SENIOR THESIS FINAL DESIGN REPORT

TRY STREET TERMINAL BUILDING

620 SECOND AVENUE
PITTSBURGH, PA

PREPARED FOR:
THE PENNSYLVANIA STATE UNIVERSITY
DEPARTMENT OFARCHITECTUAL ENGINEERING
FALL ADVISOR: JAMES D. FREIHAUT
SPRING ADVISOR: JELENA SREBRIC

BY:
ERIN M. FAULDS
MECHANICAL OPTION
APRIL 12, 2007

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Art Institute
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SOUTH ELEVATION

GENERAL BUILDING DATA

- Location: Pittsburgh, PA
- Size: 230,000 SF
- 10 total floors, 9 floors above grade
- Renovation: October 2005 – April 2007
- Cost of Renovation: $21,000,000

MECHANICAL SYSTEM

- Water source heat pumps fed by 2 boilers and a fluid cooler on the roof
- 4 gas fired roof top make-up units supply required outdoor air to apartments
- 4 AHUs serve the basement and first floor spaces; each AHU is equipped with an electric duct heater

STRUCTURAL SYSTEM

- Cast-in-place concrete
- Flat slab floor system with 6.5" drop panels
- New 6" thick one way slabs frame to 44"x12" concrete beams
- Infill steel wide flange beams to reinforce where needed
- Modified Concrete Beams allow smaller member depth

LIGHTING

- Primarily fluorescent lighting
- Addition of a light well in the core of the building provides daylighting to interior apartments

ELECTRICAL SYSTEM

- (3) 750kVA vault transformers step down to 208/120V 3 phase 4 wire
- 250kW diesal generator provides emergency power at 208/120V

ARCHITECTURE

- Originally built in 1910 as an industrial building
- Facade includes existing concrete and brick with the addition of new historically accurate insulating windows
- Exterior walls are a mass wall construction
- Roof system consists of the existing roof slab with a new roofing membrane over rigid insulation

PROJECT TEAM

-Architect:	TKA Architects
-General Contractor:	Massaro Corporation
-Structural Engineer:	The Kachelle Group
-Mechanical Engineer:	McKamish
-Plumbing Engineer:	Sauer, Inc
-Fire Protection:	Ruthrauff, Inc.
-Electrical Engineer:	Star Electric Co.

EXECUTIVE SUMMARY

The Try Street Terminal Building project involves renovations to the 10 story, 230,000 square foot building originally constructed in 1910. Although the main function is to provide apartments for the Art Institute of Pittsburgh, other features include: an atrium, exercise room, first-floor retail space and possibly a convenience store and casual dining restaurant.

The existing mechanical system consists of water source heat pumps which are fed by 2 boilers and a fluid cooler on the roof. Ventilation air is brought in to these spaces on the 1^{st} thought 9^{th} floors by 4 Aaon 100% outdoor air units. Four self contained air handling units serve the unassigned basement and first floor spaces. However, these spaces are not the focus of this project.

The concentration of this thesis report was on the design of a geothermal heat pump system for the Try Street Terminal Building. The system was evaluated and compared to the conventional heat pump system. Based on the information and calculations performed the indirect-open loop system was recommended.

In addition, a computational fluids model was used to evaluate the temperature and air distribution in the two-story atrium spaces. The diffuser placement in this lobby and exercise room was found to be sufficient. Finally, an air quality study was performed to look at the benefits of implementing an ultraviolet germicidal irradiation system in some of the apartment units.

1.0 BUILDING OVERVIEW

1.1 SITE, ARCHITECTURE AND CONSTRUCTION

In 2000, when The Art Institute of Pittsburgh (AIP) moved across town to its current location on 420 Boulevard of the Allies, a considerable distance was created between the college and its sponsored housing at the Allegheny Center Apartment complex. Therefore, as can be seen in Figure 1.1-b the location of the Try Street Terminal Building at 620 Second Avenue provides a housing solution that is much closer to the AIP college campus.

Figure 1.1-a AIP Campus to Allegheny Center

Figure 1.1-b AIP Campus to Try Street Terminal

In addition to the distance created by the Art Institute of Pittsburgh's move in 2000, six years ago the college changed their degree program from a 2-year associate degree to a 4-year bachelor's degree program. This resulted in a greater need to house the increased number of students in the program. Consequently, the Art Institute became far more involved in residential construction. The Try Street Terminal Building has

since become 1 of 3 Downtown building renovations that the college is involved in. The restoring of these old building is not only meeting the needs of the Art Institute, but the city as well. These renovations are helping to bring younger people back to the city.

The building at 620 Second Avenue was originally constructed in 1910 as a nine-story concrete warehouse structure. With the disappearance of the railroad the use of the building has changed throughout the years. The building also known as, The Keystone Grocery Building, was also a former site of American Thermoplastics.

Figure 1.1-c The Try Street Terminal Building on left

Renovations, including the addition of a mezzanine level between floors 1 and 2, have transformed this 230,000 square foot building into a 10-story apartment complex which can accommodate 650 residents. Although the main function is to provide apartments for the Art Institute of Pittsburgh, other features include: a two-story atrium, sports

court and recreation space, 11,000 square foot activities lounge, and 9,000 square feet of retail space reserved for a convenience store and casual dining restaurant.

Because the project does include renovations to an industrial building that was constructed in 1910, special considerations were taken in order to preserve the appearance of the building's façade. In fact, according to a news article found on The Art Institute's website, the building is in the process of being designated a historic landmark. A lightwell in the core of the building was also added in order to satisfy a natural lighting requirement for the interior apartments set forth by the IBC 2003. The building footprint is approximately 24,600 square feet. On the 2nd through 9th floors, a 30 foot by 50 foot lightwell was cut in the core of the building. A driveway approximately equal to 3,700 square feet reduces the area on floors 1, 1A and the basement. Also equal to 3,700 square feet, a building setback decreases the area of the 8th and 9th floors. The primary focus of this project will be the apartment units on floors one through nine.

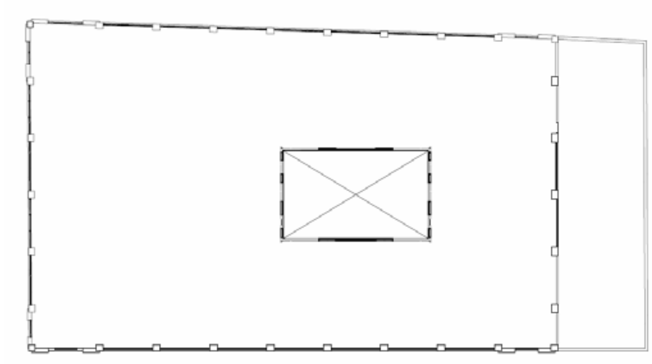


Figure 1.1-d Building Footprint - also shows location of lightwell and setback

Construction began on the existing structure in October 2005. The project team includes: **TKA Architects** as the architect, **Massaro Corporation** as the general

contractor, **The Kachelle Group** as structural engineer, **McKamish** as mechanical engineer, **Sauer, Inc.** as plumbing engineer, **Ruthrauff, Inc.** for fire protection and **Star Electric Company** as the electric engineer. The Try Street Terminal Building is still currently under construction and is expected to be complete in June 2007.

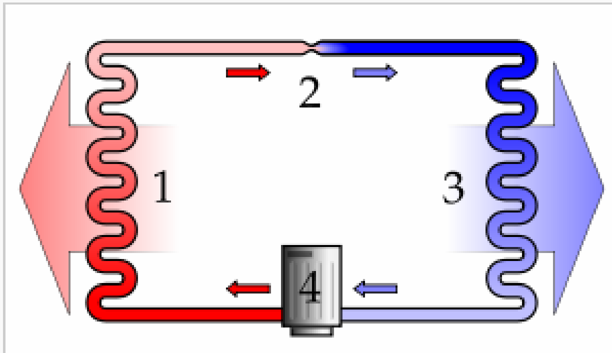
1.2 EXISTING MECHANICAL SYSTEM

The existing mechanical system consists of water source heat pumps (WSHPs) fed by 2 boilers and a fluid cooler on the roof. The 1^{st} through 9^{th} floor apartments are served by this system. Four self contained air handling units serve the unassigned basement and first floor spaces.

1.2.1 HEAT PUMP OPERATION

Heat pumps are devices that operate on a cycle known as vapor compression refrigeration. This cycle consists of four basic components which include the condenser coil, expansion valve, evaporator coil and compressor.

The condenser coil acts as a heat exchanger through which high temperature refrigerant flows and transfers its heat to a heat sink. During this process, the vapor condenses to a liquid which remain at a high temperature and high pressure. This liquid refrigerant then flows through an expansion valve where the temperature and pressure of the fluid are reduced. The liquid then flows through an evaporator which absorbs heat from the heat source. The heat source is the medium to be cooled. Therefore, as the source is cooled the refrigerant is heated causing it to evaporate within the coil back to a low pressure, low temperature vapor. Finally, this vapor then enters the compressor where its pressure and temperature are raised to a value in which it can condense back into a liquid in the following condenser step.



A diagram of a simple heat pump's vapor-compression refrigeration cycle: 1) condenser, 2) expansion valve, 3) evaporator, 4) compressor.

Figure 1.2-a Vapor Compression Refrigeration Cycle

Heat pumps also include an additional component called a reversing valve which reverses the direction of the refrigerant flow. Reversing the flow provides the heat pump with the capability of providing heating or cooling to the building. When the valve is switched the condenser functions as the evaporator and the evaporator functions as the condenser.

Conventional or geothermal exchange may be used by the heat pump system in order to absorb heat or reject heat to the environment. Geothermal exchange will be studied later in this report.

1.2.2 WATER SOURCE HEAT PUMPS

The conventional WSHP system in the Try Street Terminal Building is a heating and cooling system which places a Whalen Series VI heat pump in each individual zone. A piping system that connects this conventional system circulates water between 60F and 90F to and from the heat pumps. The advantage of this arrangement is that the heat pumps are capable of simultaneously heat and cooling. When this occurs the water

loop generally maintains its 60-90F range because heat removed from one space is rejected to the loop and then used to heat a space that is in heating mode.

