything discussed in this section.

The total cooling load is a sum of the energy required to maintain a temperature of 75 degrees Fahrenheit within the building. This includes occupancy heat generation, light energy, solar energy, ventilation, infiltration, and external heat gains through the buildings shell. A few assumptions had to be made in order to create a building model, most of which were referred from ASHRAE guidelines.

The max occupancy of 294 people was modeled with an average energy generation rate of 118 watts/person. The reference data for the conditions in Providence was Typical Mean Year – 2 data. The systems goal temperature or the internal temperature of the building was modeled to be 75°F with an indoor humidity of 55%; well within the ASHRAE standards. Calculations were then made for the total heat transfer of each factor in order to determine the total maximum cooling load. He required ventilation was calculated for the square footage standard and the occupancy standard. The occupancy standard dictated a higher requirement of 1500 cfm; so this is the design ventilation rate. For the determination of the peak-cooling load see Appendix O.

**Eq. 12**

$$Q_{max} = Q_{granite} + Q_{concrete} + Q_{doors} + Q_{glass} + Q_{solar} + Q_{gen} + Q_{vent/Inf}$$

These Q values were determined for every hour in our typical mean year data for our model and the maximum value for Qmax was 79 kW. About 51 kW of this comes from exterior temperature difference and solar gains through the exterior surfaces. The other 28 kW comes from latent heat sources; the OA ventilation, infiltration and occupancy heat gains. This translates to a total of 22.5 tons of cooling required for the building, or about 427 square feet per ton. With a portion of the building already being cooled by the Leibert unit, the cooling load attributed to these spaces was not included for the rest of the design. Due to The physical location and low ceilings of the offices and the children's room it is recommended that these areas retain their current means of cooling. This leaves us with a system tasked with maintaining a total cooling load of around 12 tons for the main floor, mezzanine and ground floor levels.

***Components:***

The decision to determine which type of system should be recommend to meet this cooling load was based on an examination of the available systems. There are many options for systems that could serve this purpose including:

- Split Systems
- Packaged-System
- Radiant Cooling

The factors that went into the final decision to utilize radiant cooling in the form of chilled beams in parallel with a dedicated outdoor air system (DOAS) are.

Early in the process, after the cooling load had been determined Justin Taylor had a meeting with William McCarthy who is the mechanical, electrical, and plumbing supervisor at RWU. In this meeting many different types of systems were discussed along with the advantageous and disadvantageous of each. One of the big advantages to using chilled beams comes in the form of sound reduction; due to having to transport less air then typical systems to achieve the same cooling load ducts can discharge at lower velocities. The factors that went into the final decision to recommend radiant cooling in the form of chilled beams in parallel with a dedicated outdoor air system (DOAS)include: lower noise levels, less alteration to the building, and those discussed below.

There are a total of sixteen advantages to the use of chilled beams discussed in the ASHRAE 2000 Handbook; [i]the ones relevant to our renovation are presented as follows:

- "Comfort levels can be better than those of other conditioning systems because radiant loads are treated directly and air motion in the space is at normal ventilation levels."
- "Supply air quantities usually do not exceed those required for ventilation and dehumidification processes"
- "A 100% Dedicated Outdoor Air System can be installed with smaller penalties, in terms of the refrigeration load due to the reduced outdoor air quantities being used. "
- "The compact design is an advantage for either retrofit design or new construction."
- "Quick accommodation of dynamics, since the panels have a time constant of about three minutes"
- "LEED Green Building rating Std., the radiant/DOAS mechanical system has the potential to generate rating points in five of the major categories: Water efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, and LEED Innovation Credits. The radiant/DOAS approach has the potential to generate up to 24 Green

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[i] ASHRAE. 2000. 2000 ASHRAE Handbook—HVAC Systems and Equipment. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc

Building Rating points, or up to 88% of the minimum points needed for certification."

Eight active beams are to be placed in the main room of the Athenaeum to meet the areas cooling needs. These beams are made by TROX and are 10ft DID-602-US Active Chilled beams. For technical data on this beam see Appendix P, for further information and the full specification pdf see the digital appendix. An equivalent beam could also be used with a similar capacity of 787 BTUH/LF. They will be placed perpendicular to the exterior walls in order to promote the best circulation of air. Their water supplies will be in parallel to ensure maximum cooling and will land in the indicated locations in figure 1.

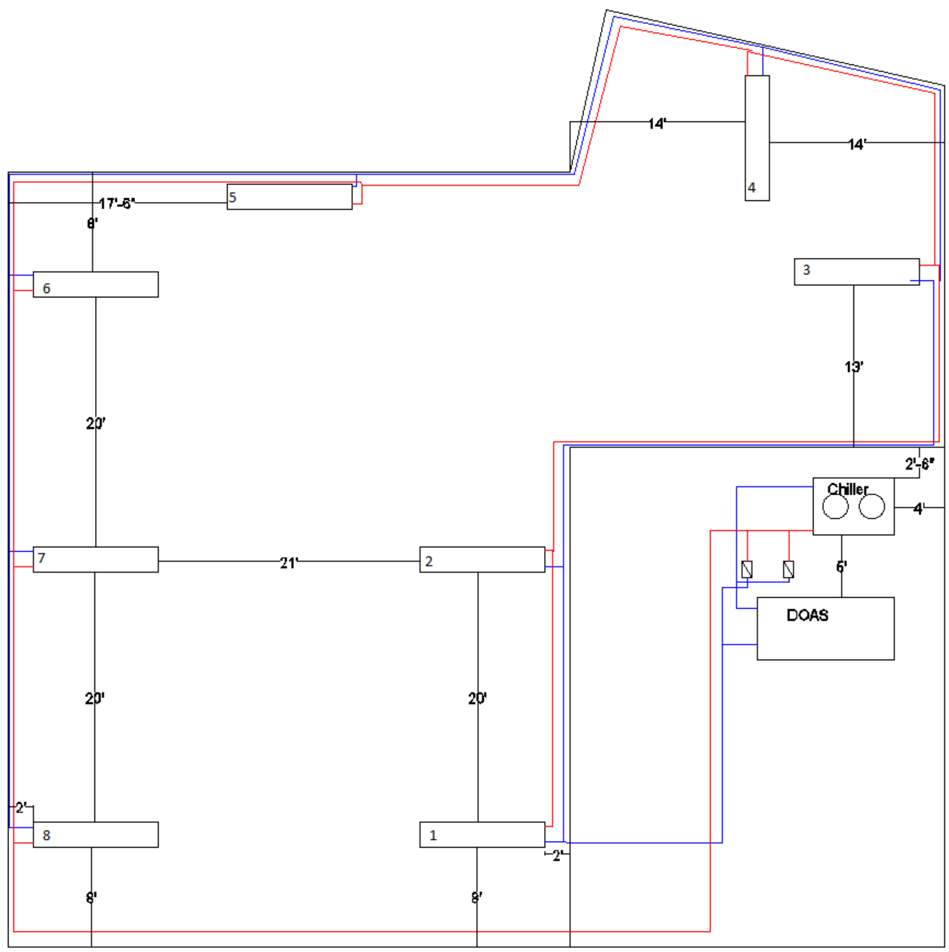


**Figure 1. Location of Chilled beams in Reference to existing surfaces.**

Each chilled beam will require the components as seen in figure 2 below: a circuit setter valve on the chilled water supply side, also known as a balancing valve, a ball valve on both the supply and return side to isolate the unit, and a strainer on the supply side.

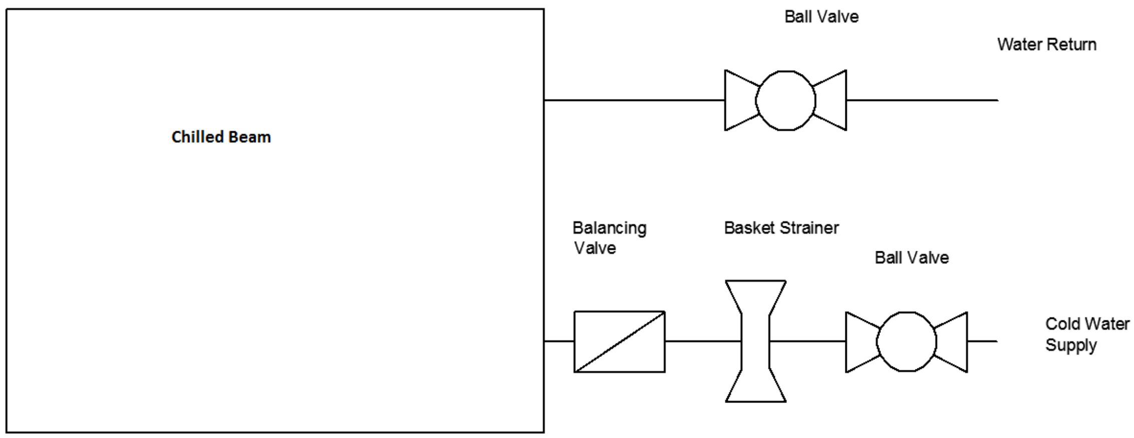


**Figure 2. A close up schematic of the components required for each beam.**

The ball valves will enable the isolation of this component in case repairs need to be made. This isolation will mean the system will not have to be drained and could continue operating throughout the rest of the beams. The strainer will stop anything that may be in the water supply that could get stuck in the beams; it is better to replace a clogged strainer then an entire clogged beam. The balancing valve will be set at instillation to limit the flow to each beam to 1.5 GPM, which is the upper limit on these beams.

The beams will be piped in parallel to one another as displayed in the design schematic above in figure 1. The important thing here is the concept of first fed, last return; which means the first beam to receive the chilled water supply will be the last beam to return its supply. Arranging the flow in this manner will help to ensure that the flow is properly balanced within the system.

These beams are not alone in handling the cooling load of the building. These beams will take in fresh air at 53°F from a dedicated outdoor air system as well as recirculate a percentage of the room’s air. The DOAS unit - a Water coil 4-row RD2XIN by Renew-Aire - will be placed in the attic space where return air will be ducted from the main room, and fresh air will be ducted from the roof. This unit is capable of providing the amount of ventilation required by ASHRAE standards as well as treating the latent load. This DOAS unit is also fairly significant in its energy recovery performance in both the summer and winter as displayed below in figure 3.

## ENERGY RECOVERY PERFORMANCE

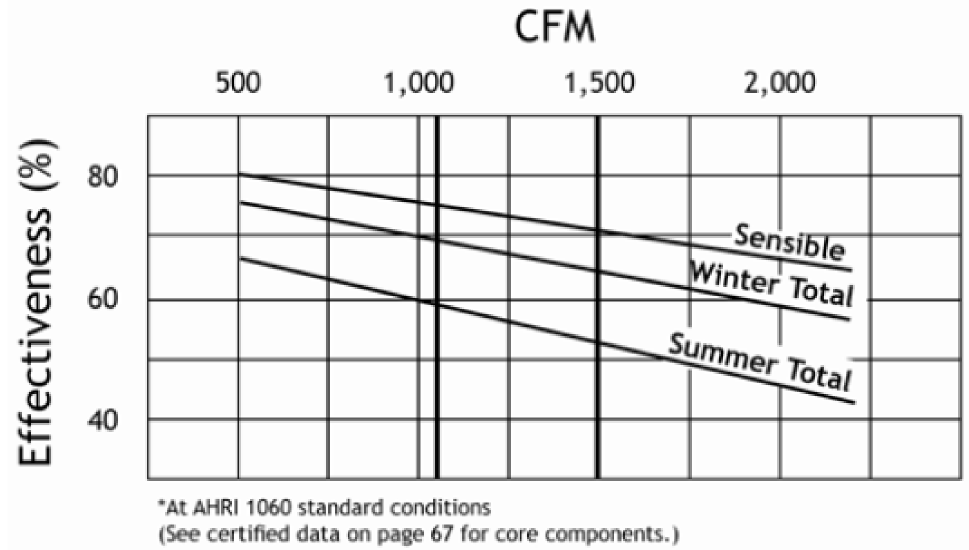


**FIGURE 2-6**
**ENERGY RECOVERY EFFECTIVENESS**

**Figure 3. Operating at 1500 CFM This system should recover about 52% of the energy that would otherwise be lost to exhausted air.**

This system will maintain the humidity by treating the latent load to ensure there is no condensation on the chilled beams. The natural rise and fall of hot and cold air respectfully maintain a constant cycle of circulation.

Cold water will supply the system from a 10S-M1-1P Central Liquid Chiller with a built in 2 HP pump capable of providing 24 GPM at 48 PSI as seen in Appendix P O. The DOAS system will receive the chilled water first at 45°F at a rate of 18.5 GPM through a 1 ¼" pipe from the chiller with a 1 ¼"→1 ½" adapter before entering the DOAS. In order to ensure the proper flow rate to the DOAS unit a bypass will be placed before the DOAS unit to the return water supply. This bypass will be fitted with a balancing valve which will be set at instillation to ensure the appropriate flow rate.

This system will take on 83 MBTUh of the cooling load as seen in Appendix P. The water will exit the DOAS system at roughly 57°F which should be well above the design DPT of 55°F. Due to the eight active beams having a maximum flow rate of 1.5 GPM each or 12 GPM when all are placed in parallel 6.5 GPM of the flow leaving the DOAS system will bypass the beams and return to the chiller via a bypass to the return water side. This bypass will be fit with a balancing valve to be balanced at instillation to ensure the design flow is met. There will be a second bypass here that will be controlled on the return end with a three way modulating valve. This modulating valve will act as the main control for the chilled beams. In its normally open position the circuit will be complete and operate as intended, when it receives a signal from the thermostat control device it will close the loop, bypassing the beams entirely.

This water supply will be carried down a main 1 -1/2” line from the DOAS unit around the perimeter of the building as seen in figure 4.

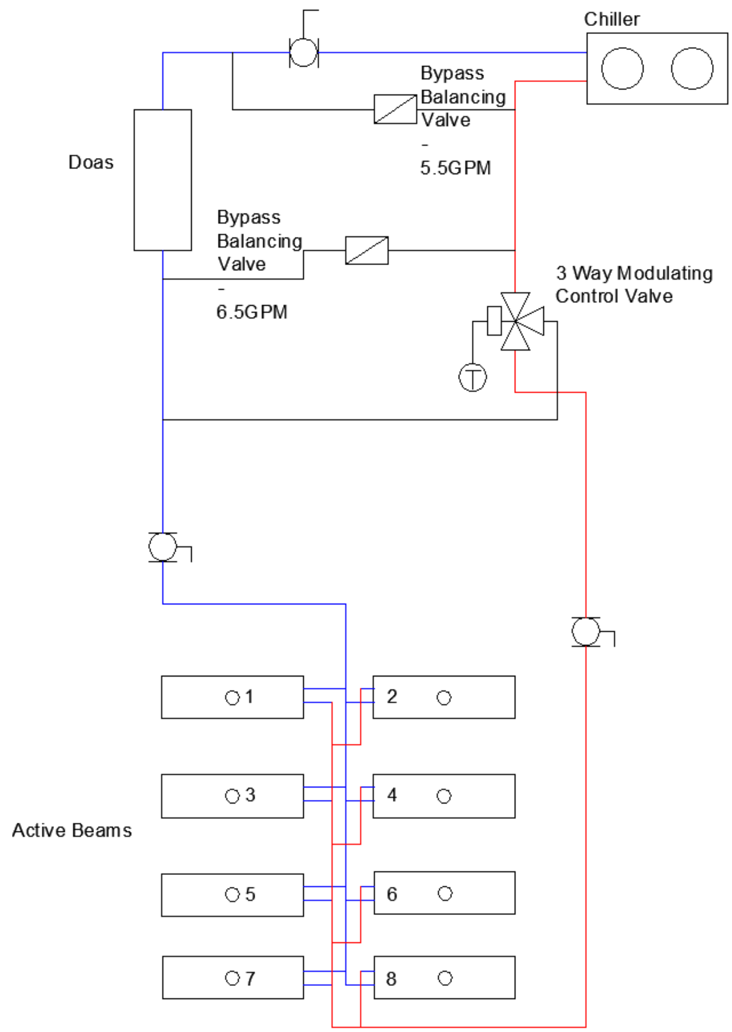


**Figure 4. Proposed system schematic.**

Where each beam meets this perimeter pipe there will be 1ft sections of ½” pipe fitted. Within this one foot section of ½” pipe there will be the strainer, ball valve, and balancing valve on the supply side and a ball valve on the return pipe for isolation. All supply piping must be insulated; return piping does not require insulation but it is recommended for areas where the design dew point temperature may be exceeded i.e. the attic. From the beam to the 1’x1/2” copper pipes there will be 2’ rubber hoses for quick connecting and easy instillation. The

12 GPM flow rate of water through the chilled beams at 57°F +- 1°F will provide the remaining 61 MBTUh of cooling that the building requires.

The cold air that is being supplied by the DOAS system will exit the unit via a 16”x16” sheet metal duct. This duct will enter the building through the attic and service beams 1 and 2 first. After serving beams 1 and 2 in order to maintain static pressure the duct size will be reduced to 16”x12”. The calculations for reducing duct size were done using a Ductulator and the velocities within each section are included Appendix O. The supply duct will continue along the perimeter, following the water supply path to service beams 3 and 4. After beam 4 the duct size will again be reduced, this time to 12x12”, and will reduce one final time after beams 5 and 6. This final reduction will be to the size of 12”x8”. These duct sizes should ensure a constant static pressure throughout the system and the proper distribution of air to the beams. The air velocity and flow rate of each section are included in table 2.

**Table 1. Air velocity flow rate for given duct size**

| Duct Size | CFM | FPM |
|---|---|---|
| 16"x16" | 1500 | 844 |
| 16"x12" | 1140 | 855 |
| 12"x12" | 780 | 780 |
| 12"x8" | 420 | 630 |

Where the beams meet the main air supply a T connection will be made to connect to the 5” beam supply circular duct. Within this branch off the main supply a balancer will be installed to ensure design flow. The supply ducts will also be insulated to ensure that the air arrives at the beams at design temperatures.

The return air will be taken from a centralized source by penetrating through the attic. This return air source will be ducted through a 14x24 sheet metal duct that will connect to the return air side of the DOAS unit. The fan power for both supply and return are provided in the DOAS unit, this along with the direction of flow can be seen in figure 5.

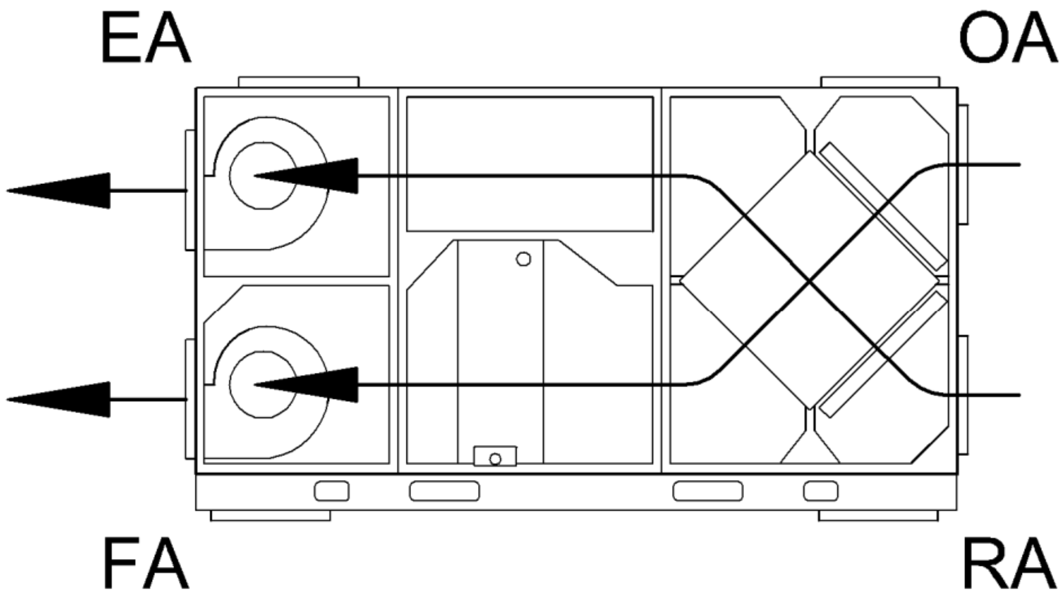


**Figure 5. Installed configuration of the DOAS unit. FA = Fresh Air from Unit; RA = Return Air; OA = Outside Air; EA = exhaust air.**

As displayed above in figure 5, the flow of the return air treats the fresh air via a heat exchanger in order to increase efficiency. In the event that the design humidity threshold has been breached due to a period of excessive infiltration the three way modulating valve will receive a signal from humidity activated sensor that will shut off the supply of water to the beams should condensation be of concern. The supply of air from the DOAS will not be interrupted and will work to treat the latent load to the point in which the beams can be reactivated. The flow of return and supply air from the DOAS unit is included below in figure 6.

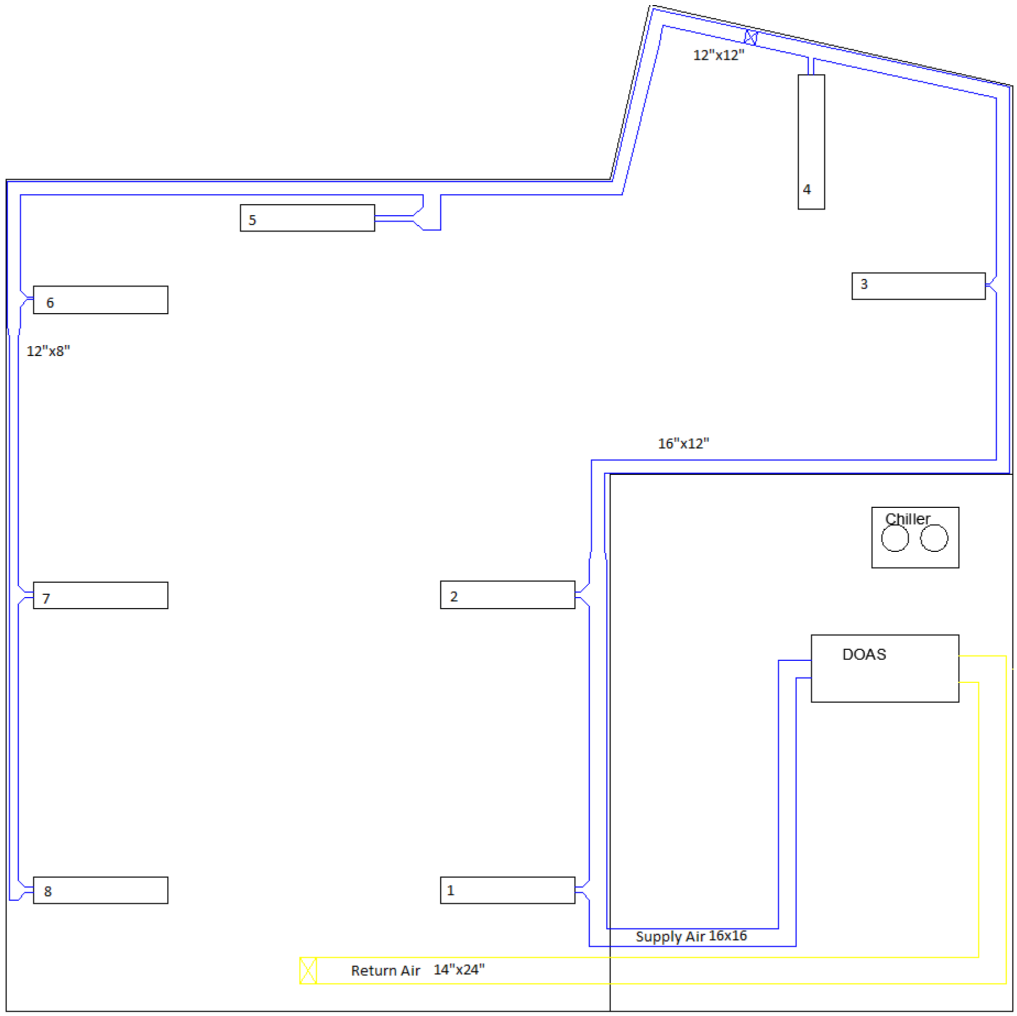

**Figure 6. Proposed air duct size and location relative to the existing structure.**

There are many benefits to the instillation of chilled beams in comparison to other systems. The simplest and most compelling argument is for the additional cooling power of water; a small diameter water pipe is capable of the same cooling capacity as a larger air duct.

Further benefits from this type of system come in the form of reduced energy costs. A smaller air supply is required for chilled beams compared to a conventional ducted system, which leads to a decrease in energy consumption.[ii] Energy consumption is also decreased due to the operational efficiency of pumps being greater than fans. It is estimated by the chilled beam manufacturer Trox USA that the average 20 year life cycle maintenance cost of one active chilled beam is roughly $150 in comparison to $2,800 over 20 years for a fan coil unit.

[ii] Trox USA – Chilled Beam Design Guide

***Control:***
To control the system the installation of a central thermostat device is recommended. This device should be capable of transmitting the necessary data to the DOAS unit, water chiller, and the three way modulating valve.
The DOAS unit has several modes of operation, the on board controllers will determine the current mode of operation. It also has the availability of external control in the form of a digital time clock relay. This can be set to operate in accordance with the building occupancy schedule.
The recommended water chiller uses an M1 controller as seen in its specification sheet in Appendix P. This controller offers the ability to adjust the water supply temperature, as well as turn the unit on and off.
A relative humidity sensor is recommended for control of the three way modulating valve. The sensor should send a signal to the valve to close when the humidity exceeds 60%. This will prevent condensation on the chilled beams.

***Cost:***
The cost of this system is broken down in the tables seen in Appendix Q by material costs and the cost of installation. The total initial cost of this system will be about $90,000. In order for the instillation to take place the Athenaeum will need to be closed, as such it is recommended that this be done at the same time as the proposed heating system. Book collections and other items along the perimeter of the building should be relocated to ensure their safety during the instillation.

## Photovoltaic Array Implementation

As a way to offset the new power consumption that will accompany the new heating and cooling systems photovoltaic panels were investigated for installation. The Athenaeum roof has a flat area that faces south with open clearance to sunlight large enough to house a medium sized photovoltaic array.

The first step in the design process was to select a solar panel to model the system. After researching different brands and model types of solar panels our team recommends the SUNPOWER X21-345 commercial solar panel with a Sunny Boy AC converter. SUNPOWER X-Series solar panels are leading the industry in efficiency and reliability; the initial system costs are slightly higher than other brands but make up for it with life span and power production. The specifications sheet for the SUNPOWER X21-345 can be found in Appendix R of this report.

Once the systems panel had been selected the Revit model given to us of the Athenaeum, a series of different sized arrays were created to maximize power output in the space available on the roof that had access to direct sunlight. The diagram of the largest allowable panel array, which consists of 20 photovoltaic panels can be found in Appendix S of this report. The next step for the design of the system was to calculate the overall power the different sized arrays would produce per day in Kilowatts. After looking up the average sun hours per day for the northeast region of the country which is 4 hrs/day and using an energy efficiency constant applying to the solar panel of 80% which accounts for heat losses and energy leakage, the total power output per day was calculated using the equation located directly below.

**Eq. 13**

$$\frac{Power[kW]}{day} = \frac{(\#\ Panels)(\frac{Power}{hr}[W])(4\ Sun\frac{hrs}{day})(0.8)}{1000}$$

Then using the average energy usage of the Athenaeum as it currently stands along with the average energy bill associated with said usage given to use by the Athenaeum the average current cost per kW was calculated. This cost per kW was then multiplied by the power produced by the photovoltaic system over a standard month to give a cost savings result produced by the panel array. By researching similar systems in the region and contacting US SolarWorks which is the closest installer of SUNPOWER solar systems we received an estimate of $40,000 installation and material cost for the entire system with a routine maintenance cost of $300-$400 per year. Using these initial costs a return on investment was calculated using the equation located directly below, where solving for months gives the time to pay off the system purely from savings.

**Eq. 14**

$$Installation\ Cost = \left(\frac{Savings}{month} - \frac{Maintenance\ Cost}{12}\right) \times Months$$

All calculations were performed and can be found in the table located in Appendix T of this report. The photovoltaic system that our team is proposing should the Athenaeum go forward with solar power is a 20 panel grid tied photovoltaic array with a Sunny boy converter that is estimated to cost $40,000 as an initial cost with a return on investment of 35 years.

## Energy conservation

The following section provides an overview of the areas of energy loss throughout the Athenaeum and recommendations to conserve energy. The conservation of energy recommendations will reduce heating bills and provide real savings for little expense. This section covers the identification of areas of energy loss, recommendations to conserve energy and an estimate of cost for the renovations.

After the initial tour of the Providence Athenaeum, the Historical Value Adding Consultants predicted that energy is lost through the skylights and windows of the building. The team used a FLIR infrared camera to identify numerous areas for energy conservation actions that are readily addressable and which can provide near term savings. The thermal imaging revealed that the majority of the heat loss occurs through the skylights of the Athenaeum. The images recorded with the FLIR infrared camera are located in Appendix U of this report.

During the thermal imaging, the recorded temperature for Providence Rhode Island was 23º F. The images in Appendix U indicate that heat is lost through the front door, windows, and skylights. The heat loss from the front door occurs around the doorframe and glass. The window frames are another area of heat loss and there is a great amount of heat loss through the roof, specifically around the base of the skylights. Such things as installing insulation in open attic space, re-glazing windows and weather-stripping of doors and window frames will provide real savings for little expense. Conserving energy will reduce the electric bill and allow for easier temperature control of the building.

As previously mentioned, the roof is a major source of heat loss at the Athenaeum. The Department of Energy estimates that a properly insulated attic can reduce the heating cost by 10 to 50 percent. [iii] Adding insulation in the attic will also stabilize the buildings indoor temperature during the summer. The attic floor is currently insulated with cellulose insulation. The cellulose insulation is unevenly placed and shows signs of water absorption. The insulation containing moisture is assumed to cause degradation of structural materials. To ensure the structural integrity of the building and the conservation of energy, the team has proposed the removal of all blown-in (cellulose) insulation and any batt insulation and install new fiberglass batt insulation (R30) in attic floor and vertical areas including a vapor barrier.

The copper clad skylights are estimated to be over 100 years old and are no longer functional. As seen in figure 6, a substantial amount of heat loss occurs at the base of the skylights.

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[iii] Goodman, Mickey. "Read This Before You Insulate Your Attic." This Old House. This Old House Magazine, 5 Dec. 2012. Web. 16 Apr. 2014.