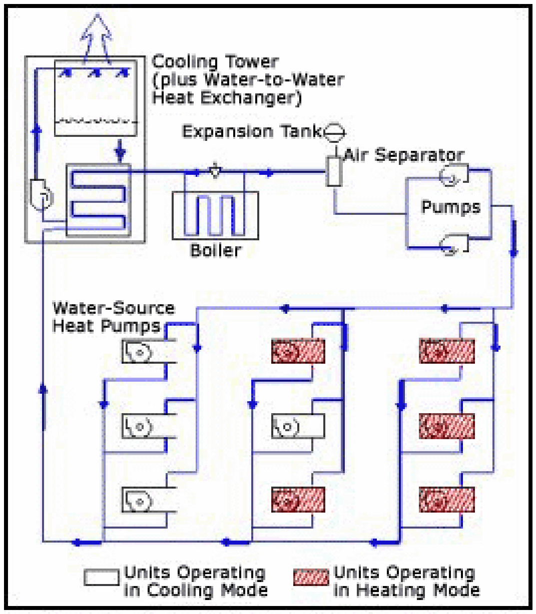


Figure 1.2-b WSHP System - can simultaneously heat and cool

When the majority of the units are in the heating mode, the loop temperature may fall below the lower range limit of 60F. In that case, heat will be added to the loop by the two Raypak gas fired boilers. This hot refrigerant flows through the air coil then warms the air to be supplied to the conditioned space. Heat added to the room is removed from the water through the water coil and through the rejected compressor heat.

In cooling mode, the loop temperature may exceed the upper limit of 90F. Therefore, a Baltimore Aircoil Company, FXV closed circuit cooling tower provides the necessary condenser water to the heat pumps. This cold refrigerant flows through the coil which then cools the conditioned supply air. Heat removed from the air is transferred to the water flowing through the water coil.

1.2.3 LAYOUT OF AIR HANDLING UNITS

The existing mechanical system in the Try Street Terminal Building consists of 8 new air handling units. Four Carrier indoor self contained, air-cooled vertical package units supply constant volume cooling of 47 tons to the basement and first floor unassigned spaces. For each of these units, approximately 30% of the supply air is fresh outdoor air. The units are also equipped with electric open coil duct heaters which provide the necessary heating. The other four units are Aaon rooftop make-up air units (MAUs). These MAUs are 100% outdoor air units that provide 122 tons of cooling. They supply the required ventilation to all the apartments and corridors on floors 1-9. The lobby is also served by these units. Since the Carrier air handling units serve unassigned spaces in the basement and first floor, these areas were not a focus of the project. The focus of this project is primarily on the apartment spaces on floors 1-9. The general distribution of the outdoor air supplied by the MAUs to floors 1-9 is shown below.

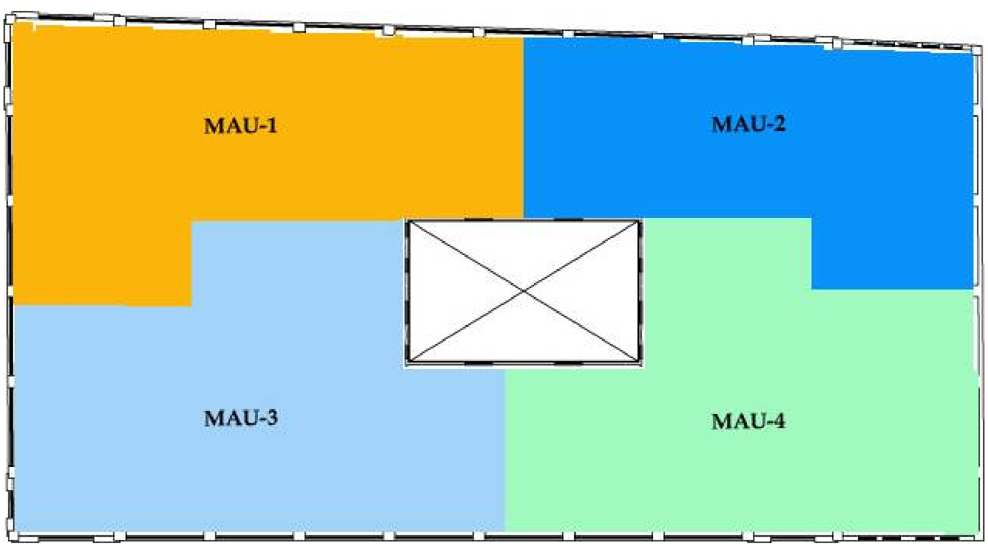


Figure 1.2-c Floors 1-9 General existing MAU layout

In addition to the units discussed above, a 10 ton fan coil unit was designed to supply the required outdoor air to the exercise room located on the first floor.

1.2.4 VENTILATION ANALYSIS: STANDARD 62.1

The main purpose of ASHRAE Standard 62.1-2004 is to specify the minimum ventilation requirements and consequent indoor air quality that will be considered acceptable to human occupants. For new buildings and renovations to existing buildings, the standard is intended to be used as a way to regulate the indoor air quality by prescription. Acceptable indoor air quality is defined as air having no harmful concentrations of contaminants. Using the Ventilation Rate Procedure it was shown that the make up air units, air handling units and fan coil unit were sized more than adequately in order to achieve an acceptable indoor air quality level.

SUMMARY OF UNITS			
UNIT NAME	V_{ot} (cfm)	OA SUPPLIED (cfm)	COMPLIES WITH STANDARD 62.1?
MAU-1	3,461	5,625	YES
MAU-2	1,988	4,820	YES
MAU-3	3,049	7,550	YES
MAU-4	2,896	5,830	YES
AHU-1	2,193	2,490	YES
AHU-2	907	1,300	YES
AHU-3	2,085	2,220	YES
AHU-4	752	960	YES
FCU-6	2,365	4,000	YES
*Note: V_{ot} is the required outdoor air intake flow			

Figure 1.2-d Ventilation air comparison

1.2.5 LEED ASSESSMENT

The Leadership in Energy and Environmental Design (LEED) rating systems were developed by the U.S. Green Building Council (USGBC) committees and meant to encourage sustainable design. The rating system is applicable to new commercial construction, as well as major renovation project. The 6 major categories that make up the rating system are: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, and Innovation and Design Process. Although the Try Street Terminal Building was a major renovation project, only a few points were earned in this assessment. Therefore, no certification was earned. LEED design was not considered in the original plans for the building nor was it considered in the alternative designs.

1.2.6 ASHRAE STANDARD 90.1 ASSESSMENT

The purpose of ASHRAE Standard 90.1 is to provide minimum requirements for the energy-efficient design of buildings with the exception of low-rise residential buildings. This standard applies to the building envelope, as well as the following systems and equipment used in buildings:

- heating, ventilation and air conditioning
- service water heating
- electric power distribution and metering provisions
- electric motors and belt drives
- lighting

The main focus of the Try Street Terminal assessment was on the building envelope and lighting compliance.

1.2.6.1 BUILDING ENVELOPE COMPLIANCE

The building envelope refers to the walls, windows, and roof that separate a building's indoor conditioned spaces from the outdoor environment. Carrier's Hourly Analysis Program (HAP) was used to determine the wall, roof and window U-values which all complied with the standard. The vertical and skylight fenestration areas also complied.

1.2.6.2 LIGHTING COMPLIANCE
The interior power lighting allowance is determined to minimize energy usage. When calculating the lighting compliance it was found that only half the spaces complied with Standard 90.1.

1.2.7 LOST RENTABLE SPACE

The mechanical system lost rentable space can be best described as the space occupied by mechanical equipment, rooms and shafts. Because these mechanical spaces reduce the amount of space rentable by the tenants, the space is considered to be a lost profit by the owner. For the Try Street Terminal Building, the lost rentable space appears to be minimized with only a 2.8% total impact on the basement through ninth floors. It is likely that this impact is minimized because of the mechanical penthouse and equipment, such as exhaust fans and make-up air units, being located on the roof.

1.2.8 MECHANICAL FIRST COST

The total HVAC cost for the Try Street Terminal Building amounted to $2,014,000.00 for floors 1-9. Therefore, the approximate cost per square foot is $9.17/ft^2. A more detailed breakdown of the mechanical cost was requested. However, this information was not available.

1.2.9 ENERGY ANALYSIS

Because the Try Street Terminal Building is currently under construction actual energy data was not available. Also, an energy analysis from the designer was not available for comparison because one was not performed. An analysis was not completed because first cost was the primary concern of the project. However, an energy analysis was conducted using Carrier's HAP for comparison to thesis depth work discussed later in this report.

Since the building's primary function is apartments, a 24 hour fully occupied schedule was assumed. The only exception to this schedule was made was for an assumed first floor retail space. In that case, the schedule was estimated from 8:00am to 9:00pm. The following tables and figures depict the existing building's annual energy consumption, as well as, the associated component and energy costs. It should also be noted that many assumptions were made in order to simplify the calculation process. Therefore, these assumptions may be the source of any inaccuracies.

Also, the source of energy for the Try Street Terminal Building is both electric and natural gas sources. Based on rates from respective energy provider websites, the energy rates assumed for this analysis were $0.087 per kWh and $1.594 per therm.

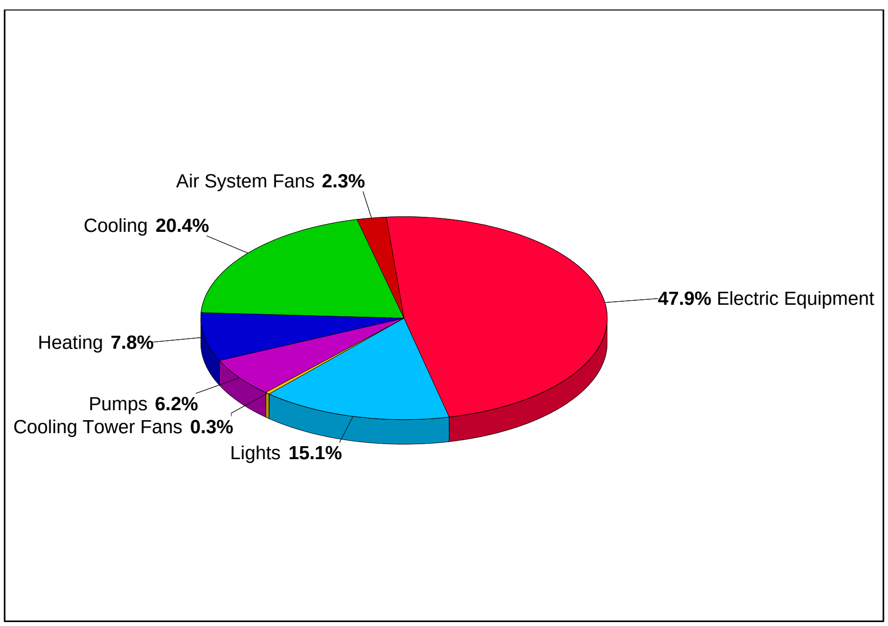


Figure 1.2-e Annual Component Costs - Existing Building

Component	Annual Cost ($)	($/ft²)	Percent of Total (%)
Air System Fans	21,335	0.127	2.3
Cooling	187,220	1.115	20.4
Heating	71,185	0.424	7.8
Pumps	56,924	0.339	6.2
Cooling Tower Fans	3,201	0.019	0.3
HVAC Sub-Total	**339,865**	**2.024**	**37.1**
Lights	138,214	0.823	15.1
Electric Equipment	439,187	2.615	47.9
Non-HVAC Sub-Total	**577,402**	**3.439**	**62.9**
Grand Total	**917,266**	**5.463**	**100**

Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area **167920.4** ft²

Conditioned Floor Area **167920.4** ft²

Table 1.2-a Annual Component Costs - Existing Building

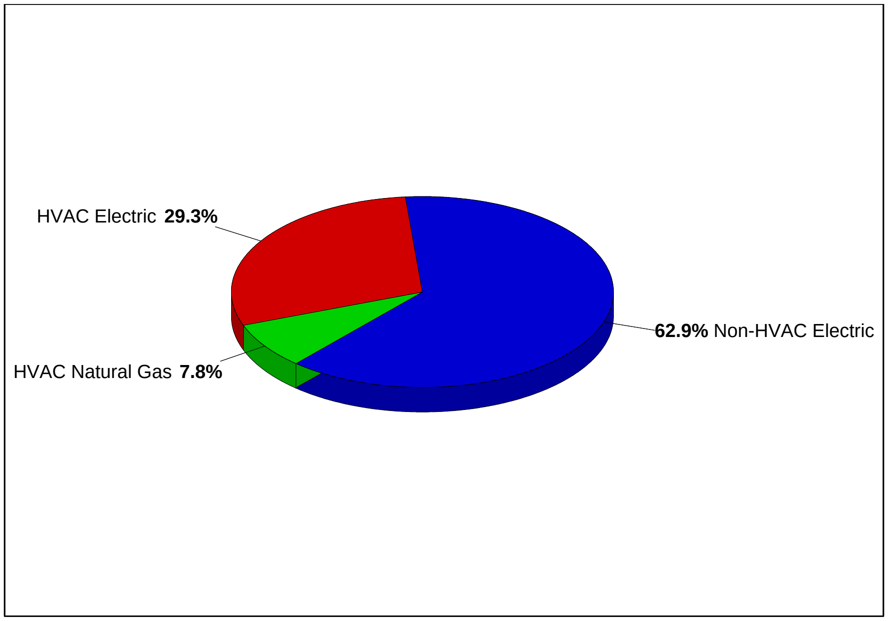


Figure 1.2-f Annual Energy Costs - Existing Building

Component	Annual Cost ($/yr)	($/ft²)	Percent of Total (%)
HVAC Components			
Electric	268,765	1.601	29.3
Natural Gas	71,097	0.423	7.8
HVAC Sub-Total	**339,863**	**2.024**	**37.1**
Non-HVAC Components			
Electric	577,381	3.438	62.9
Natural Gas	0	0	0
Non-HVAC Sub-Total	**577,381**	**3.438**	**62.9**
Grand Total	**917,243**	**5.462**	**100**

Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area	**167920.4**	ft²
Conditioned Floor Area	**167920.4**	ft²

Table 1.2-b Annual Energy Costs - Existing Building

It should also be noted that this model for the existing building differs from the model presented in last semester's technical reports. In the previous model a pumping component and energy cost was nearly fifty percent of the cost. Therefore, further review of the model was completed and a new model was generated. The results of this energy model as seen above seems to depict numbers that correspond more to my building application.

2.0 DEPTH WORK – ALTERNATIVE MECHANICAL DESIGN

2.1 OBJECTIVES OF ALTERNATIVE

The main goal of the design alternative system is to analyze potential energy savings compared to the current conventional water source heat pump system. While first cost was the primary concern for the existing design, this report will evaluate the possible savings over the life of the building. Factors such as installation, operation, and maintenance costs will be taken into consideration. It is important to note that the alternative presented in no way implies that there were any problems with the original design or that another design should have been pursued.

2.2 OVERVIEW OF GROUND SOURCE HEAT PUMP SYSTEMS

The concentration of this thesis depth is on the use of a geothermal system for the Try Street Terminal Building. With a ground source heat pump (GSHP) system design there are many factors to consider. Compared to the conventional system, the geothermal system can significantly reduce the energy consumed by a building. The operation and maintenance associated with the geothermal system is also considerably less when compared to the conventional. However, the installation cost can be more expensive.

The two types of ground source heat pumps that will be discussed in this section are the closed and open loop systems. There are two classifications of closed loop that include vertical and horizontal loops. With these two classifications, the ground-coupled system will be considered. As for the open loop system, the groundwater heat pump system will be presented. It should be noted that GSHP can be referred to as several

different names. In this document they may be referenced to as: geothermal, earth-coupled, groundwater, ground-coupled, closed loop and open loop heat pump systems. Following this open and closed loop system discussion, the application chosen as the primary geothermal focus will be confirmed.

2.2.1 CLOSED LOOP SYSTEMS

With the closed loop ground-coupled heat pump (GCHP), a vertical or horizontal design may be chosen. In this system, heat is exchanged between the water circulating in the pipes and the relatively constant temperature of the soil. With the vertical arrangement, a series of vertical pipes that circulate water are buried deep within the ground. This arrangement requires approximately 250 to 300 ft^2 of surface area per ton of cooling. With the horizontal GCHP, a network of pipes is distributed horizontally at a more shallow depth. The horizontal system requires approximately 2500 ft^2 of surface area per ton of cooling. An advantage of this geothermal system is that the need for a cooling tower and boiler may be eliminated. This is possible because in the summer, heat from the building is rejected to the ground. While in the winter, the ground source heat pump would utilize the heat stored in the ground.

Figure 2.2-a Vertical (left) & Horizontal (right) Closed Loop

Assuming that there is adequate room on the site, the horizontal system provides several advantages over the vertical system. Some of these advantages include: known geology, lower excavation cost, and lower installation equipment cost. However, disadvantages exist such as pipe loops close to surface, removal of rocks and the likelihood of additional required excavation.

2.2.2 OPEN LOOP SYSTEMS

The concept of heating and cooling in an open loop is similar to the closed loop ground-coupled system except that groundwater is the source. With the open loop ground water heat pump (GWHP) system the fluid is not confined to a loop of pipes. Rather a pumping well is used to move the water through the heat pump. The open loop system can take on several configurations which include: direct use, indirect use, and standing column. With the direct arrangement, groundwater is used directly in the heat pump units and is typically limited to the smallest applications. The standing column system produces and returns water to the same well. Both the standing column and direct use are susceptible to water quality induced problems, such as scaling of the refrigerant-to-water heat exchangers. However, the indirect method utilizes a plate heat exchanger to isolate the building loop from the ground water which protects the building equipment from the scaling mentioned above. In addition, the separation allows the loops to operate at different flow rates which optimize the system performance. The following figure depicts the three different open loop configurations.

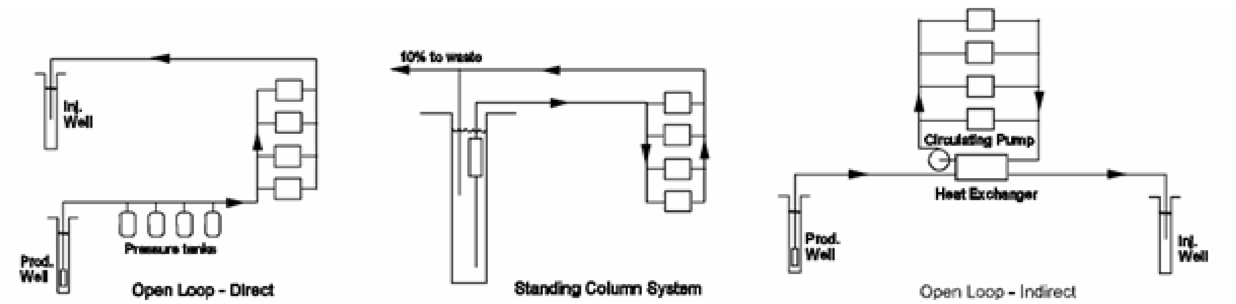


Figure 2.2-b Open Loop Configurations

2.2.3 PRIMARY FOCUS – OPEN LOOP-INDIRECT SYSTEM

Based on the information presented in the previous sections, it was determined that the open loop-indirect use system would best meet the design requirements of the Try Street Terminal Building. Due to site limitations and high installation cost, the closed loop systems were eliminated as possibilities. The scale of the project and water quality induced problems were some of the factors causing the dismissal of the open loop-direct and standing column systems.

For the indirect open loop, one and two well systems are possible. The one-well system that utilizes a surface disposal method was not chosen for several reasons. With the surface disposal, the return water is diverted to a surface body of water, such as a river. This was not considered a feasible option because of the building's location downtown. The closest body of water, the Monongahela River is approximately 600 feet away. Discharging this return water into the river may also require a National Pollutant Discharge Elimination System (NPDES) permit. Therefore, the more common commercial two-well approach was chosen to be analyzed. One well will be used for supply/production and the other for return/injection. It was also found that return wells for groundwater heat pumps are classified as Class V injection well by the U.S.

Environmental Protection Agency. These types of wells have been determined not to pose a significant threat to the environment. In Pennsylvania these wells are also known as return, recharge, or diffusion wells and do not require a permit.

2.3 UNDERGROUND RIVER

The water source to be used for this groundwater application is an aquifer. The proper name for this underground river is the Wisconsin Glacial Flow. This is because it was formed by the Wisconsin Ice Sheet that covered much of the Northern United States during the Ice age (70,000 year ago). Geologists also refer to this water source as an aquifer. An aquifer is described as having irregular, widespread flow and not following a channel. However, the underground river differs from these characteristics making it more like a true river.

The underground river water is said to be a fresh, fairly constant 55F source with no bacteriological count. It is actually a drinking source for much of downtown Pittsburgh. The fountain at Point State Park is also fed by this water.