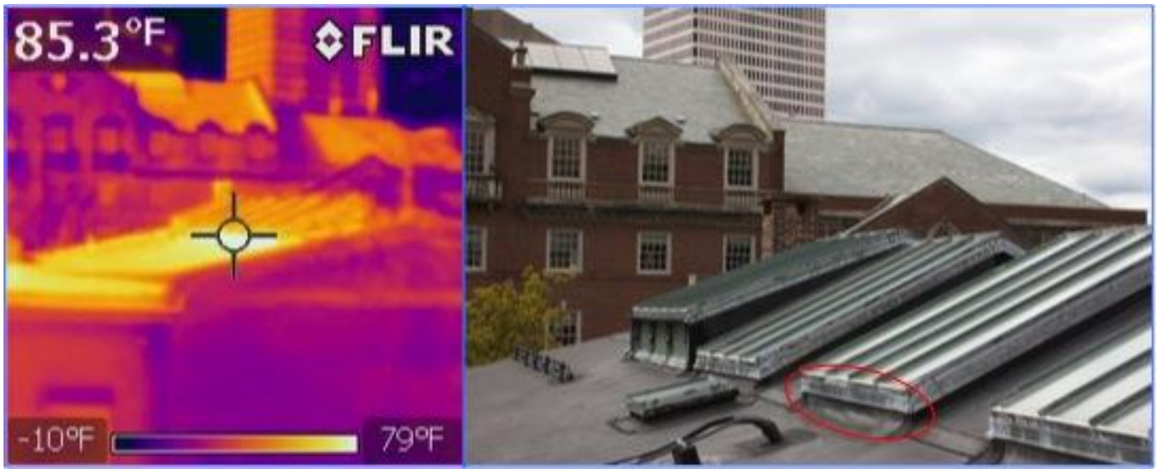


**Figure 7. Thermal imaging at the base of the skylight taken from the east side of the Athenaeum.**

To properly reduce heat loss and solar gain from the skylights, a skylight shaft would be utilized but the skylights on the ceiling of the main floor restrict this application. In order to maintain the transmission of light through the attic and conserve energy, the team has recommended the installation of fiberglass batt insulation, rigid foam insulation, and a vapor barrier in the open attic space. To further improve the skylights, the team recommends replacing the skylight glass with double glazed tempered glass. This is an insulating glass that will reduce the amount of heat transfer from the skylights.

Thermal imaging also revealed heat loss through the windows of the Athenaeum. The heat loss through the windows is not as great as the loss through the skylights but these areas are readily addressable and can provide near term savings by installing weather stripping. The front and rear doors of the Athenaeum also contribute to heat loss. As seen in figure 7, heat is lost around the doorframe and glass.

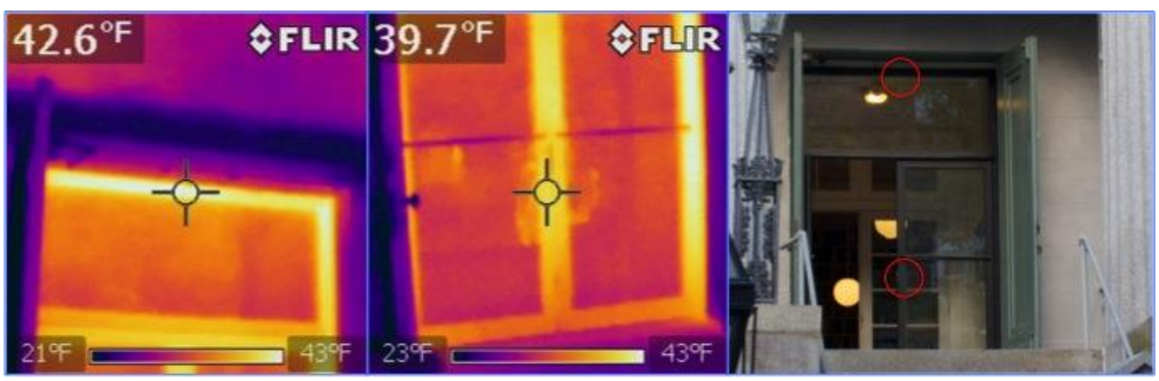


**Figure 8: Thermal imaging of the front door of the Athenaeum.**

Installing high-density rubber foam weather stripping and door sweeps can reduce the heat loss through the doors of the Athenaeum. Insulating foam sealant can be used around windows and doors to create an airtight seal and increase the conservation of energy.

The following table presents the total cost estimate for the conservation of energy methods. The cost of installation and materials was estimated using *RS Means Building Construction Cost Data.*[iv] This book contains established material prices based on a national average and computed labor costs based on a 30 city national average of union wage rates.

**Table 2. Conservation of energy cost estimate**

| Item | Qty | Total Amount |
|---|---|---|
| *9-1/2" thick R30 Batt insulation* | 6041 sf | $8,276.17 |
| *Polyethylene vapor barrier .002" thick* | 4905 sf | $532.19 |
| *Polystyrene 1" thick R4 foam board insulation* | 2016 sf | $1,612.80 |
| *Threashold weatherstripping door sweep* | 5 units | $145.50 |
| *Insulating glass reduce heat transfer 1" thick 1/4" float, 1/4" tempered (skylights)* | 800 sf | $22,400.00 |
| *window weatherstripping* | 739.5 sf | $3,056.60 |
| *Insulation removal* | | $3,382.96 |
| | Grand Total | $39,406.22 |

[iv] Waier, Phillip R. *RSMeans Building Construction Cost Data 2012*. Norwell, MA: RSMeans, 2011. Print. 70th Anniversary.

## IV. Conclusion

The Providence Athenaeum is one of the oldest buildings in Providence, Rhode Island. The independent member-supported library offers the public access to its rare books collection as well as sponsoring community-oriented programs. However, the facility's HVAC systems are aged. A team of Roger Williams University engineering students was asked to accomplish the following tasks.

- Conduct an assessment of existing conditions of the Athenaeum's HVAC and related systems.
- Develop a conceptual preliminary HVAC design that meets the operation requirements of the facility as specified by the owner.
- Identify and investigate opportunities to incorporate more modern energy generating technologies into the facility.
- Provide the client with a general overall report and recommendations for moving forward.

After conducting the assessment of the existing conditions of the Providence Athenaeum, financial data was analyzed to determine the energy usage of the building. A building energy model was created to evaluate the cost and efficiency of the new boiler system. The proposed renovation to the system includes the removal of the current system and its replacement with a modern heating system that includes a single 375,000 Btu/hr high efficiency boiler and a slant fin radiator system. Chilled beams in parallel with a Dedicated Outdoor Air System will provide the cooling and ventilation for the Athenaeum. To offset energy costs, team HVAC has proposed the installation of photovoltaic panels on the roof of the Athenaeum. The team identified numerous areas that are readily addressable for energy conservation improvements such as replacing insulation in the attic and installing weather stripping around doorframes. This report can be used to develop a consensus for improvement of the facility.

## Appendix A

**Table A. 1. Roof load analysis equations**

| Equation Number | Equation |
|---|---|
| 1 | $1.2D + 1.6S + 0.8W$ |
| 2 | $\frac{WuL^2}{8}$ |
| 3 | $FB' = 2050C_f k_f$ |
| 4 | $C_f = (\frac{12}{d})^{\frac{1}{9}}$ |
| 5 | $S = \frac{1}{6}wh^2$ |
| 6 | $1536Wu = 410207.26$ |

**Table A. 2. Roof load calculations**

| Providence Athenaeum Roof Loads | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| Effetive Area | 341 ft^2 | | | | | |
| Load Combination | 1.2D+1.6S+0.8W | | | | | |
| | D= dead load | 15 | These 3 numbers came from the Principles of Structural Design text book | | | |
| | S= snow load | 25 | | | | |
| | W= wind load | 8 | | | | |
| | | | | | | |
| Load Combination | 64.4 psf | | This is what the roof is currently holding | | | |
| | | | | | | |
| (WuL^2)/8 | 1536 psi | | | | | |
| | | | | | | |
| Reference Design | Fb'= 2050Cfkf | | | | | |
| | Cf= (12/13.75)^(1/9) | 0.98 | | | | |
| | kf= 2.16 | | | | | |
| | | | | | | |
| Fb'= | 4339.44 psi | | | | | |
| | | | | | | |
| S= | (1/6)*width*height | | The beam is 3" by 13.75" | | | |
| | 94.53 in^2 | | | | | |
| | | | | | | |
| Bending Moment | ϕMn=Fb'S | | | | | |
| | 410207.3 psi | | | | | |
| | | | | | | |
| Tributary Area | 3 ft^2/ft | | | | | |
| | | | | | | |
| Mu=ϕMn | 1536Wu=410207.26 | | | | | |
| | 267.06 psi | | | | | |
| | | | | | | |
| Design Load | 89.02 psf | | This is the max before failure | | | |

# Appendix B

**Table B. 1. Heat load calculations**

| Heat Load Calculation | | | |
|---|---|---|---|
| Level | Room | Sq Ft | Btu/hr |
| Lower Floor | | | |
| | Reading Room | 1470 | 44100 |
| | Staff Room | 647 | 19410 |
| Main Level | | | |
| | Vestibule/Main Room/Stacks | 3416 | 102480 |
| | Directors Office | 216 | 6480 |
| | Second Office | 216 | 6480 |
| | Platner Wing | 400 | 12000 |
| | Isham Wing | 504 | 15120 |
| Upstairs | | | |
| | Stacks | 2402 | 72060 |
| Total before Pickup | | | 278130 |
| Total Heat Load | | | 319850 |

## Appendix C

**LAARS NeoTherm Boiler Spec sheet**

# Appendix D

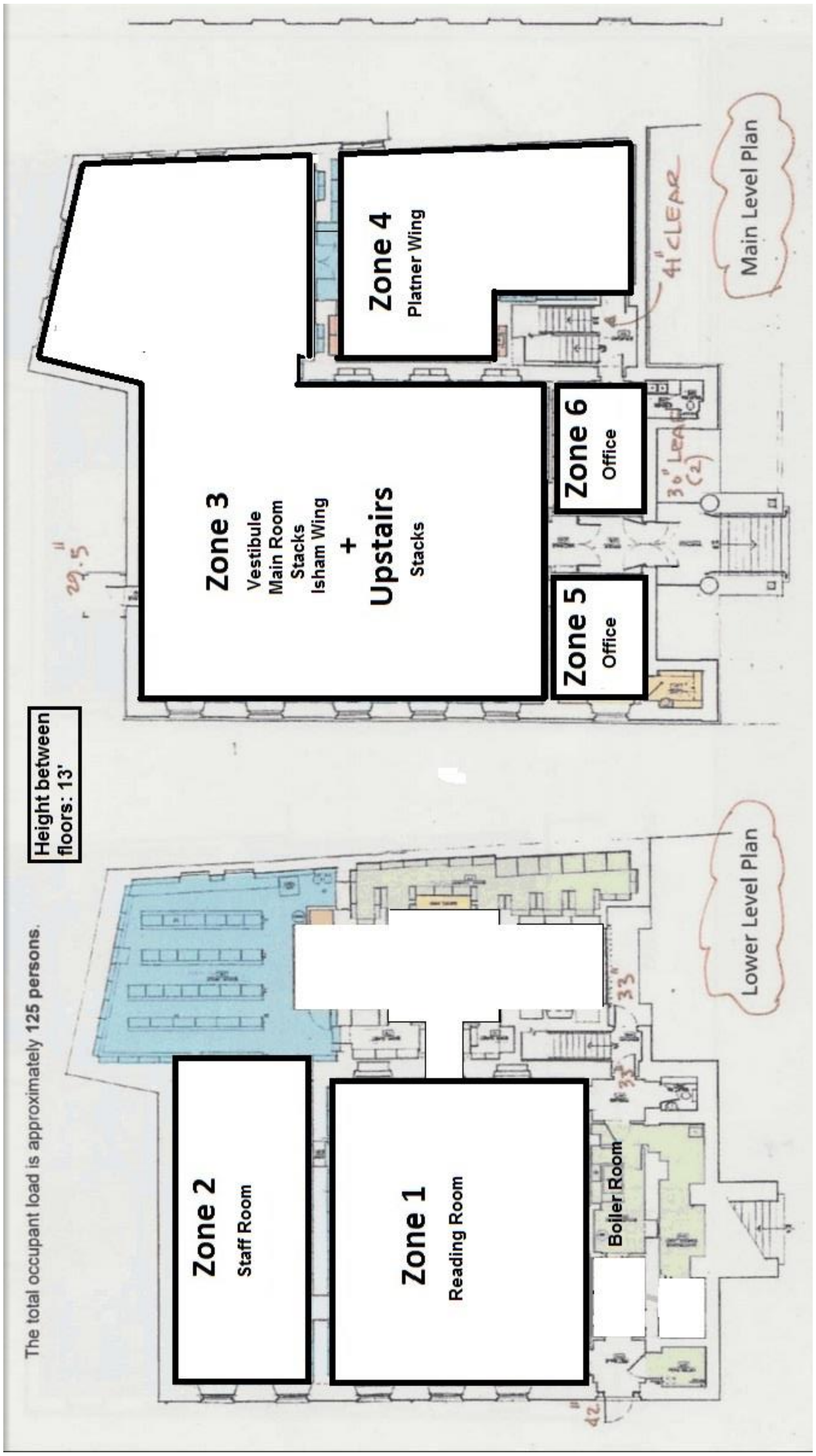
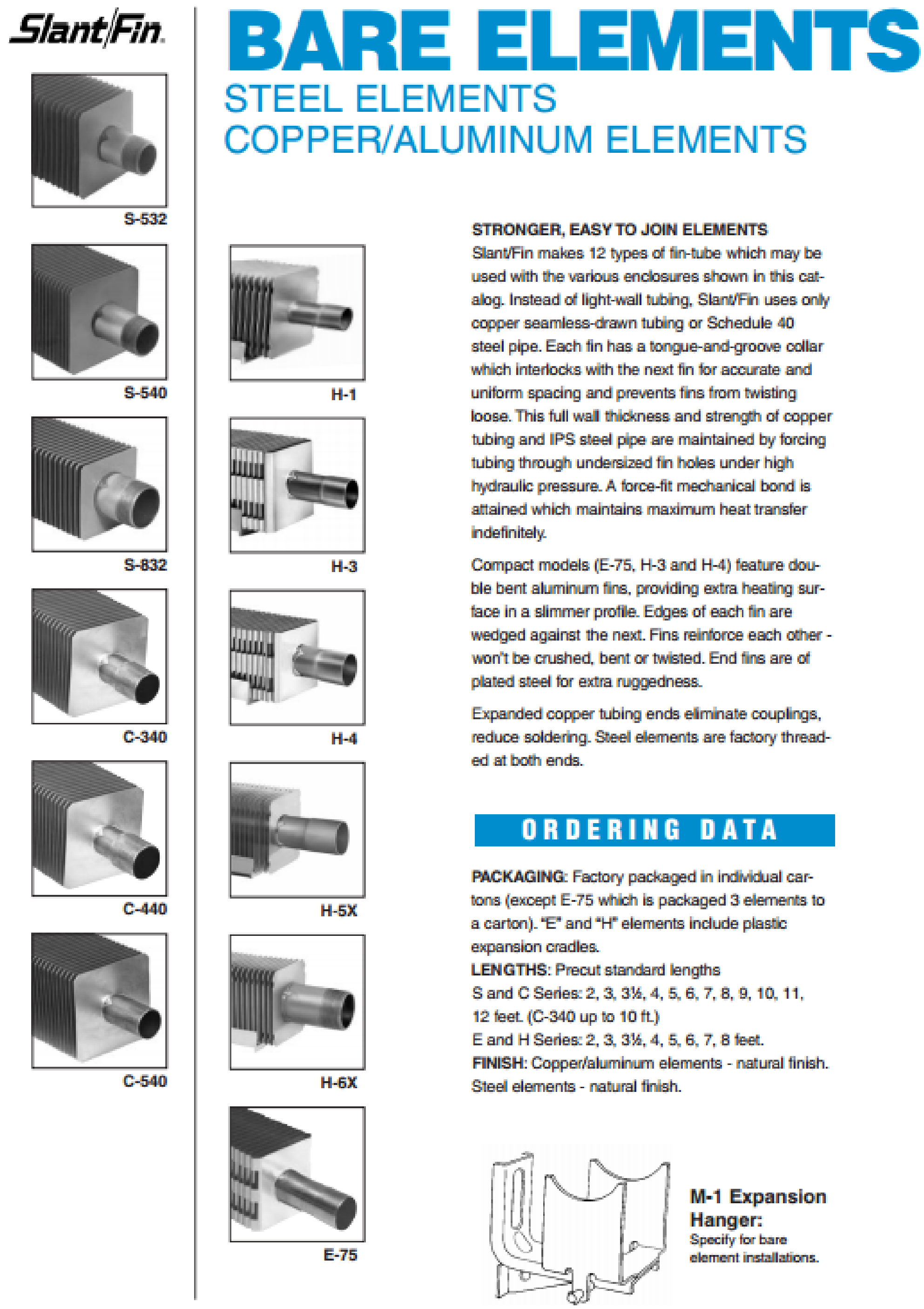



Figure D. 1. Heating system zone layout

## Appendix E

**Zone Controllers.zip on drive for specifications sheets**

# Appendix F



Slant/Fin

# BARE ELEMENTS

## STEEL ELEMENTS
## COPPER/ALUMINUM ELEMENTS

S-532, S-540, S-832, C-340, C-440, C-540

H-1, H-3, H-4, H-5X, H-6X, E-75

**STRONGER, EASY TO JOIN ELEMENTS**

Slant/Fin makes 12 types of fin-tube which may be used with the various enclosures shown in this catalog. Instead of light-wall tubing, Slant/Fin uses only copper seamless-drawn tubing or Schedule 40 steel pipe. Each fin has a tongue-and-groove collar which interlocks with the next fin for accurate and uniform spacing and prevents fins from twisting loose. This full wall thickness and strength of copper tubing and IPS steel pipe are maintained by forcing tubing through undersized fin holes under high hydraulic pressure. A force-fit mechanical bond is attained which maintains maximum heat transfer indefinitely.

Compact models (E-75, H-3 and H-4) feature double bent aluminum fins, providing extra heating surface in a slimmer profile. Edges of each fin are wedged against the next. Fins reinforce each other - won't be crushed, bent or twisted. End fins are of plated steel for extra ruggedness.

Expanded copper tubing ends eliminate couplings, reduce soldering. Steel elements are factory threaded at both ends.

**ORDERING DATA**

**PACKAGING:** Factory packaged in individual cartons (except E-75 which is packaged 3 elements to a carton). "E" and "H" elements include plastic expansion cradles.
**LENGTHS:** Precut standard lengths
S and C Series: 2, 3, 3½, 4, 5, 6, 7, 8, 9, 10, 11, 12 feet. (C-340 up to 10 ft.)
E and H Series: 2, 3, 3½, 4, 5, 6, 7, 8 feet.
**FINISH:** Copper/aluminum elements - natural finish. Steel elements - natural finish.

**M-1 Expansion Hanger:**
Specify for bare element installations.

26

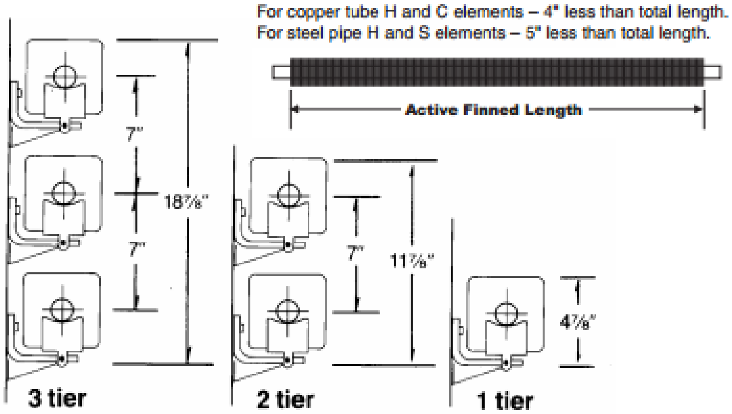
**Figure F. 1. Bare Elements slant fin radiator system.**

# BARE ELEMENT RATINGS

| Model Number | Tube Size and Material | Fin Size and Material | Fins per Foot | No. of Tiers 7" cl | Pressure Drop † | Steam 1 PSI* Btu/Hr. Per Foot | HOT WATER RATINGS* BTU/HR./FT. (Flow Rate 3 Ft./Sec.) 110°F | 120°F | 130°F | 140°F | 150°F | 160°F | 170°F | 180°F | 190°F | 200°F | 210°F | 220°F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S-532 | 1¼"IPS steel | 4¼" x 4¼" x .024" electro-gal. steel | 32 | 1 | 420 | 1080 | 216 | 281 | 356 | 432 | 486 | 572 | 659 | 745 | 842 | 929 | 1026 | 1134 |
| | | | | 2 | | 1950 | 390 | 507 | 644 | 780 | 878 | 1034 | 1190 | 1346 | 1521 | 1677 | 1853 | 2048 |
| | | | | 3 | | 2560 | 512 | 666 | 845 | 1024 | 1152 | 1357 | 1562 | 1766 | 1997 | 2202 | 2432 | 2688 |
| S-540 | 1¼"IPS steel | 4¼" x 4¼" x .024" electro-gal. steel | 40 | 1 | 420 | 1300 | 260 | 338 | 429 | 520 | 585 | 689 | 793 | 897 | 1014 | 1118 | 1235 | 1365 |
| | | | | 2 | | 2210 | 442 | 575 | 729 | 884 | 995 | 1171 | 1348 | 1525 | 1724 | 1901 | 2100 | 2321 |
| | | | | 3 | | 2810 | 562 | 731 | 927 | 1124 | 1265 | 1489 | 1714 | 1939 | 2192 | 2417 | 2670 | 2951 |
| S-832 | 2"IPS steel | 4¼" x 4¼" x .024" electro-gal. steel | 32 | 1 | 252 | 1130 | 226 | 294 | 373 | 452 | 509 | 599 | 689 | 780 | 881 | 972 | 1074 | 1187 |
| | | | | 2 | | 2010 | 402 | 523 | 663 | 804 | 905 | 1065 | 1226 | 1387 | 1568 | 1729 | 1910 | 2111 |
| | | | | 3 | | 2650 | 530 | 689 | 875 | 1060 | 1193 | 1405 | 1617 | 1829 | 2067 | 2279 | 2518 | 2783 |
| C-340 | ¾"copper | 4¼" x 4¼" x .020" aluminum | 40 | 1 | 708 | 1610 | 322 | 419 | 531 | 644 | 725 | 853 | 982 | 1111 | 1256 | 1385 | 1530 | 1691 |
| | | | | 2 | | 2830 | 566 | 736 | 934 | 1132 | 1274 | 1500 | 1726 | 1953 | 2207 | 2434 | 2689 | 2972 |
| | | | | 3 | | 3620 | 724 | 941 | 1195 | 1448 | 1629 | 1919 | 2208 | 2498 | 2824 | 3113 | 3439 | 3801 |
| C-440 | 1" copper | 4¼" x 4¼" x .020" aluminum | 40 | 1 | 504 | 1650 | 330 | 429 | 545 | 660 | 743 | 875 | 1007 | 1139 | 1287 | 1419 | 1568 | 1733 |
| | | | | 2 | | 2890 | 578 | 751 | 954 | 1156 | 1301 | 1532 | 1763 | 1994 | 2254 | 2485 | 2746 | 3035 |
| | | | | 3 | | 3710 | 742 | 965 | 1224 | 1484 | 1670 | 1966 | 2263 | 2560 | 2894 | 3191 | 3525 | 3896 |
| C-448 | 1" copper | 4¼" x 4¼" x .020" aluminum | 48 | 1 | 504 | 1690 | 338 | 439 | 558 | 676 | 761 | 896 | 1031 | 1166 | 1318 | 1453 | 1606 | 1775 |
| | | | | 2 | | 2970 | 594 | 772 | 980 | 1188 | 1337 | 1574 | 1812 | 2049 | 2317 | 2554 | 2822 | 3119 |
| | | | | 3 | | 3790 | 758 | 985 | 1251 | 1516 | 1706 | 2009 | 2312 | 2615 | 2956 | 3259 | 3601 | 3980 |
| C-540 | 1¼" copper | 4¼" x 4¼" x .020" aluminum | 40 | 1 | 396 | 1700 | 340 | 442 | 561 | 680 | 765 | 901 | 1037 | 1173 | 1326 | 1462 | 1615 | 1785 |
| | | | | 2 | | 2990 | 598 | 777 | 987 | 1196 | 1346 | 1585 | 1824 | 2063 | 2332 | 2571 | 2841 | 3140 |
| | | | | 3 | | 3830 | 766 | 996 | 1264 | 1532 | 1724 | 2030 | 2336 | 2643 | 2987 | 3294 | 3639 | 4022 |
| H-1 | ¾" copper | 3" x 3¼" x .024" aluminum | 48 | 1 | 708 | — | 218 | 283 | 360 | 436 | 491 | 578 | 665 | 752 | 850 | 937 | 1036 | 1145 |
| | | | | 2 | | — | 392 | 510 | 647 | 784 | 882 | 1039 | 1196 | 1352 | 1529 | 1686 | 1862 | 2058 |
| | | | | 3 | | — | 640 | 832 | 1056 | 1280 | 1440 | 1696 | 1952 | 2208 | 2496 | 2752 | 3040 | 3360 |
| H-5X | 1¼" copper | 3" x 3¼" x .020" aluminum | 48 | 1 | 396 | 940 | 188 | 244 | 310 | 376 | 423 | 498 | 573 | 649 | 733 | 808 | 893 | 987 |
| | | | | 2 | | 1330 | 266 | 346 | 439 | 532 | 599 | 705 | 811 | 918 | 1037 | 1144 | 1264 | 1397 |
| | | | | 3 | | 2110 | 422 | 549 | 696 | 844 | 950 | 1118 | 1287 | 1456 | 1646 | 1815 | 2005 | 2216 |
| H-6X | 1¼" IPS steel | 3" x 3¼" x .028" aluminized steel | 48 | 1 | 420 | 850 | 170 | 221 | 281 | 340 | 383 | 451 | 519 | 587 | 663 | 731 | 808 | 893 |
| | | | | 2 | | 1290 | 258 | 335 | 426 | 516 | 581 | 684 | 787 | 890 | 1006 | 1109 | 1226 | 1355 |
| | | | | 3 | | 1840 | 368 | 478 | 607 | 736 | 828 | 975 | 1122 | 1270 | 1435 | 1582 | 1748 | 1932 |

* Based on 65°F entering air temperature. † Millinches per foot, based on flow rate of 3FPS; according to ASHRAE fundamentals handbook, 2001
NOTE: H-3, H-4 and E-3 elements are not recommended for bare-element installation. H-1 is not recommended for steam applications.
Ratings are based on active finned length (S & C series 5-1/4" less than overall length.) (H series=3" less than overall length.)

Active length of each element is as follows:
For copper tube H and C elements – 4" less than total length.
For steel pipe H and S elements – 5" less than total length.




Dimensions for bare element installation without enclosures ("S" and "C" elements).

The installed height for elements is defined as the distance from the finished floor to the top of the fin. The minimum mounting height on all elements without enclosures is 5¾" from finished floor to bottom of fins of lowest element.