The David L. Lawrence Convention Center, is a 1.5 million square foot convention, conference and exhibition building in downtown Pittsburgh, Pennsylvania. It sits along the Allegheny River and about a mile from the Try Street Terminal Building. It is also the first LEED certified "green" convention center in North America and one of the first in the world. The reason this is mentioned is because one of the proposed designs included the underground river to be used for 5000 tons of condenser cooling. With their intention to use this water source further investigation was needed to determine items such as the water table depth below the surface, quality of the soil, and flow rate of the water. As a result, a 12hr and 24hr drawdown test was performed and showed that the flow rate available was 1100 gpm.

2.4 PROCEDURE AND CALCUATIONS

The rating intended for the conventional WSHP systems is the ARI 320 rating, where stands for the Air Conditioning & Refrigeration Institute. The cooling performance (EER) is reported for an 85F entering water temperature and a 70F value for heating. Because this equipment is not intended for GSHP system, new heat pumps should be selected. The ARI rating for the GSHP system is reported as both the EER and COP having 70F and 50F entering water temperatures.

In most applications, the optimum system performance occurs when the groundwater flow rate is between 1 to 2.25 gpm/ton and the building loop flow rate is in the range of 2 to 3 gpm/ton. Therefore, knowing the heat of rejection and absorption of 4,200 MBH and 1053 MBH, respectively the plate and frame heat exchanger was sized using the Mueller Accu-Calc Heat Exchanger Calculator for the governing cooling conditions. The entering groundwater loop temperature of 55F was known along with a 59F leaving water loop temperature. Therefore, to size the heat exchanger various combinations of the building and ground loop in the ranges mentioned above were entered until the optimum combination shown in Figure 2.4-a were achieved. This calculation resulted in an 875 gpm building loop flow rate and a 788 gpm groundwater loop flow rate with a 3.4F approach. The program used to calculate this information is show below. Based on this calculation a Mueller 60MH model heat exchanger with 348 plates and 2,320 ft^2 heat transfer area was chosen.

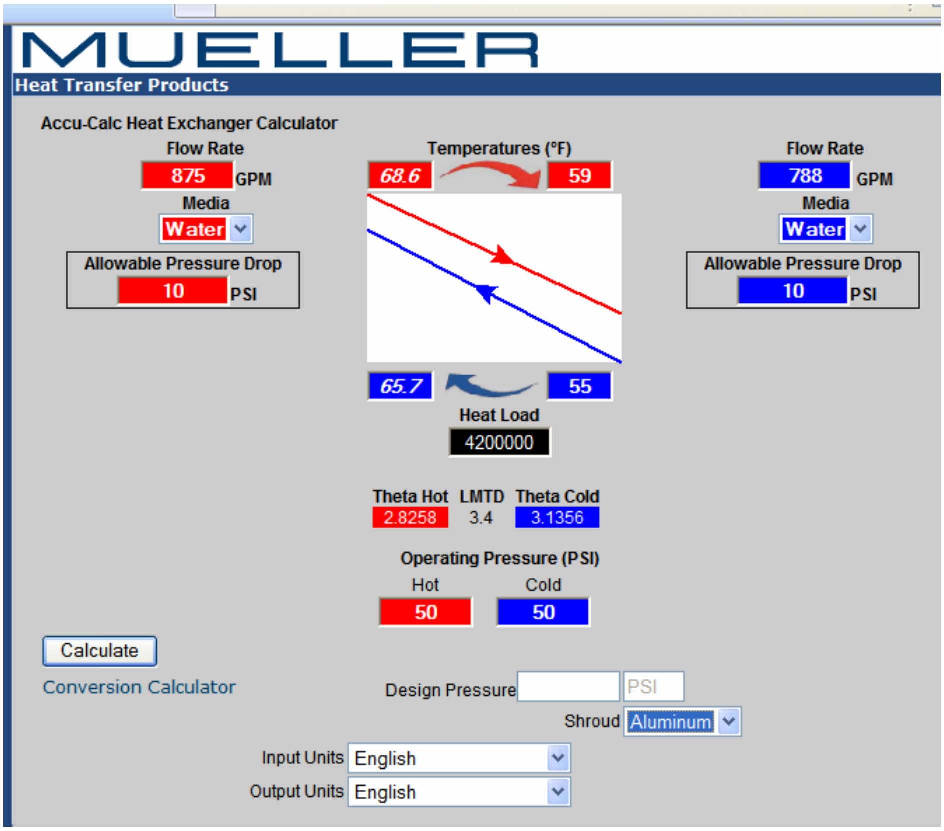


Figure 2.4-a Heat Exchanger Calculator

2.4.1 HAP ENERGY ANALAYSIS

Using the existing building model as a base case, Carrier's Hourly Analysis Program (HAP) was used to perform an energy analysis of the new groundwater open loop system. It should be noted that an indirect model was not able to be performed with this software. Therefore, an open loop direct use system was modeled. For the purpose of this evaluation the model was considered to be an accurate representation of the indirect use system. When viewing the results below, one may notice a building area lower than that of the Try Street Terminal Building. Since the apartments are the primary focus of this project, this area represents the total percent of apartment and other spaces with heat pump units. Comparing these results to the existing building results it is noticed that there is a reduction of about 30% in cooling component cost.

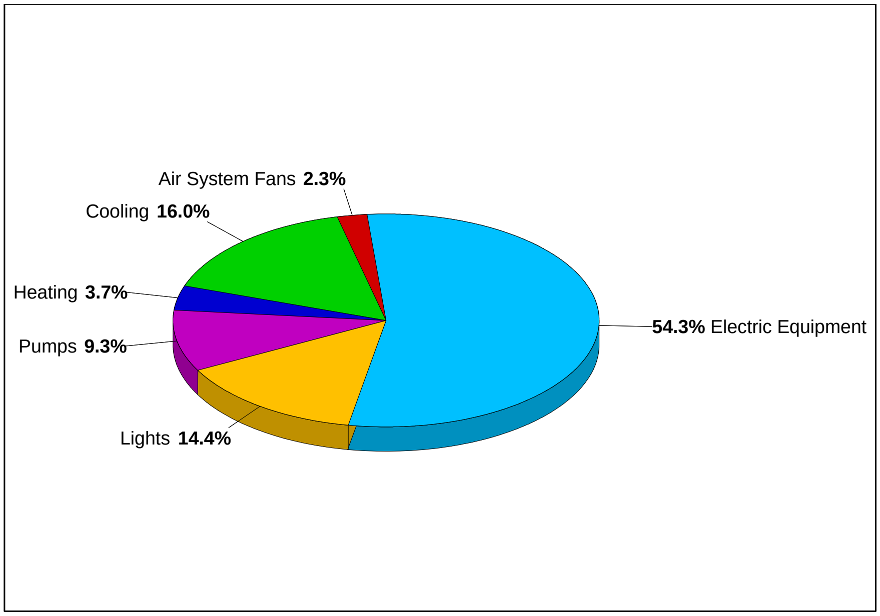


Figure 2.4-b Annual Component Cost - GWHP design

Component	Annual Cost ($)	($/ft²)	Percent of Total (%)
Air System Fans	18,554	0.131	2.3
Cooling	129,843	0.919	16
Heating	30,234	0.214	3.7
Pumps	75,128	0.532	9.3
Cooling Tower Fans	0	0	0
HVAC Sub-Total	**253,758**	**1.796**	**31.4**
Lights	116,317	0.823	14.4
Electric Equipment	439,187	3.108	54.3
Non-HVAC Sub-Total	**555,505**	**3.931**	**68.6**
Grand Total	**809,263**	**5.727**	**100**

Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area **167920.4** ft²

Conditioned Floor Area **167920.4** ft²

Table 2.4-a Annual Component Costs - GWHP design

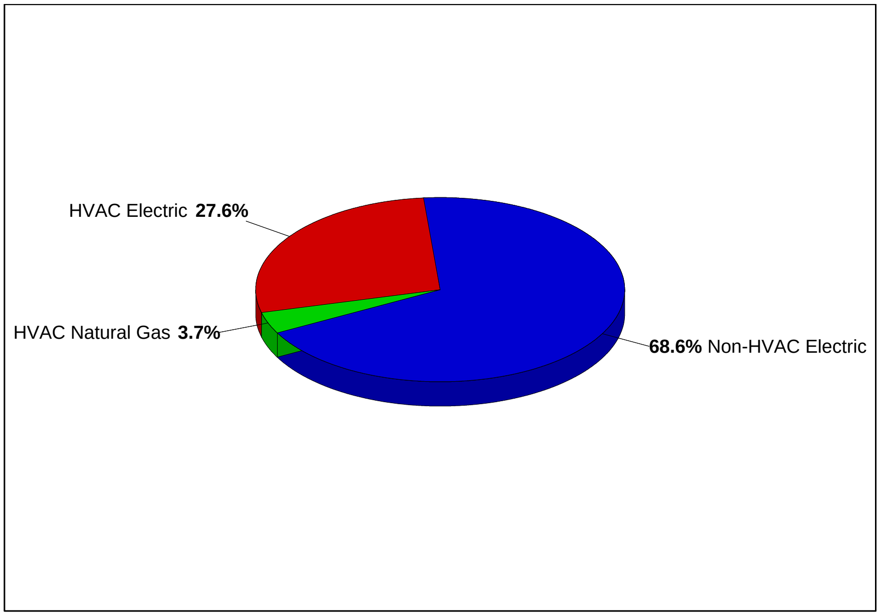


Figure 2.4-c Annual Energy Costs - GWHP design

Component	Annual Cost ($/yr)	($/ft²)	Percent of Total (%)
HVAC Components			
Electric	223,635	1.583	27.6
Natural Gas	30,126	0.213	3.7
HVAC Sub-Total	**253,762**	**1.796**	**31.4**
Non-HVAC Components			
Electric	555,486	3.931	68.6
Natural Gas	0	0	0
Non-HVAC Sub-Total	**555,486**	**3.931**	**68.6**
Grand Total	**809,248**	**5.727**	**100**

Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area **167920.4** ft²

Conditioned Floor Area **167920.4** ft²

Table 2.4-b Annual Energy Costs - GWHP design

2.4.2 RETScreen PROJECT MODEL

RETScreen software was used to create a ground source heat pump project model. With this program a project was created that evaluated the heating and cooling loads, performed an energy model, completed a cost analysis, analyzed the reduction of greenhouse gas emissions, and included a financial summary. A sensitivity and risk analysis was chosen not to be competed.

Overall, compared to the HAP analysis the RETScreen model provided comparable results in corresponding HAP categories such as heating and cooling loads and building/groundwater loop calculations. Therefore, the year-to-positive cash flow of 12 years was considered reasonable estimate.

2.5 FINAL RECOMMENDATION

Based on the information available and the calculation performed it would be recommended for an indirect-open loop heat pump system to be installed. Although the simple payback exceeds the typical 3-5 year payback period, the energy savings remains appealing. Also, the Art Institute has made a 20 year commitment to the property. Therefore, the Art Institute would be able to benefit from the energy savings associated with this geothermal system.

3.0 BREADTH WORK – COMPUTATIONAL FLUID MODEL ANALYSIS

3.1 ANALYSIS OF ATRIUM SPACES

When the Art Institute of Pittsburgh chose to restore the Try Street Terminal Building for student housing, many features and amenities were included in the renovation design in order to add to the residents' campus experience. Two of these features include a two-story lobby and exercise room located in the building core of the 1^{st} floor. The first floor areas of these spaces are 1,650 ft^2 and 2,750 ft^2, respectively. However, on the second level the floor intrudes this atrium space reducing the total opening over these areas to approximately 90 ft x 30 ft. Also, the lightwell above the lobby and exercise room provides natural light to these spaces through (4) 30 ft^2 skylights. Additionally, the lobby area has (4) 330 cfm and (2) 140 cfm supply air diffusers, while the exercise room has (4) 1000 cfm supply diffusers. Some typical problems associated with atriums are air and temperature distribution due to the improper location of diffusers. Therefore, to analyze if these problems occur in the Try Street Terminal Building a Computational Fluid Model of the space was developed using Phoenics VR.

3.1.1 PHOENICS MODEL

Using the Phoenics VR Editor a three dimensional model of the atrium space was developed. The dimensions of the lobby and exercise room were added and entered in meters for the domain size. The equivalent size of the domain is 36m x 12.192m x 5.6m. The geometric setup of the model also included choosing the cell size, number of cells, number of regions, and cells per region. The distribution of the computational grid mesh created is important because it effects the calculations which are performed in each cell in the model. Three thousand iterations were set to be calculated in this model. This means that each cell in the model will be calculated 3,000 times. Therefore,

Phoenics will have to complete millions of calculations simultaneously. The calculation time needed to perform these calculations was 4 hours.

Figure 3.1-a below shows the location of major blockages such as the walls, columns, and floors. Inlets for the diffusers were then inserted into the model with the appropriate flow rate. Because no exhaust is shown on the mechanical plan the only outlets represented in the model are doorways into the spaces. The estimated total heat gain in the lobby and exercise room was also determined based on occupancy, occupancy activity and average incident solar radiation through the skylights. A total of 5000 W was calculated for the lobby and 12,000 W for the exercise room. To account for this, a heat source was then introduced into each space as a flat plat on the floor surface. The approximate heat gain was then evenly distributed throughout this surface.

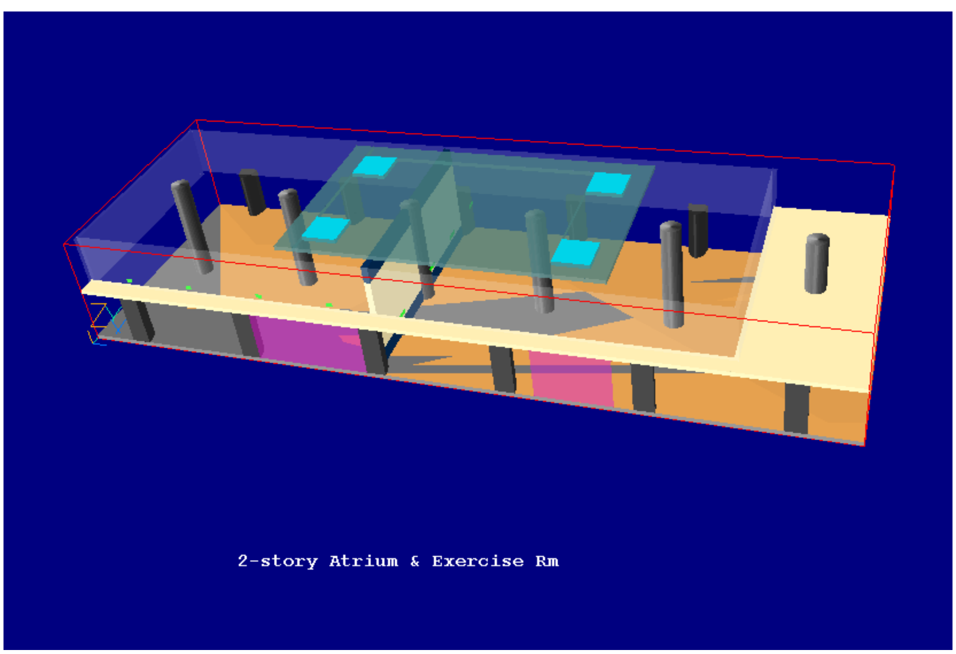


Figure 3.1-a Phoenics 3-D Building Model

3.1.2 PHOENICS RESULTS

After the model was set up and the Solver completed the calculations, the results could be viewed in the VR Viewer. The following figures in this section will show the resulting velocity and temperature files of the Phoenics program. Shown in Figure 3.1-b is the result for the model after 3,000 iterations. Since the values of the variables on the left convergence monitor have not fully approached a constant value the resulting calculated flow field parameters may not be reliable. However, for educational purposes the results will serve as a demonstration of the realistic result.

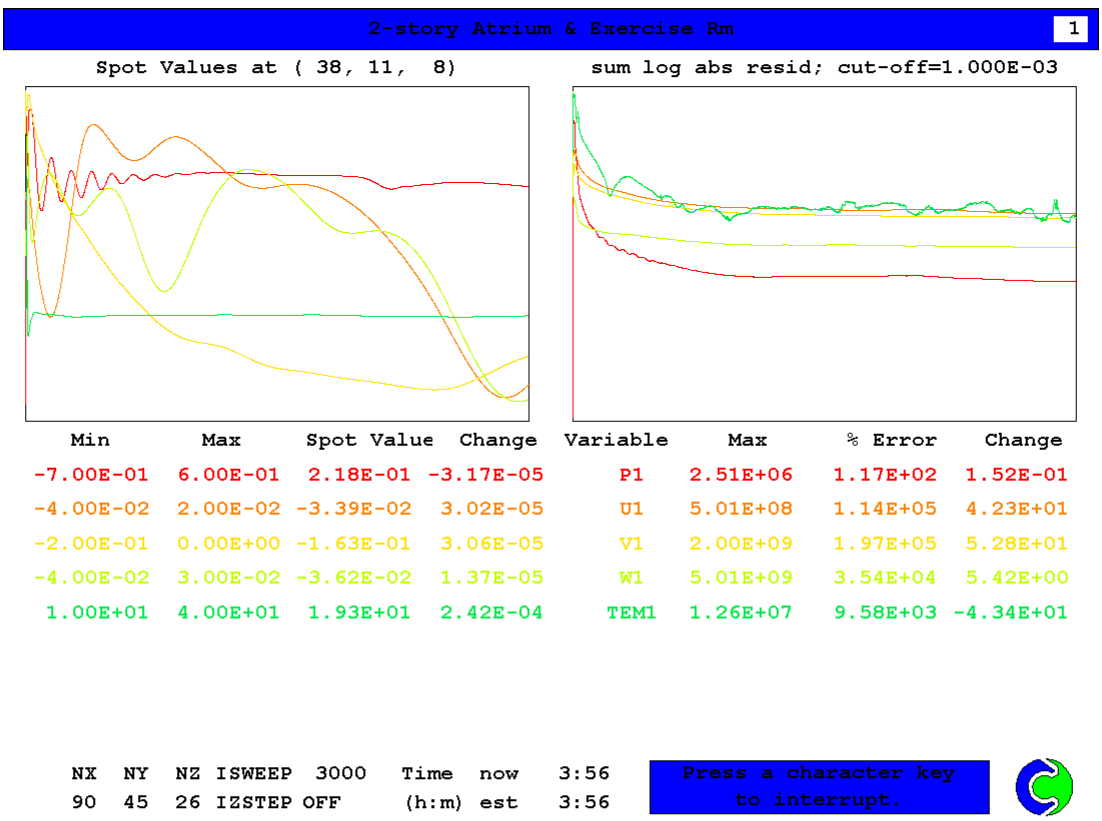


Figure 3.1-b Phoenics Result

Figure 3.1-d to Figure 3.1-g below show velocity cuts on the X, Y and Z axis. The velocity Z slices are taken at the level of the diffusers and directly through them. From these figures one can tell that the direction of air flow is correct. Referring to the side velocity legend in the figures shows that the velocity ranges from 0.88 - 3 m/s. This maximum velocity only appears in the slices directly through the diffusers and at the 2.6 m height of the diffusers. The velocity in the area beneath the diffusers and closer to the level of occupants at 1.5 m is an air velocity of less than or equal to about 1 m/s. This velocity would still be considered acceptable. Even thought the air movement might be slightly more noticeable the majority of the occupants should have a pleasant comfort level.

Air Velocity - Comfort	
m/s	**Occupant Comfort**
0.25	unnoticed
0.25-0.51	pleasant
0.51-1.02	geneally aware of air movement
1.02-1.52	drafty
>1.52	problem

Figure 3.1-c Occupant Comfort as result of Air Velocity

The X and Y axis model slices only go to further show the points discussed above. These figures simply depict the results in a different perspective.