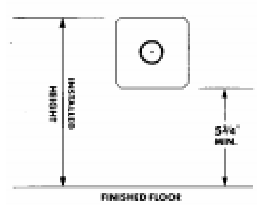




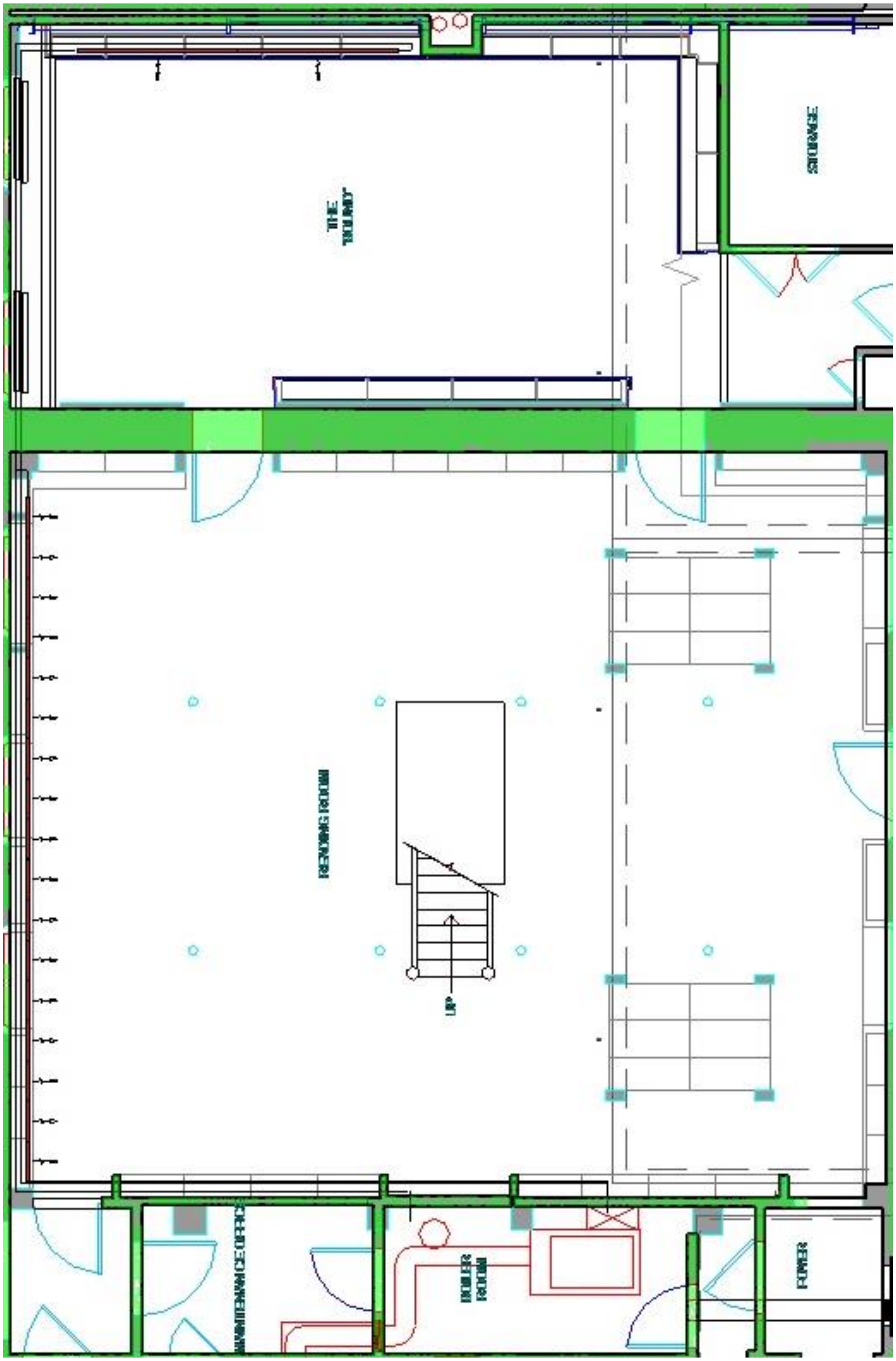

**Figure F. 2. Bare Elements slant fin radiator specification sheet.**

## Appendix G

Table G.1 Boiler Zone Calculations

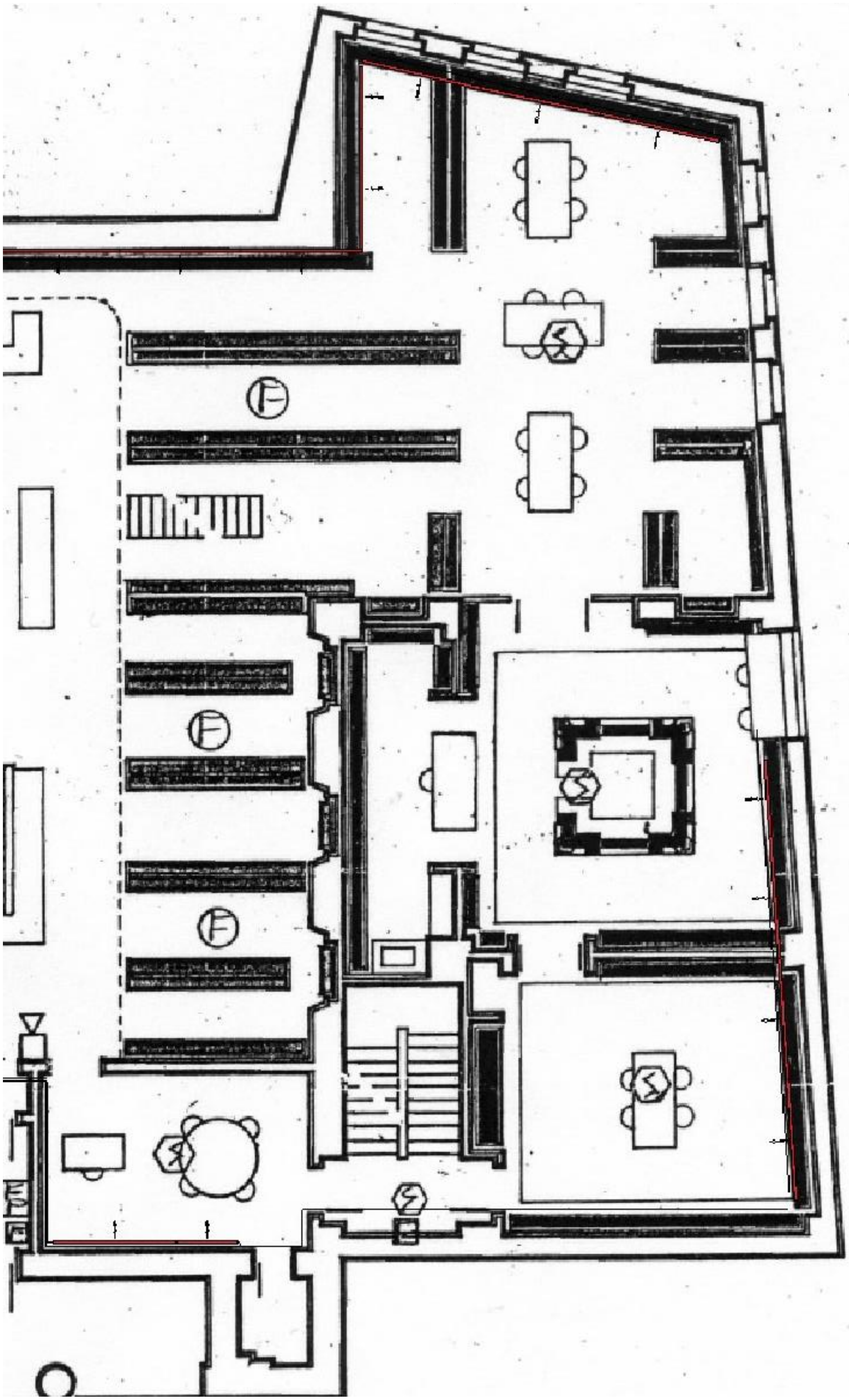
| Boiler- Baseboard System | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Zone | sqft | Btu/hr Needed | T-supply (F) | T-return (F) | Baseboard Length Needed (ft) | Pipe Diameter (in) | Velocity (fps) | Flow Rate (GPM) | Baseboard | |
| 1 | 1470 | 44100 | 180 | 168.0 | 37.8 | 1 | 3 | 7.35 | V water (fps) | 3 |
| 2 | 647 | 19425 | | 174.7 | 16.7 | 1 | 3 | 7.35 | Diameter (In) | 1 |
| 3 | 5818 | 174540 | | 151.5 | 149.7 | 1 | 5 | 12.25 | Output | 1166 btu/hr/ft |
| 4 | 904 | 27090 | | 172.6 | 23.2 | 1 | 3 | 7.35 | Price/ft | $ 22.72 |
| 5 | 216 | 6480 | | 178.2 | 5.6 | 1 | 3 | 7.35 | | |
| 6 | 216 | 6480 | | 178.2 | 5.6 | 1 | 3 | 7.35 | | |

## Appendix H

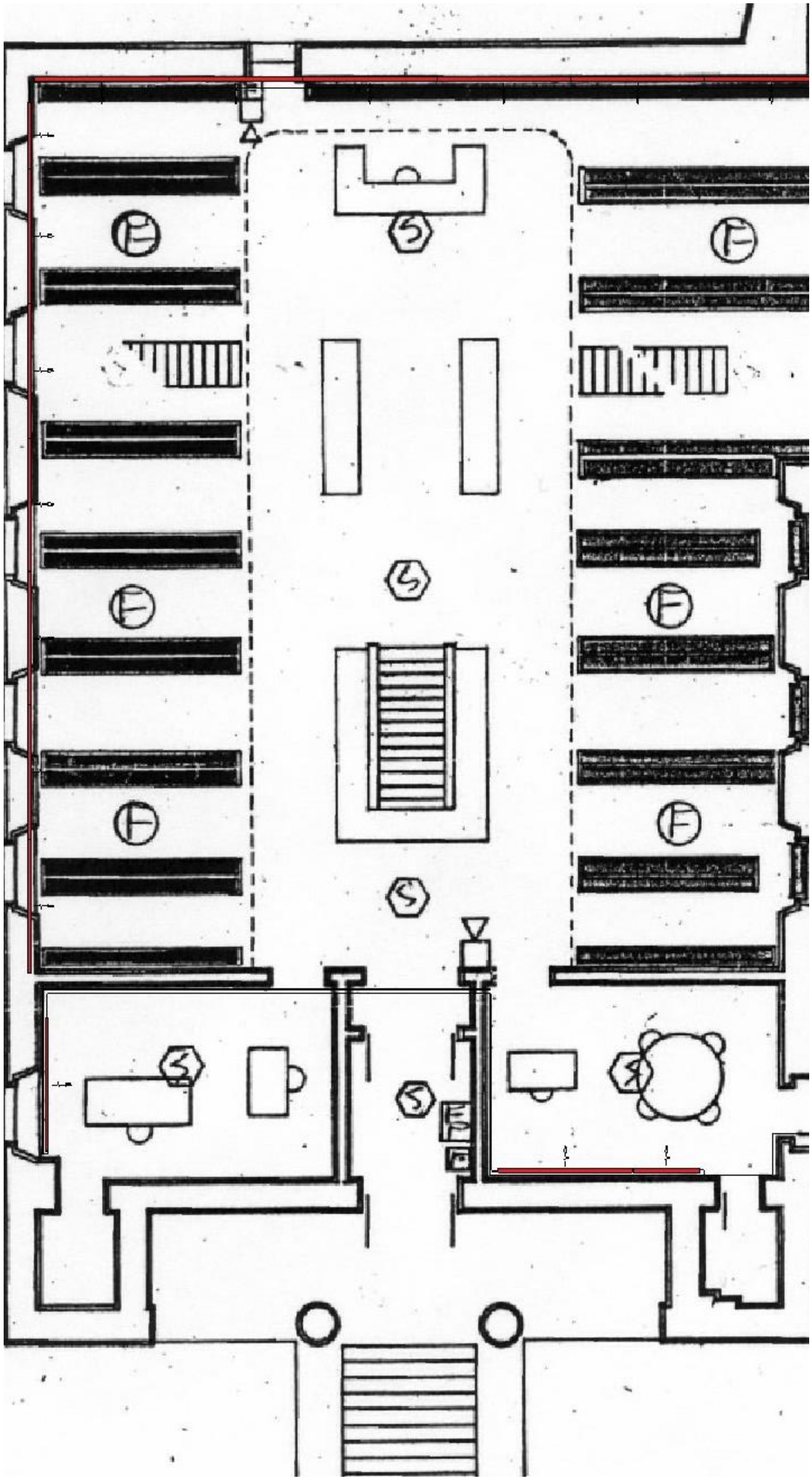



Basement Floor Level Baseboard Schematics

**Main Level (South) Baseboard Schematics**



**Main Level (North) Baseboard Schematics**



# Appendix I

**Figure 3.34 I: Pressure Drop vs. Flow Rates**

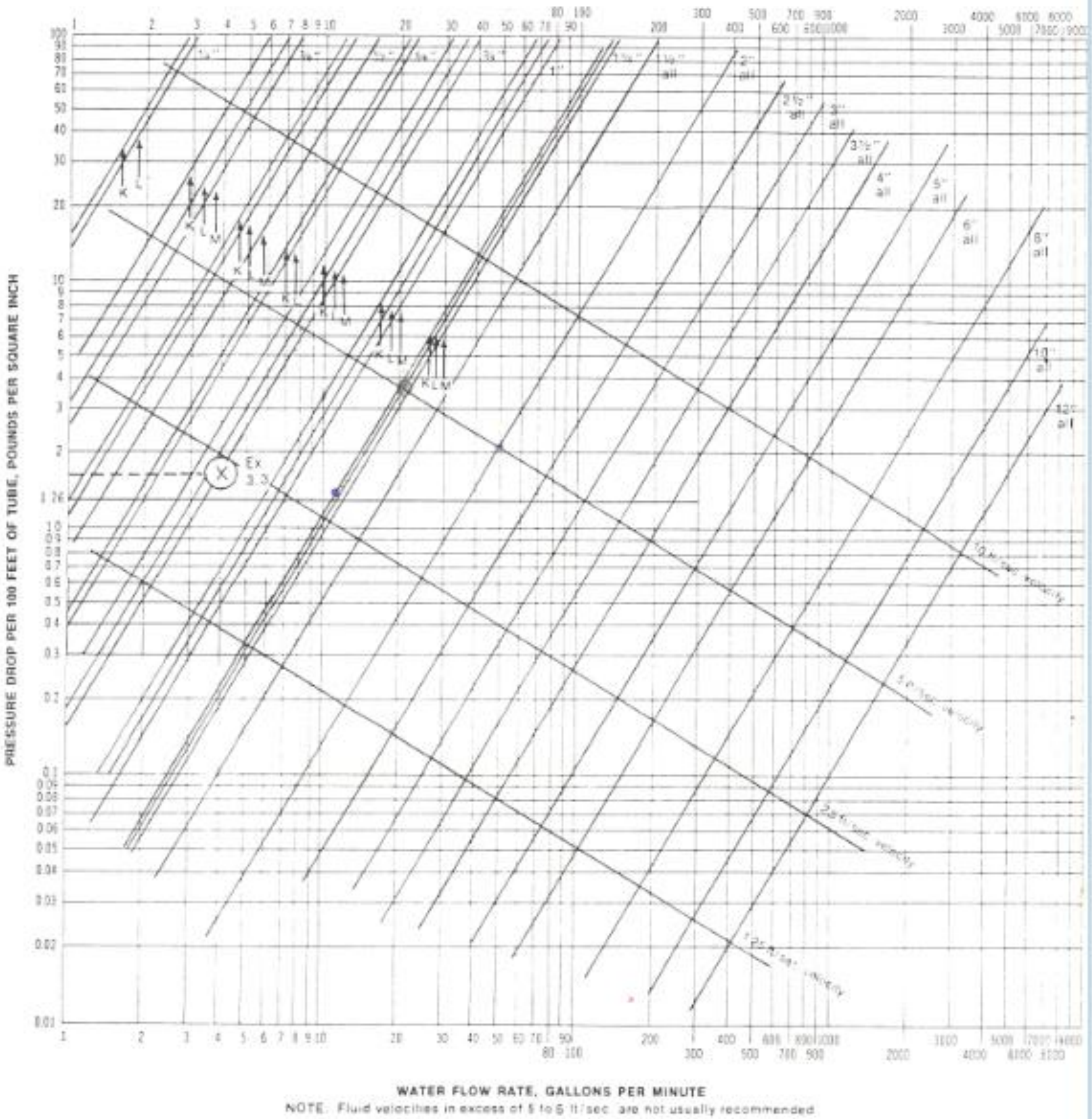



**Figure 3.34** Chart showing pressure drop and water velocity for varying flow rates of water in copper pipe, types K, L and M. The horizontal line drawn at 1.26 psi represents a friction drop of 350 millinches (of water) per foot of pipe. See text in Example 3.5. (Courtesy of Copper Development Association.)

**Table 3.15** Allowance for Friction Loss in Valves and Fittings Expressed as Equivalent Length of Tube

| Fitting Size, in. | *Equivalent Length of Tube, ft* | | | | | | |
|---|---|---|---|---|---|---|---|
| | *Standard Ells* | | *90° Tee* | | | | |
| | *90°* | *45°* | *Side Branch* | *Straight Run* | *Coupling* | *Gate Valve* | *Globe Valve* |
| 3/8 | 0.5 | 0.3 | 0.75 | 0.15 | 0.15 | 0.1 | 4 |
| 1/2 | 1 | 0.6 | 1.5 | 0.3 | 0.3 | 0.2 | 7.5 |
| 3/4 | 1.25 | 0.75 | 2 | 0.4 | 0.4 | 0.25 | 10 |
| 1 | 1.5 | 1.0 | 2.5 | 0.45 | 0.45 | 0.3 | 12.5 |
| 1 1/4 | 2 | 1.2 | 3 | 0.6 | 0.6 | 0.4 | 18 |
| 1 1/2 | 2.5 | 1.5 | 3.5 | 0.8 | 0.8 | 0.5 | 23 |
| 2 | 3.5 | 2 | 5 | 1 | 1 | 0.7 | 28 |
| 2 1/2 | 4 | 2.5 | 6 | 1.3 | 1.3 | 0.8 | 33 |
| 3 | 5 | 3 | 7.5 | 1.5 | 1.5 | 1 | 40 |
| 3 1/2 | 6 | 3.5 | 9 | 1.8 | 1.8 | 1.2 | 50 |
| 4 | 7 | 4 | 10.5 | 2 | 2 | 1.4 | 63 |
| 5 | 9 | 5 | 13 | 2.5 | 2.5 | 1.7 | 70 |
| 6 | 10 | 6 | 15 | 3 | 3 | 2 | 84 |

Note: Allowances are for streamlined soldered fittings and recessed threaded fittings. For threaded fittings, double the allowances shown in the table.

*Source.* Courtesy of Copper Development Association.