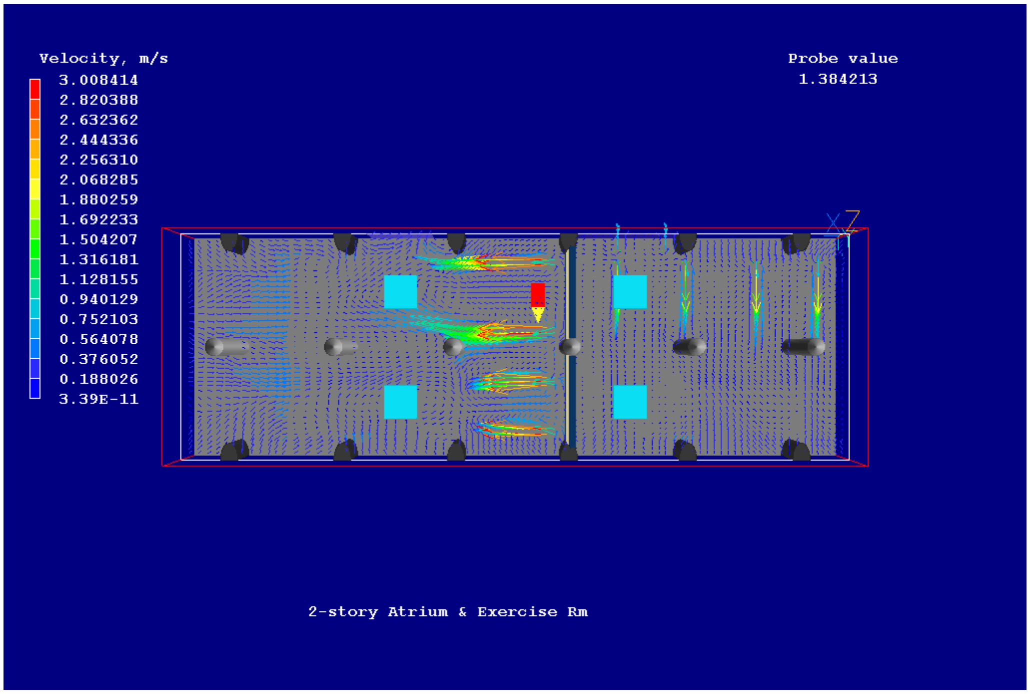


Figure 3.1-d Phoenics Velocity Z Slice 1

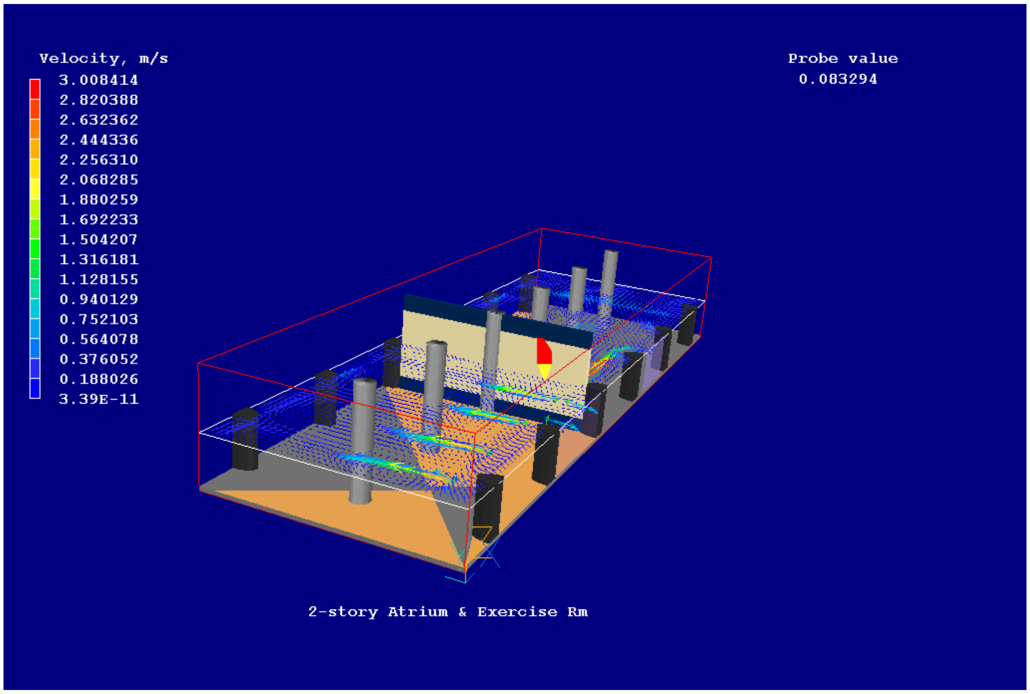


Figure 3.1-e Phoenics Velocity Z Slice 2

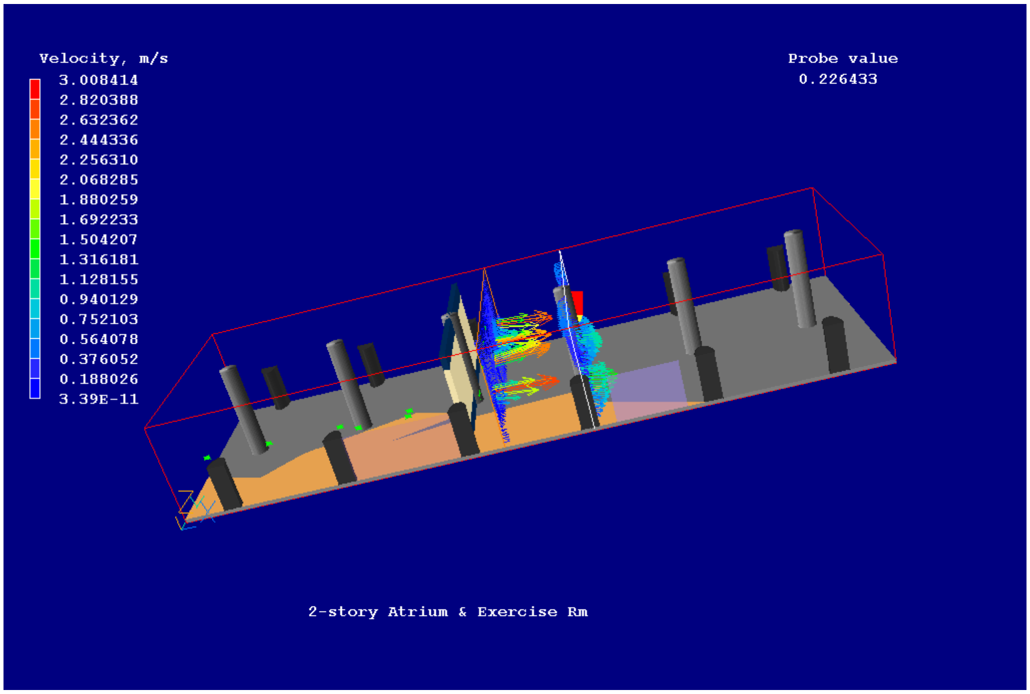


Figure 3.1-f Phoenics Velocity X Slice

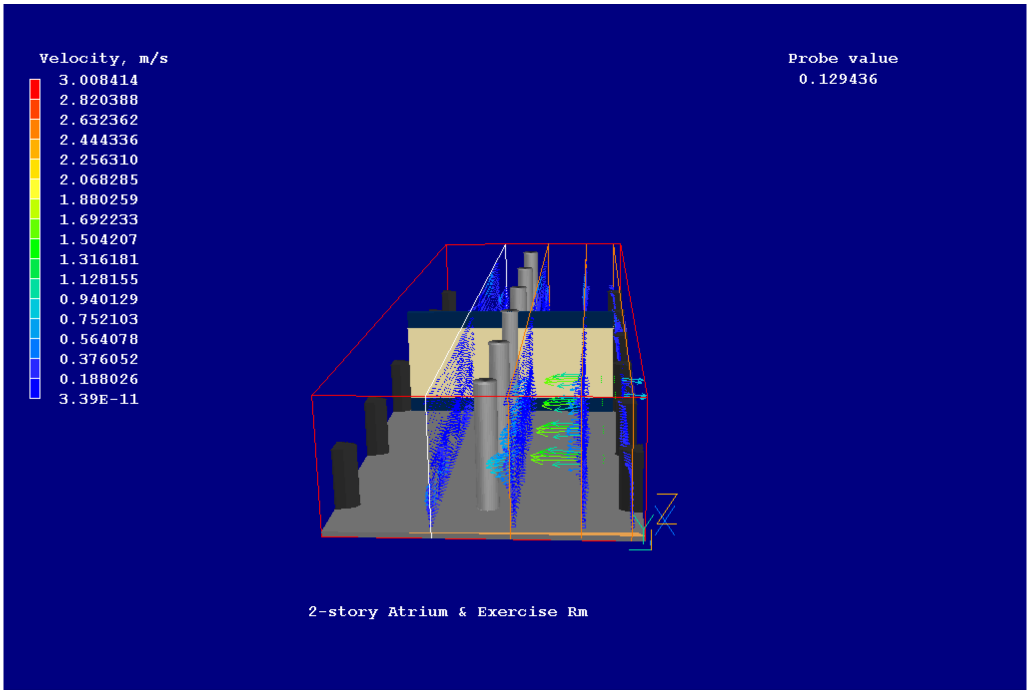


Figure 3.1-g Phoenics Velocity Y Slice

Now, Figure 3.1-h through Figure 3.1-k will portray the temperature results. It is important to note that this atrium space was evaluated for cooling with a supply air temperature of 55 F or 13 C. Similar to the velocity profiles, the Z slices through the diffuser show the extreme conditions. The dark blue in the diffuser stream represents a temperature of about 59 F. Based on the figures below the temperatures seem to be distributed throughout the space well. Most temperatures in the lower level of the atrium appear to be around 66F (19 C).

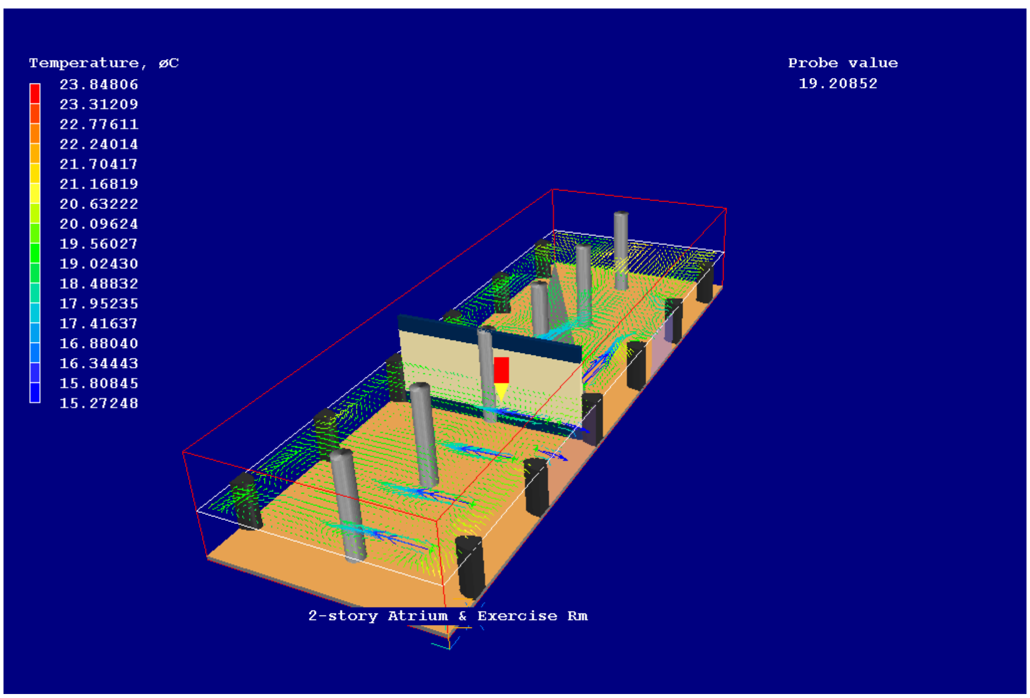


Figure 3.1-h Phoenics Temperature Z Slice 1

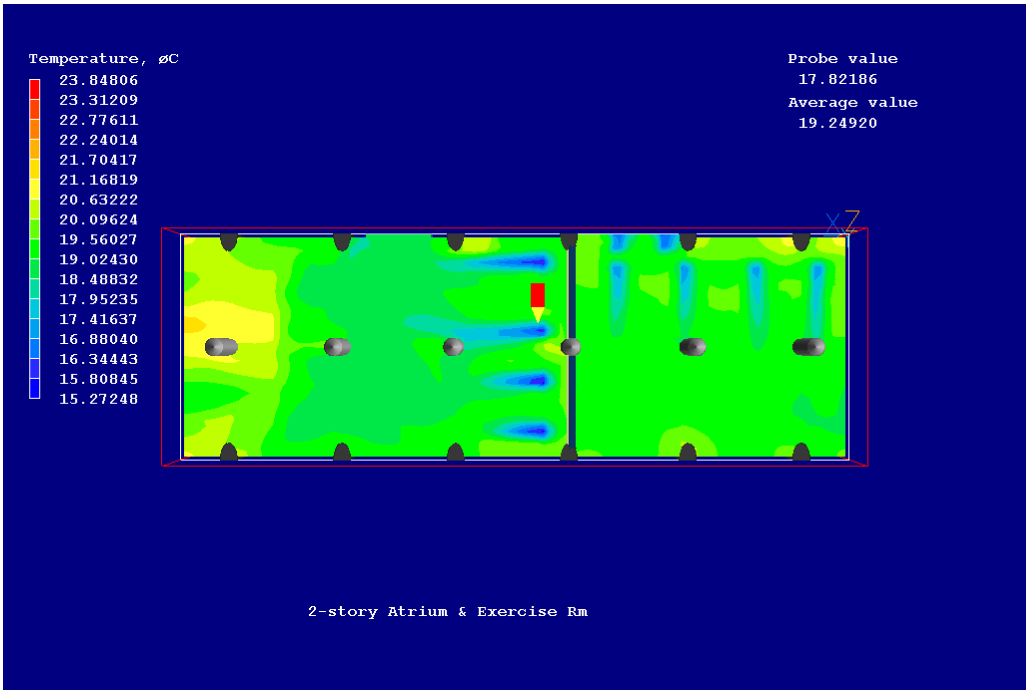


Figure 3.1-i Phoenics Temperature Z Slice 2

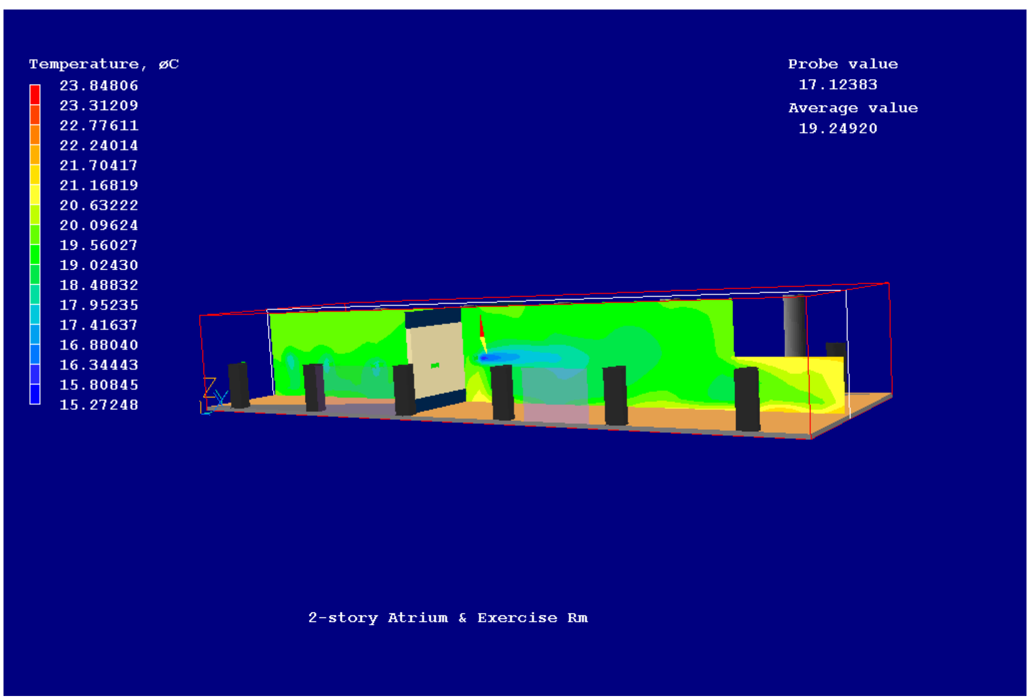


Figure 3.1-j Phoenics Temperature Y Slice 1

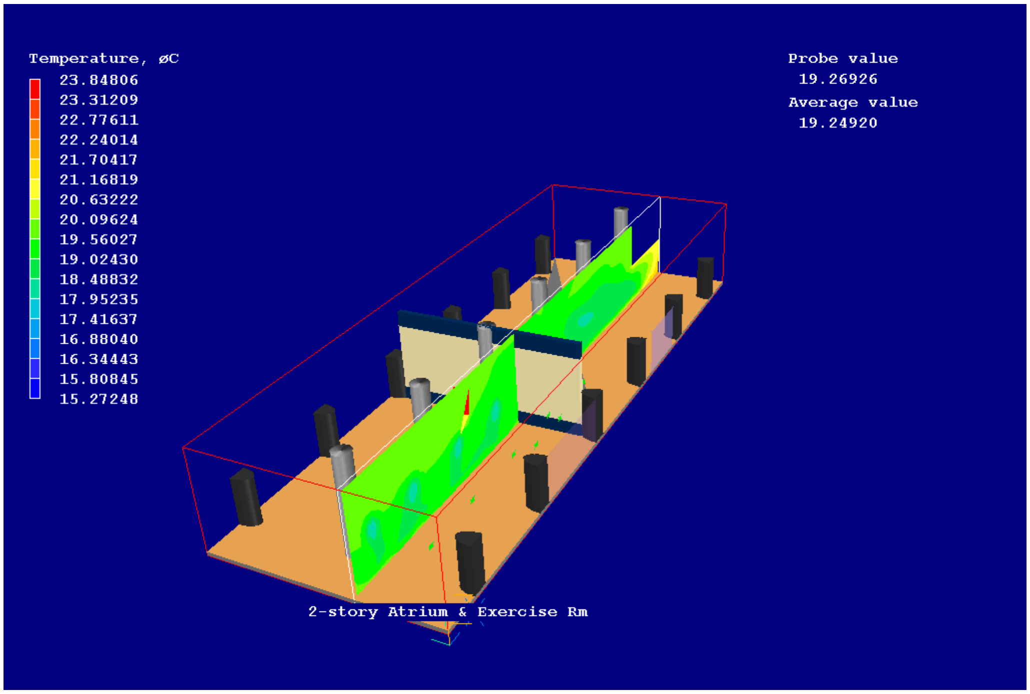


Figure 3.1-k Phoenics Temperature Y Slice 2

3.1.3 CONCLUSION DRAWN FROM MODEL

Based on the computational fluid model the design appears to sufficiently distribute the temperature and air throughout the atrium. Even though the convergence monitor did not completely approach a constant value, the results of the model appear to be a reasonable representation of the atrium space. Therefore, the conclusion is that the current diffuser layout and supply flow rates are acceptable.

4.0 BREADTH – INDOOR AIR QUALITY STUDY

4.1 UNIQUE APARTMENT AMENITY

As mentioned in the building overview section of this report, the Art Institute of Pittsburgh plans to offer many amenities to its students who will inhabit the Try Street Terminal Building. The design includes many features to enhance their living and educational experience. In spirit of this effort to create an optimum place to live, it is felt that an additional benefit that could be added to this list is contaminate free apartments.

4.2 ULTRAVIOLET GERMICIDAL IRRADIATION

Indoor air quality is said to be one of the five most urgent environmental risks to public health according to the EPA. Therefore, the interest in using of ultraviolet germicidal irradiation (UVGI) as a technology in building applications has been renewed. UVGI systems are used for air and surface disinfection. Airborne and surface microbial problems include: allergens, mold spores, viruses, bacteria, and mold. In general, this technology can be applied to any type of building seeking to improve indoor quality. It is important recognize that UVGI systems are a complicated technology and the many types are available, each of which have there own design parameters. The International Ultraviolet Association draft documents identify 11 distinct types. Some of the most common units are: in-duct, standalone recirculation units, microbial growth control in an AHU, and upper air distribution.

4.3 CREON2000 SYSTEM

After an exhaustive search it was determined that the CREON2000 system would best meet the design needs of the Try Street Terminal Building. The General Innovation and

Good Inc. offers the Creon2000 for residential, commercial, and in-room uses. Because the apartments have outdoor air supplied by make-up air units and water source heat pumps that recirculate the room air the question was where to locate the UVGI system. It was decided that a room unit would be the best possible solution. This option would allow the Art Institute of Pittsburgh to decide how many apartments to apply this system to if they chose to do so.

The CREON2000 system destroys cells of bacteria, mold, spores, and other germs by employing germicidal ultraviolet light which impedes there ability to reproduce and infect people. Its patented technology focuses the power of the ultraviolet light onto the microbes while magnifying the ultraviolet light's ability to kill them. Figure 4.3-a below demonstrates how this works. Compared to the electronic and HEPA type filters which reduce the number of microbes in indoor air by 2-3 time, the CREON2000 can reduce the number by 20 times. The CREON2000 offers a low maintenance design which only requires a replacement bulb and filter after one year of use under normal operating conditions.