# Appendix J

| Zone1 | Run | Length | Fittings Length | Total Length [ft] | Flow [gpm] | Pipe Size [in] | Velocity [fps] | Pres Drop [psi/100ft] | Pres Drop [psi] | Pres Drop [Head Ft] | Pump |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Boiler-Baseboard | 30 | 3 | 33 | 7.35 | 0.75 | 5.333333 | 6 | 1.98 | | TACO Model 0010 |
| | Baseboard | 37.8 | 0 | 37.8 | 7.35 | 1 | 3 | 1.5 | 0.567 | | |
| | Baseboard-1,2 Return | 1 | 11 | 12 | 7.35 | 1 | 3 | 1.5 | 0.18 | | |
| | 1,2 Return-Full Return | 56 | 4 | 60 | 14.7 | 1.25 | 3.84 | 2 | 0.6 | | |
| | Full Return | 8 | 24.9 | 32.9 | 49 | 2 | 5 | 2.1 | 0.11515 | | |
| | Total | | | | | | | | 3.44215 | 7.916945 | |

| Zone2 | Run | Length | Fittings Length | Total Length [ft] | Flow [gpm] | Pipe Size [in] | Velocity [fps] | Pres Drop [psi/100ft] | Pres Drop [psi] | Pres Drop [Head Ft] | Pump |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Boiler-Baseboard | 128 | 4.25 | 132.25 | 7.35 | 0.75 | 5.333333 | 6 | 7.935 | | TACO Model 0013 |
| | Baseboard | 16.7 | 0 | 16.7 | 7.35 | 1 | 3 | 1.5 | 0.2505 | | |
| | Baseboard-1,2 Return | 52 | 12.5 | 64.5 | 7.35 | 1 | 3 | 1.5 | 0.9675 | | |
| | 1,2 Return-Full Return | 56 | 4 | 60 | 14.7 | 1.25 | 3.84 | 2 | 0.6 | | |
| | Full Return | 8 | 24.9 | 32.9 | 49 | 2 | 5 | 2.1 | 0.11515 | | |
| | Total | | | | | | | | 9.86815 | 22.69675 | |

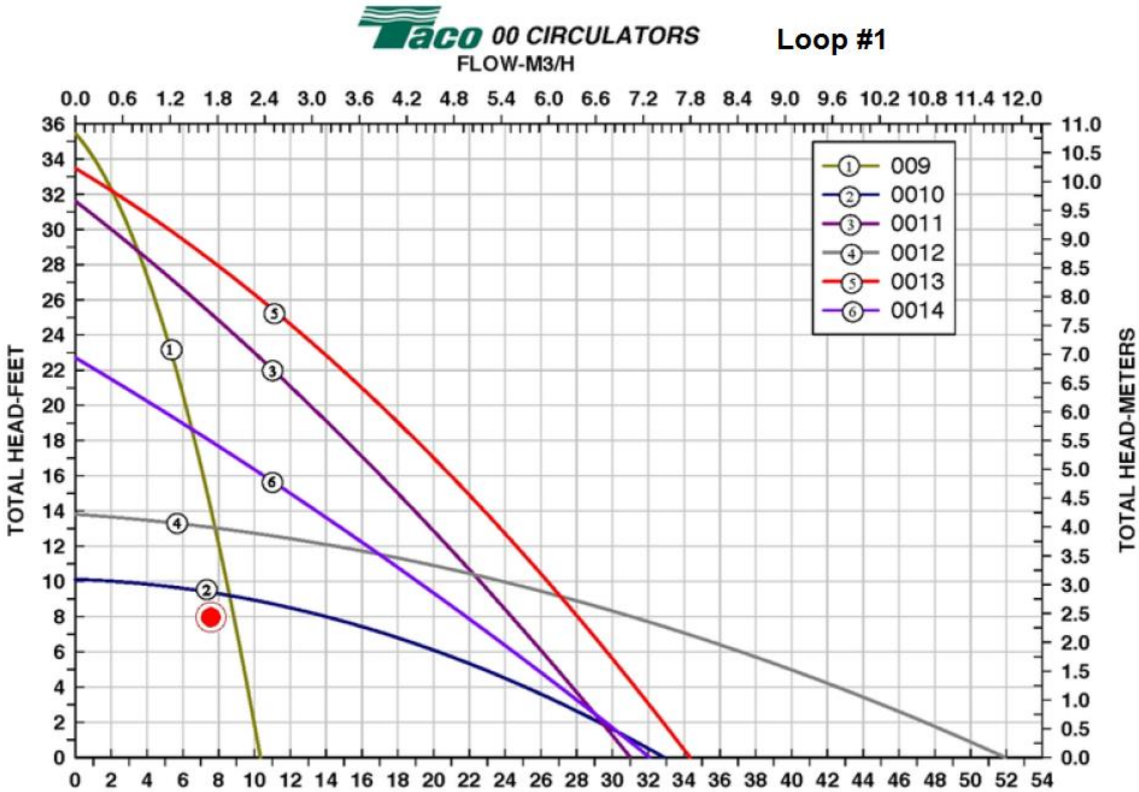
| Zone3 | Run | Length | Fittings Length | Total Length [ft] | Flow [gpm] | Pipe Size [in] | Velocity [fps] | Pres Drop [psi/100ft] | Pres Drop [psi] | Pres Drop [Head Ft] | Pump |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Boiler-Baseboard | 38 | 3.6 | 41.6 | 12.25 | 1 | 5 | 4.8 | 1.9968 | | TACO Model 1615 |
| | Baseboard | 139 | 5.5 | 144.5 | 12.25 | 1 | 5 | 4.8 | 6.936 | | |
| | Baseboard-3,5 Return | 145 | 16.5 | 161.5 | 12.25 | 1 | 5 | 4.8 | 7.752 | | |
| | 3,5 Return - 3,4,5,6 Return | 20 | 2 | 22 | 19.6 | 1.25 | 5.12 | 4 | 0.44 | | |
| | 3,4,5,6 Return - Full Return | 12 | 2.5 | 14.5 | 34.3 | 1.5 | 6.222222 | 4 | 0.145 | | |
| | Full Return | 8 | 24.9 | 32.9 | 49 | 2 | 5 | 2.1 | 0.11515 | | |
| | Total | | | | | | | | 17.385 | 39.98539 | |

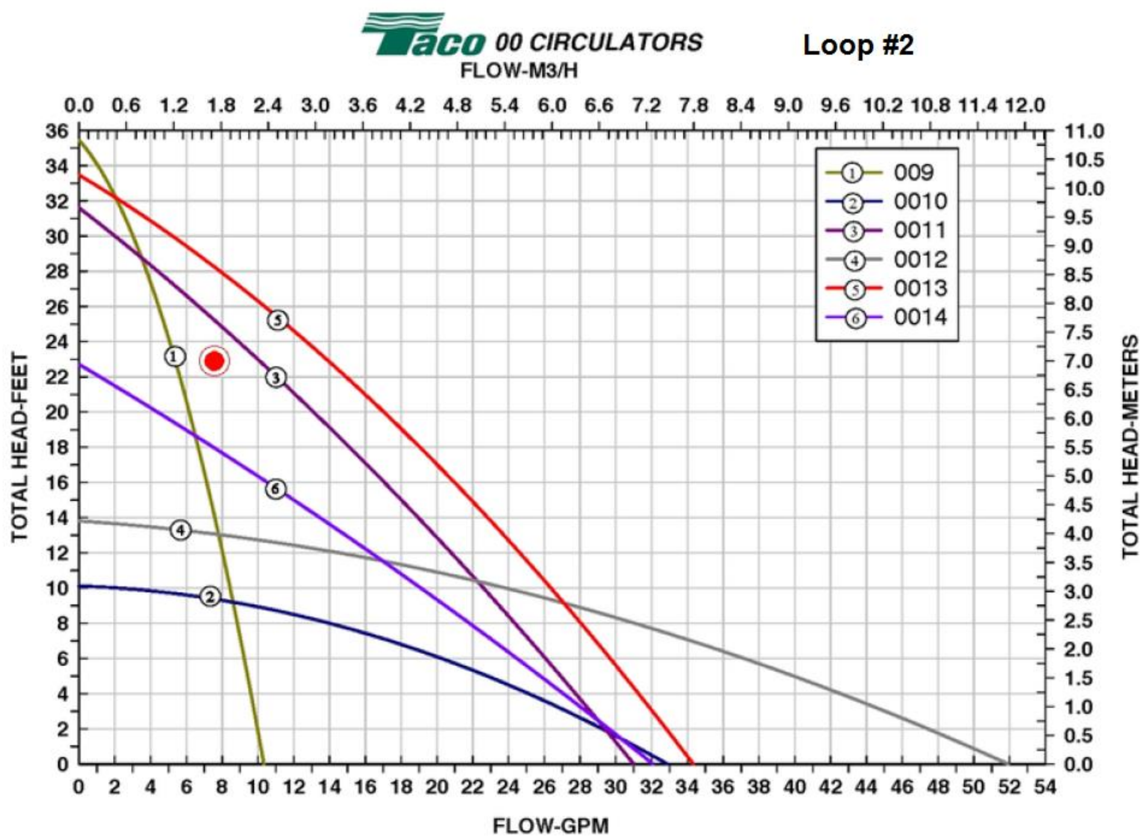
| Zone4 | Run | Length | Fittings Length | Total Length [ft] | Flow [gpm] | Pipe Size [in] | Velocity [fps] | Pres Drop [psi/100ft] | Pres Drop [psi] | Pres Drop [Head Ft] | Pump |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Boiler-Baseboard | 76 | 8.1 | 84.1 | 7.35 | 1 | 3 | 1.5 | 1.2615 | | TACO Model 0011 |
| | Baseboard | 23.2 | 0 | 23.2 | 7.35 | 1 | 3 | 1.5 | 0.348 | | |
| | Baseboard-4,6 Return | 74 | 15.5 | 89.5 | 7.35 | 1 | 3 | 1.5 | 1.3425 | | |
| | 4,6 Return - 3,4,5,6 Return | 23 | 6 | 29 | 14.7 | 1.25 | 3.84 | 2 | 0.29 | | |
| | 3,4,5,6 Return - Full Return | 12 | 2.5 | 14.5 | 34.3 | 1.5 | 6.222222 | 4 | 0.145 | | |
| | Full Return | 8 | 24.9 | 32.9 | 49 | 2 | 5 | 2.1 | 0.11515 | | |

| Zone5 | Run | Length | Fittings Length | Total Length [ft] | Flow [gpm] | Pipe Size [in] | Velocity [fps] | Pres Drop [psi/100ft] | Pres Drop [psi] | Pres Drop [Head Ft] | Pump |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Boiler-Baseboard | 38 | 3.6 | 41.6 | 7.35 | 1 | 3 | 1.5 | 0.624 | | TACO Model 007 |
| | Baseboard | 5.6 | 0 | 5.6 | 7.35 | 1 | 3 | 1.5 | 0.084 | | |
| | Baseboard-3,5 Return | 8 | 12.5 | 20.5 | 7.35 | 1 | 3 | 1.5 | 0.3075 | | |
| | 3,5 Return - 3,4,5,6 Return | 20 | 2 | 22 | 19.6 | 1.25 | 5.12 | 4 | 0.44 | | |
| | 3,4,5,6 Return - Full Return | 12 | 2.5 | 14.5 | 34.3 | 1.5 | 6.222222 | 4 | 0.145 | | |
| | Full Return | 8 | 24.9 | 32.9 | 49 | 2 | 5 | 2.1 | 0.11515 | | |
| | Total | | | | | | | | 1.71565 | 3.945995 | |

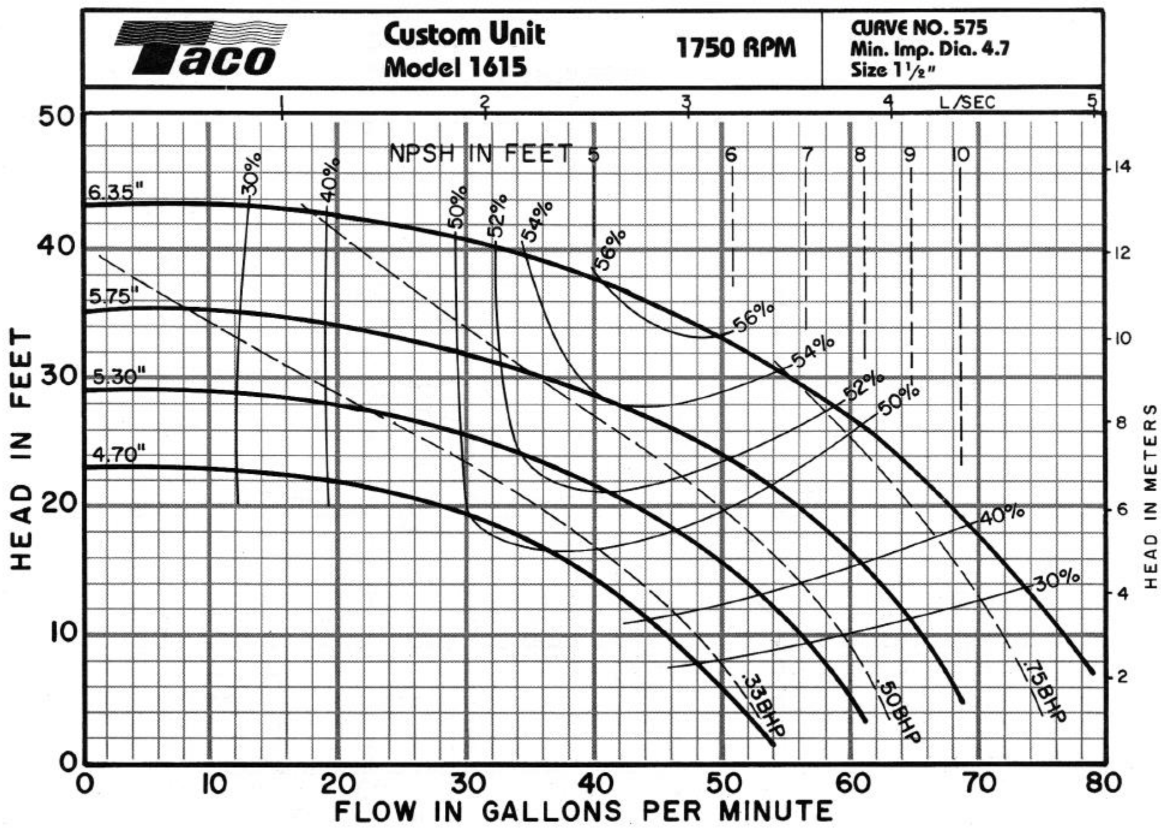
| Zone6 | Run | Length | Fittings Length | Total Length [ft] | Flow [gpm] | Pipe Size [in] | Velocity [fps] | Pres Drop [psi/100ft] | Pres Drop [psi] | Pres Drop [Head Ft] | Pump |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Boiler-Baseboard | 18 | 3.6 | 21.6 | 7.35 | 1 | 3 | 1.5 | 0.324 | | TACO Model 007 |
| | Baseboard | 5.6 | 0 | 5.6 | 7.35 | 1 | 3 | 1.5 | 0.084 | | |
| | Baseboard-4,6 Return | 1 | 11 | 12 | 7.35 | 1 | 3 | 1.5 | 0.18 | | |
| | 4,6 Return - 3,4,5,6 Return | 23 | 6 | 29 | 14.7 | 1.25 | 3.84 | 2 | 0.29 | | |
| | 3,4,5,6 Return - Full Return | 12 | 2.5 | 14.5 | 34.3 | 1.5 | 6.222222 | 4 | 0.145 | | |
| | Full Return | 8 | 24.9 | 32.9 | 49 | 2 | 5 | 2.1 | 0.11515 | | |
| | Total | | | | | | | | 1.13815 | 2.617745 | |

## Appendix K


Taco 00 CIRCULATORS
Loop #1
FLOW-M3/H
TOTAL HEAD-FEET
TOTAL HEAD-METERS
1 009
2 0010
3 0011
4 0012
5 0013
6 0014

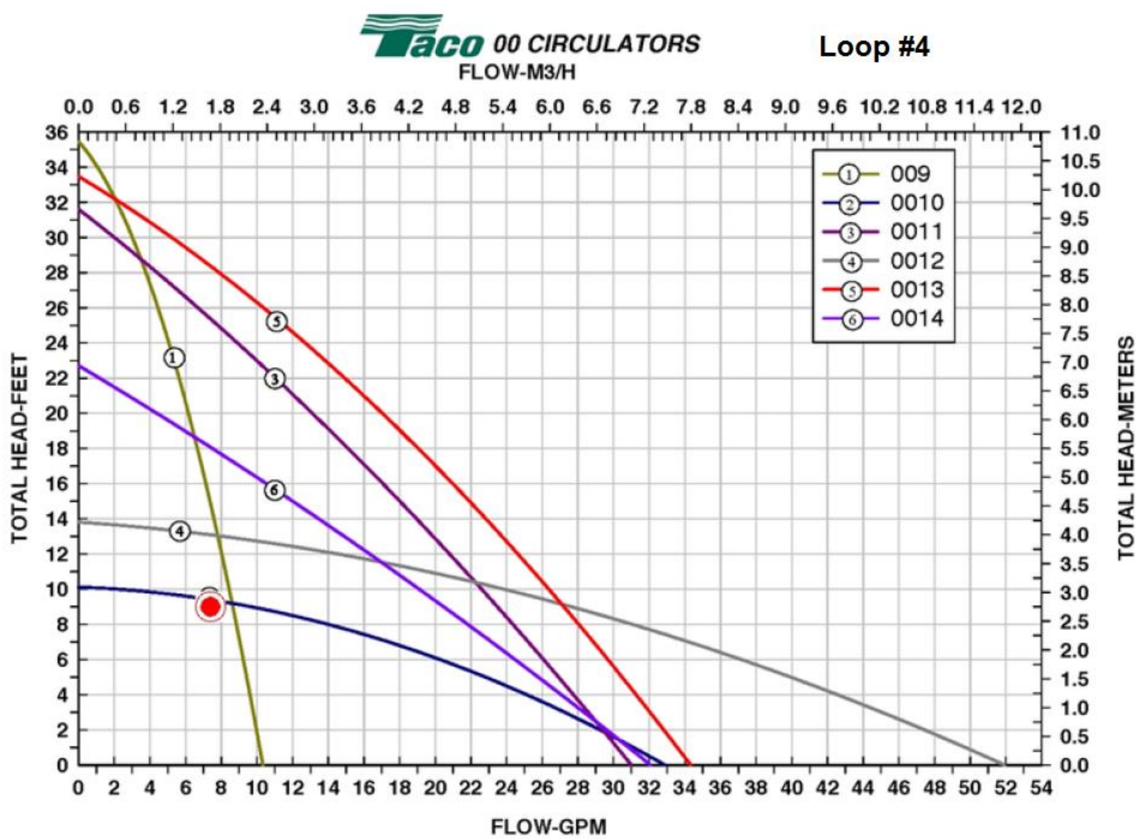

Taco 00 CIRCULATORS
Loop #2
FLOW-M3/H
TOTAL HEAD-FEET
TOTAL HEAD-METERS
FLOW-GPM
1 009
2 0010
3 0011
4 0012
5 0013
6 0014

**Loop #3**



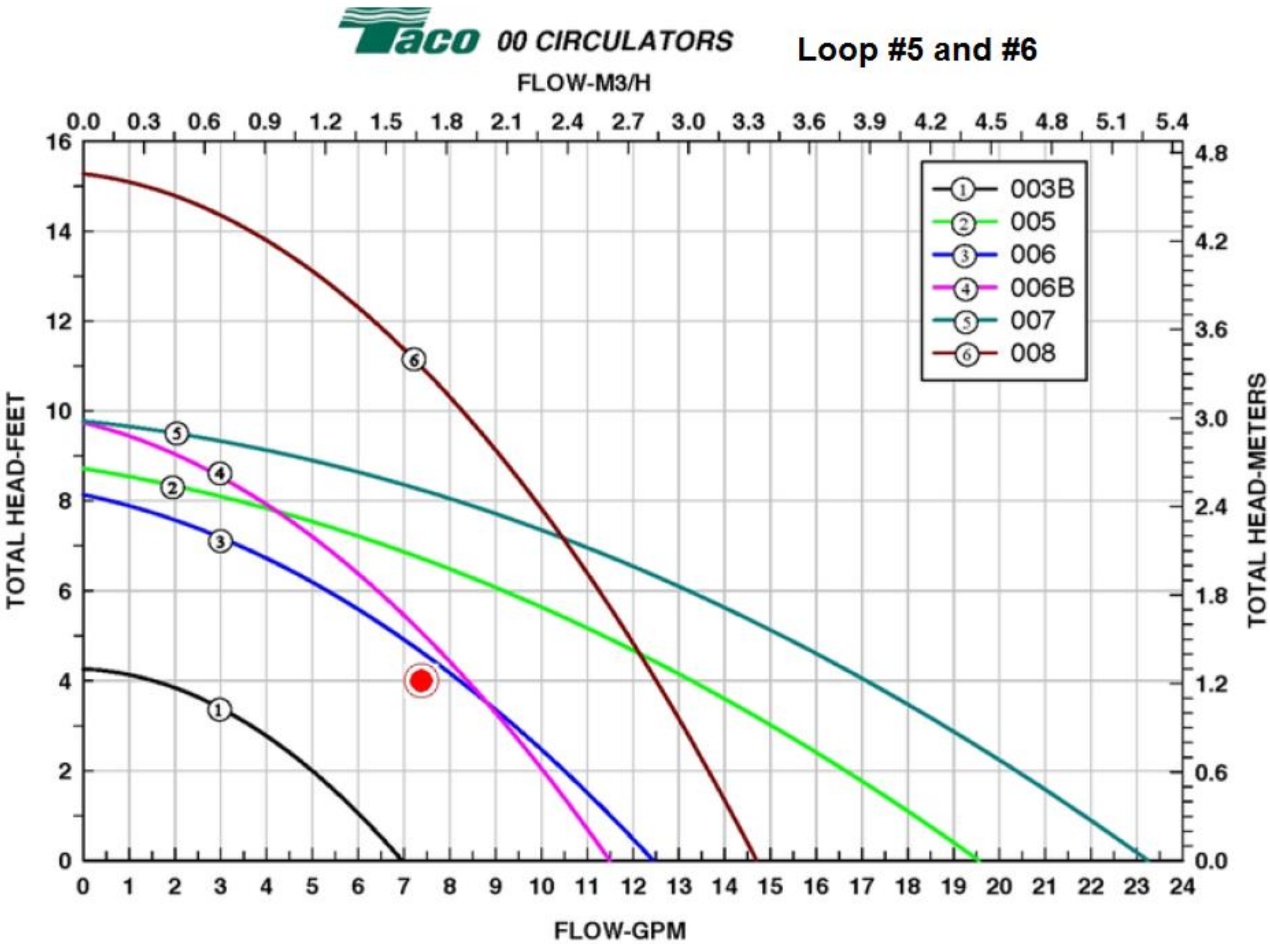
Taco
Custom Unit
Model 1615
1750 RPM
CURVE NO. 575
Min. Imp. Dia. 4.7
Size 1 1/2"
L/SEC
NPSH IN FEET
HEAD IN FEET
HEAD IN METERS
FLOW IN GALLONS PER MINUTE
6.35"
5.75"
5.30"
4.70"
.33BHP
.50BHP
.75BHP


**Loop #4**



Taco 00 CIRCULATORS
FLOW-M3/H
TOTAL HEAD-FEET
TOTAL HEAD-METERS
FLOW-GPM
009
0010
0011
0012
0013
0014

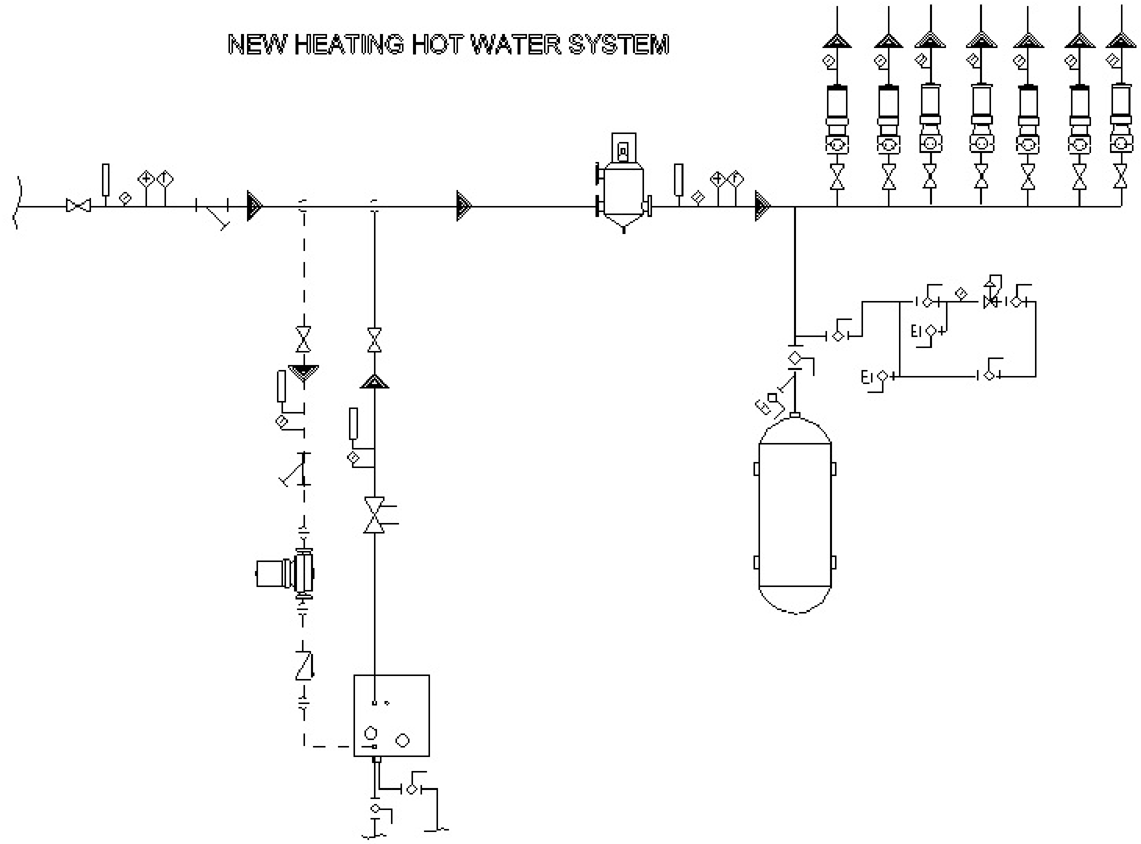
# Loop #5 and #6

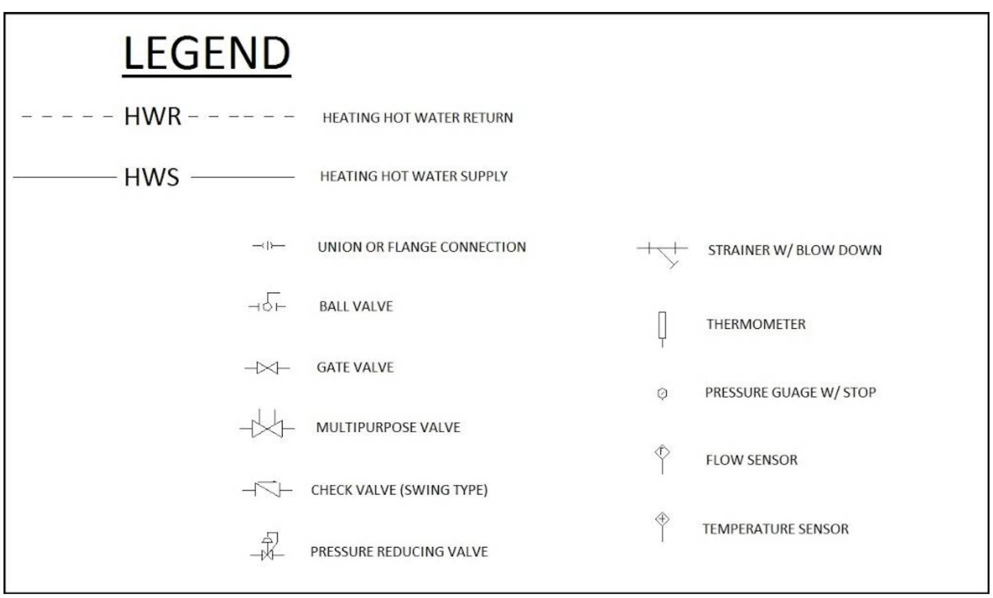

Taco 00 CIRCULATORS
FLOW-M3/H
0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7 3.0 3.3 3.6 3.9 4.2 4.5 4.8 5.1 5.4
TOTAL HEAD-FEET
16 14 12 10 8 6 4 2 0
TOTAL HEAD-METERS
4.8 4.2 3.6 3.0 2.4 1.8 1.2 0.6 0.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
FLOW-GPM
1 003B
2 005
3 006
4 006B
5 007
6 008

# Appendix L

Expansion Tank specs – located in Expansion Tank.zip on drive

# Appendix M


NEW HEATING HOT WATER SYSTEM
EI
EI


LEGEND
HWR
HEATING HOT WATER RETURN
HWS
HEATING HOT WATER SUPPLY
UNION OR FLANGE CONNECTION
BALL VALVE
GATE VALVE
MULTIPURPOSE VALVE
CHECK VALVE (SWING TYPE)
PRESSURE REDUCING VALVE
STRAINER W/ BLOW DOWN
THERMOMETER
PRESSURE GUAGE W/ STOP
FLOW SENSOR
TEMPERATURE SENSOR

# Appendix N

| Cost Analysis of New Boiler System | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Project: | Providence Athenaeum | Calculations/Estimates done using RSMeans Building Construction Cost Data 2012 Ed | | | | | | |
| Location: | Providence RI | | | | | | | |
| | | | | | | | | |
| SPEC | DESCRIPTION | QUANTITY | Labor Hrs | Labor Cost/HR | Labor Cost | Equipment Cost/Uni | Equipment Cost | TOTAL |
| | **Demolition** | | | | | | | |
| | Boiler | 1 | 40 | $ 78.06 | $ 3,122.40 | | | $ 3,122.40 |
| | Baseboard Heating | 966 | 289.8 | $ 73.83 | $21,395.93 | | | $21,395.93 |
| | **Installation** | | | | | | | |
| 2930 | LAARs Neotherm 399 Hydronic Boiler | 1 | 57.97 | $ 78.40 | $ 4,544.93 | $ 8,593.59 | $ 8,593.59 | $13,138.52 |
| 2060 | AMTROL AX-20 Expansion Tank | 1 | 1.80 | $ 75.60 | $ 136.08 | $ 662.42 | $ 662.42 | $ 798.50 |
| 0040 | TACO 4900 Air Separator | 1 | 2.67 | $ 75.60 | $ 201.63 | $ 209.00 | $ 209.00 | $ 410.63 |
| 1200 | Slant/Fin C-440 Baseboard | 240 | 101.04 | $ 75.60 | $ 7,638.62 | $ 22.72 | $ 5,452.80 | $13,091.42 |
| 5130 | TACO 6 Zone Actuator Valve Control | 1 | 0.89 | $ 75.60 | $ 67.21 | $ 144.85 | $ 144.85 | $ 212.06 |
| 3140 | TACO Zone Valve 1" | 6 | 3.00 | $ 75.60 | $ 226.80 | $ 161.38 | $ 968.28 | $ 1,195.08 |
| 8150 | Pipe Insulation 3' | 200 | 18.20 | $ 5.31 | $ 96.64 | $ 5.84 | $ 1,168.00 | $ 1,264.64 |
| 2180 | Copper Tubing 3/4" Diameter | 160 | 16.80 | $ 74.13 | $ 1,245.38 | $ 6.99 | $ 1,118.40 | $ 2,363.78 |
| 2200 | Copper Tubing 1" Diameter | 680 | 80.24 | $ 74.13 | $ 5,948.19 | $ 8.99 | $ 6,113.20 | $12,061.39 |
| 2220 | Copper Tubing 1 1/4" Diameter | 100 | 13.80 | $ 74.13 | $ 1,022.99 | $ 11.99 | $ 1,199.00 | $ 2,221.99 |
| 2240 | Copper Tubing 1 1/2" Diameter | 16 | 2.46 | $ 74.13 | $ 182.66 | $ 14.99 | $ 239.84 | $ 422.50 |
| 2260 | Copper Tubing 2" Diameter | 10 | 1.90 | $ 74.13 | $ 140.85 | $ 21.99 | $ 219.90 | $ 360.75 |
| 4140 | Backflow Preventer | 6 | 4.00 | $ 74.13 | $ 296.67 | $ 455.00 | $ 2,730.00 | $ 3,026.67 |
| 2040 | TACO In-Line Circulator 007 | 2 | 5.33 | $ 74.13 | $ 395.41 | $ 140.00 | $ 280.00 | $ 675.41 |
| 2040 | TACO In-Line Circulator 0010 | 1 | 2.67 | $ 74.13 | $ 197.70 | $ 256.00 | $ 256.00 | $ 453.70 |
| 2040 | TACO In-Line Circulator 0011 | 1 | 2.67 | $ 74.13 | $ 197.70 | $ 273.00 | $ 273.00 | $ 470.70 |
| 2180 | TACO In-Line Circulator 0013 | 1 | 3.20 | $ 74.13 | $ 237.22 | $ 365.00 | $ 365.00 | $ 602.22 |
| 2180 | TACO In-Line Circulator 1615 | 1 | 3.20 | $ 74.13 | $ 237.22 | $ 850.00 | $ 850.00 | $ 1,087.22 |
| 180 | Venturi Flow Sensor | 2 | 1.45 | $ 75.60 | $ 109.92 | $ 300.00 | $ 600.00 | $ 709.92 |
| | Strainer w/ Blow Down | 2 | 1.23 | $ 75.60 | $ 92.99 | $ 110.00 | $ 220.00 | $ 312.99 |
| | Gate Valve | 6 | 9.60 | $ 74.13 | $ 711.65 | $ 610.00 | $ 3,660.00 | $ 4,371.65 |
| 9500 | Honeywell Wireless Thermostat | 6 | 0.40 | $ 64.13 | $ 25.65 | $ 200.00 | $ 1,200.00 | $ 1,225.65 |
| | | | | | | | | |
| Totals | | | | | $ 19,409 | | $ 27,930 | $ 84,996 |

## Appendix O

**Beam calculation to determine the cooling load**

$$N_{beams} = \frac{Total\ cooling\ load - DOAS\ Cooling}{Beam\ cooling\ factor} = \frac{(144000 - 83000)\ BTUh}{787\ \frac{BTUh}{Lf_{Beam}}}$$

$$N_{Beams} = 77\ linear\ feet\ of\ beams = \frac{77}{10\ ft\ beams} = 8\ Beams$$

## Appendix P

Technical data for chilled beam.

## Appendix Q

**Table Q. 1. Cooling/ventilation cost breakdown**

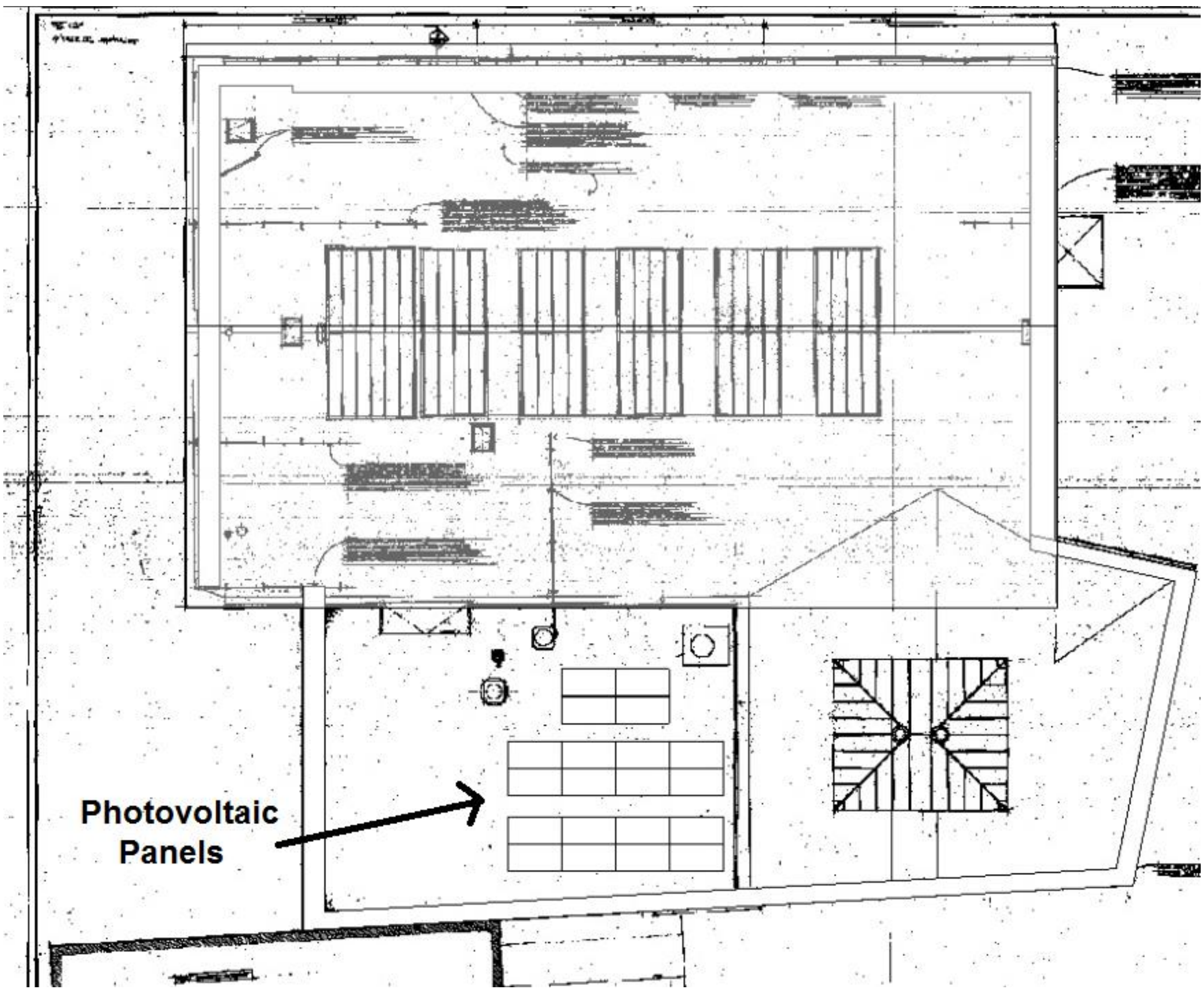
| Item | Cost |
| --- | --- |
| Chilled beams | $12,800.00 |
| DOAS unit | $10,900.00 |
| Packaged chiller | $29,400.00 |
| Copper pipe | $20,000.00 |
| Grand Total | $90,000.00 |

## Appendix R

Spec sheet for SUNPOWER X21-345
Spec sheet for Sunnyboy converter

## Appendix S

**Diagram of Photovoltaic Panel Positioning**



# Appendix T

## Photovolataic Pricing Breakdown

| Panel Type | # Panels | Panel Sqft | Power/hr (W) | Efficiency Constant | Avg Sun hrs/day | Power (kW) / day | Power (kW) / Month | Power (kW) / Year | % of Total Athenaeum Energy Consumption | Savings / Month | ROI (Years) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SUNPOWER X21-345-COM | 8 | 143 | 345 | 0.8 | 4 | 8.83 | 264.96 | 3179.52 | 3.9% | $ 47.69 | 147 |
| | 12 | 215 | | | | 13.25 | 397.44 | 4769.28 | 5.8% | $ 71.54 | 72 |
| | 16 | 287 | | | | 17.66 | 529.92 | 6359.04 | 7.7% | $ 95.39 | 47 |
| | 20 | 358 | | | | 22.08 | 662.4 | 7948.8 | 9.7% | $ 119.23 | 35 |

| Providence Athenaeum | |
|---|---|
| Average Energy Usage / Month (kWh) | 6840.5 |
| Average Energy Usage / Day (kWh) | 228 |
| Average Cost $/kW | 0.18 |
| Average Cost / Month | 1142 |

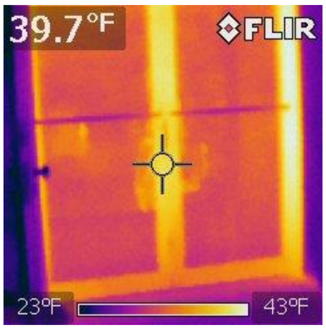
| Upfront Costs | |
|---|---|
| Installation (approx) | $ 40,000.00 |
| Maintenance / Year (approx) | $300 - $400 |

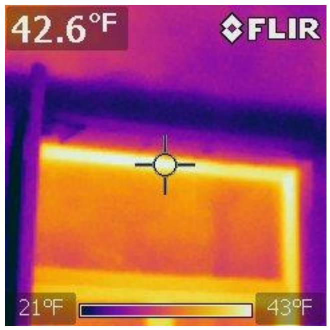
| # Panels | ROI equation | Months | Years |
|---|---|---|---|
| 8 | $ - | 1763 | 147 |
| 12 | $ - | 859 | 72 |
| 16 | $ - | 568 | 47 |
| 20 | $ - | 424 | 35 |

# Appendix U

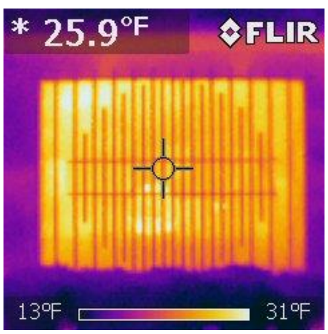
## Thermal Imaging

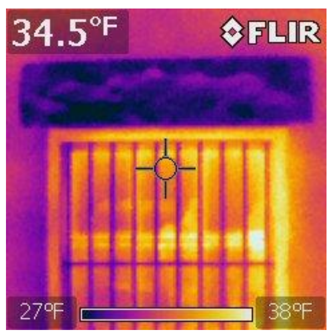
Front door

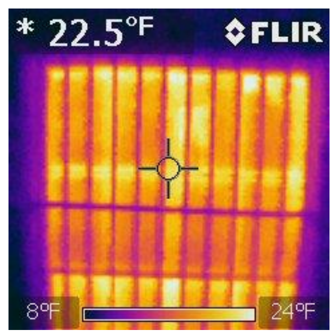


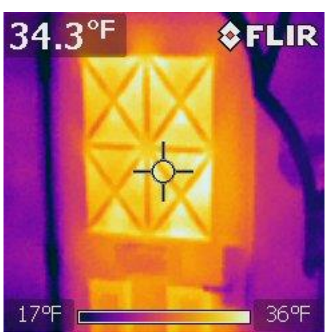

Windows

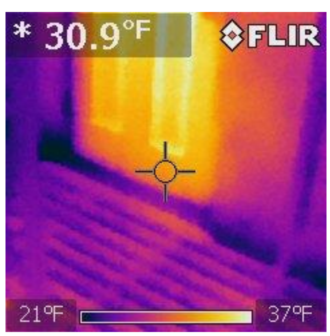


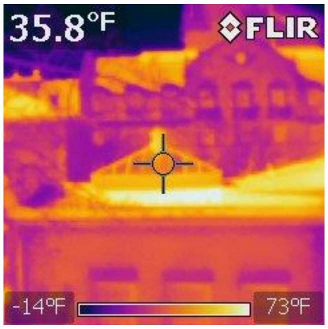




Back Door



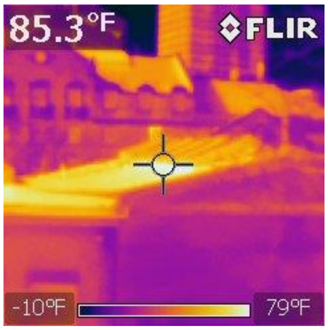



Roof

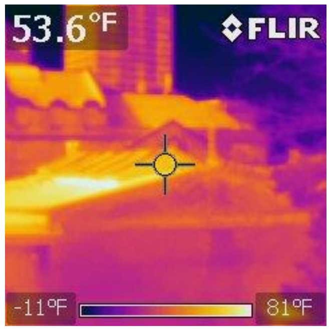


35.8°F
FLIR
-14°F
73°F


73.0°F
FLIR
-9°F
73°F

85.3°F
FLIR
-10°F
79°F

53.6°F
FLIR
-11°F
81°F

**Cost Breakdown**

**Table U. 1. Quantity of materials for conservation of energy**

| Item | Qty | Unit |
|---|---|---|
| *Batt R-30 fiberglass insulation* | 6041 | sf |
| *Vapor barier* | 4905 | sf |
| *Rigid board insulation* | 2016 | sf |
| *door sweep* | 5 | units |
| *Skylight ceiling panels* | 800 | sf |
| *window weatherstriping* | 739.5 | sf |

Table U. 2. Cost breakdown for conservation of energy materials and installation

| Item | crew | daily output | labor hours | unit | material | labor | equipment | total |
|---|---|---|---|---|---|---|---|---|
| *9-1/2" thick R30 Batt insulation* | 1 carp | 500 | 0.016 | s.f. | 0.66 | 0.71 | 0 | 1.37 |
| *Polyethylene vapor barrier .002" thick* | 1 carp | 37 | 0.216 | sq (100sf) | 1.3 | 9.55 | 0 | 10.85 |
| *Polystyrene 1" thick R4 foam board insulation* | 1 carp | 680 | 0.012 | s.f. | 0.28 | 0.52 | 0 | 0.8 |
| *Threashold weatherstripping door sweep* | 1 carp | 25 | 0.32 | ea | 15 | 14.1 | 0 | 29.1 |
| *Insulating glass reduce heat transfer 1" thick 1/4" float, 1/4" tempered* | 2 glaz | 75 | 0.213 | s.f. | 18.9 | 9.1 | 0 | 28 |
| *window weatherstripping* | 1 carp | 7.2 | 1.111 | 0png | 13 | 49 | 0 | 62 |
| *Insulation removal* | 2 clab | 1000 | 0.016 | b.f. | 0 | 0.56 | 0 | 0.56 |

**Table U. 3. Cost of conservation of energy renovations**

| Item | Qty | Total Amount |
|---|---|---|
| *9-1/2" thick R30 Batt insulation* | 6041 sf | $8,276.17 |
| *Polyethylene vapor barrier .002" thick* | 4905 sf | $532.19 |
| *Polystyrene 1" thick R4 foam board insulation* | 2016 sf | $1,612.80 |
| *Threashold weatherstripping door sweep* | 5 units | $145.50 |
| *Insulating glass reduce heat transfer 1" thick 1/4" float, 1/4" tempered* | 800 sf | $22,400.00 |
| *window weatherstripping* | 739.5 sf | $3,056.60 |
| *Insulation removal* | | $3,382.96 |
| | Grand Total | $39,406.22 |

cpc
Community Partnerships Center
at Roger Williams University

Roger Williams University
One Old Ferry Road
Bristol, Rhode Island 02809

cpc@rwu.edu
http://cpc.rwu.edu