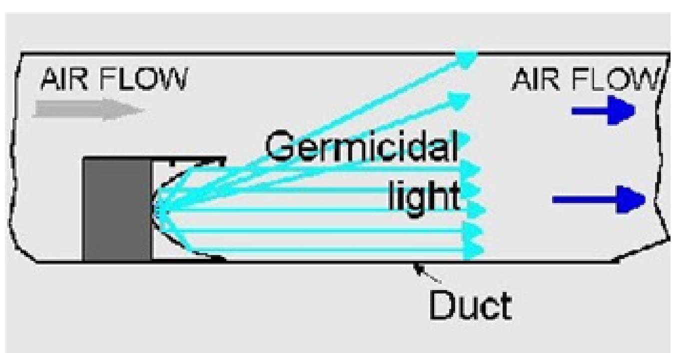


Figure 4.3-a CREON2000 - how it works

An article from the Journal of Asthma titled "Health Effects of Ultraviolet Irradiation in Asthmatic Children's Home," also features a study comparing which compares the symptoms of children in the homes with a CREON2000 system verse those children in a placebo group without the system. The study showed that they severity of asthma symptoms was less for the children in the CREON2000 group. These children also experienced less frequent chest tightness and shortness of breath. This result is listed in the figure below.

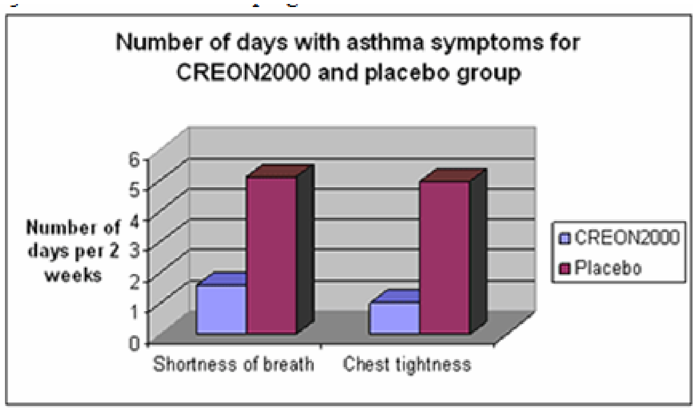


Figure 4.3-b Graph from Journal of Asthma article

4.4 SUGGESTIONS FOR IMPROVED IAQ

Based on the information presented, the CREON2000 system appears to be a possible solution towards improving the indoor air quality in the apartments. This room unit was also suggested because it could offer the Art Institute of Pittsburgh the flexibility of choosing how many apartments they would want to advertise as contaminant free. Even if only applied to a handful of apartments it is reasonable to believe that this unique amenity would be appealing to many, especially those with medical problems.

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TKA Architects, Documents and rendering for Try Street Terminal Building.

The Pennsylvania State University Department of Architectural Engineering Faculty Advisors

Past Penn State AE Thesis Technical Reports

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My professional contacts Dave Lyon and Jim Synan for answering my questions and giving me a tour of the building; Michelle Payanzo for providing me with a building rendering and additional material; and to Bob Kalan for answering my questions.

APPENDICES

BUILDING OVERVIEW

MECHNICAL DEPTH

APPENDIX – BUILDING OVERVIEW

FCU	CLG mbh	HTG mbh
1	12.009	16.218
2	18.153	25.339
3	23.628	31.52
4	29.29	32.928
5	33.684	41.56
6	114.148	147.334

						WSHP Systems												
						cooling HAP equipment								**heating HAP equipment**				
						max load				**gross capacity**	**comp calc**			**max load**	**gross capacity**	**comp calc**		
MAU	FCUs scheduled	FCU nom ton	**chosen FCU Fan FLA**	**#of FCUs**	**Zone #**	**total mbh**	**mbh/ht pump**	**total tons**	**tons/ht pump**	**scheduled mbH**	**Clg kW**	**Fan kW**	**Comp. Power kW**	**mbh**	**scheduled mbh**	**Htg kW**	**Fan kW**	**Comp. Power kW**
MISC (no OA from MAU/direct vent)	1	1	0.8	7	1 - laundry	36.3	5.2	3.0	0.4	84.1	7.64	0.18	7.46	0	113.5	7.92	0.18	7.738
	2	1.5	1.1	1	2-mail	14.3	14.3	1.2	1.2	18.2	1.65	0.25	1.40	6.2	25.3	1.77	0.25	1.515
	6	10		1	3-gym	218.6	218.6	18.2	18.2	114.1	10.38	0.00	10.38	173.3	147.3	10.28	0.00	10.281
										216.4	19.67	0.44	**19.23**		**286.2**	19.97	0.44	**19.534**
MAU 1	4 (5 on 9th)	2.56	2.7	9	1-A	295.8	32.9	24.7	2.7	268.0	24.36	0.62	23.74	82.1	305.0	21.28	0.62	20.661
	2 (3 on 9th)	1.56	1.5	9	2-B	225.8	25.1	18.8	2.1	168.9	15.35	0.35	15.01	51.5	234.2	16.35	0.35	16.000
	2 (3 on 9th)	1.56	1.5	9	3-C	216.7	24.1	18.1	2.0	168.9	15.35	0.35	15.01	43.6	234.2	16.35	0.35	16.000
	2 (3 on 9th)	1.56	1.5	9	4-D	222.6	24.7	18.6	2.1	168.9	15.35	0.35	15.01	51.5	234.2	16.35	0.35	16.000
	4 (5 on 9th)	2.56	2.7	9	5-P	301.3	33.5	25.1	2.8	268.0	24.36	0.62	23.74	62.7	305.0	21.28	0.62	20.661
										1042.6	94.78	2.28	**92.50**		**1312.7**	91.60	2.28	**89.323**
MAU 2	2 (3 on 9th)	1.56	1.5	9	1-E	212.5	23.6	17.7	2.0	168.9	15.35	0.35	15.01	48.8	234.2	16.35	0.35	16.000
	2 (3 on 9th)	1.56	1.5	8	2-F	170.9	21.4	14.2	1.8	150.7	13.70	0.35	13.35	36	208.9	14.58	0.35	14.232
	3	2	2.7	6	3-G	189.9	31.7	15.8	2.6	141.8	12.89	0.62	12.27	54.2	189.1	13.20	0.62	12.576
										461.3	41.94	1.31	**40.63**		**632.2**	44.12	1.31	**42.808**
MAU 3	3	2	2.7	9	1-L	282.4	31.4	23.5	2.6	212.7	19.33	0.62	18.71	72.1	283.7	19.80	0.62	19.175
	2 (3 on 9th)	1.55	1.5	10	2-M	178.4	17.8	14.9	1.5	187.0	17.00	0.35	16.66	34.7	228.1	15.91	0.35	15.569
	4 (5 on 9th)	2.55	2.7	10	3-N	385.7	38.6	32.1	3.2	297.3	27.03	0.62	26.41	110.8	337.9	23.58	0.62	22.959
	3 (4 on 9th)	2.06	2.7	8	4-Q	258.9	32.4	21.6	2.7	218.3	19.85	0.62	19.23	34.1	285.1	19.89	0.62	19.273
										915.3	83.21	2.21	**81.00**		**1134.7**	79.18	2.21	**76.975**
MAU 4	3	2	2.7	6	1-H	204.5	34.1	17.0	2.8	141.8	12.89	0.62	12.27	50.1	189.1	13.20	0.62	12.576
	3	2	1.5	9	2-J	231.0	25.7	19.3	2.1	263.6	23.96	0.35	23.62	36	296.4	20.68	0.35	20.335
	3	2	2.7	10	3-K	312.5	31.3	26.0	2.6	336.8	30.62	0.62	30.00	77.2	415.6	29.00	0.62	28.380
	3 (4 on 9th)	2.06	2.7	8	4-R	240.4	30.1	20.0	2.5	194.7	17.70	0.62	17.08	27.8	253.6	17.69	0.62	17.073
										936.9	85.17	2.21	**82.97**		**1154.6**	80.57	2.21	**78.365**
				147		4198.5							EER 11	1052.7				COP 4.2

Annual Cost Summary

EXISTING BLDG_WSHP6 04/15/2007
Penn State 09:11AM

Table 1. Annual Costs

Component	TRY STREET TERMINAL BLDG ($)
Air System Fans	21,335
Cooling	187,220
Heating	71,185
Pumps	56,924
Cooling Tower Fans	3,201
HVAC Sub-Total	**339,865**
Lights	138,214
Electric Equipment	439,187
Misc. Electric	0
Misc. Fuel Use	0
Non-HVAC Sub-Total	**577,402**
Grand Total	**917,266**

Table 2. Annual Cost per Unit Floor Area

Component	TRY STREET TERMINAL BLDG ($/ft²)
Air System Fans	0.127
Cooling	1.115
Heating	0.424
Pumps	0.339
Cooling Tower Fans	0.019
HVAC Sub-Total	**2.024**
Lights	0.823
Electric Equipment	2.615
Misc. Electric	0.000
Misc. Fuel Use	0.000
Non-HVAC Sub-Total	**3.439**
Grand Total	**5.463**
Gross Floor Area (ft²)	167920.4
Conditioned Floor Area (ft²)	167920.4

Note: Values in this table are calculated using the Gross Floor Area.

Table 3. Component Cost as a Percentage of Total Cost

Component	TRY STREET TERMINAL BLDG (%)
Air System Fans	2.3
Cooling	20.4
Heating	7.8
Pumps	6.2
Cooling Tower Fans	0.3
HVAC Sub-Total	**37.1**
Lights	15.1
Electric Equipment	47.9
Misc. Electric	0.0
Misc. Fuel Use	0.0
Non-HVAC Sub-Total	**62.9**
Grand Total	**100.0**

Table 1. Annual Costs

Component	TRY STREET TERMINAL BLDG ($)
HVAC Components	
Electric	268,766
Natural Gas	71,097
Fuel Oil	0
Propane	0
Remote HW	0
Remote Steam	0
Remote CW	0
HVAC Sub-Total	**339,863**
Non-HVAC Components	
Electric	577,381
Natural Gas	0
Fuel Oil	0
Propane	0
Remote HW	0
Remote Steam	0
Non-HVAC Sub-Total	**577,381**
Grand Total	**917,243**

Table 2. Annual Energy Consumption

Component	TRY STREET TERMINAL BLDG
HVAC Components	
Electric (kWh)	3,089,258
Natural Gas (Therm)	44,603
Fuel Oil (na)	0
Propane (na)	0
Remote HW (na)	0
Remote Steam (na)	0
Remote CW (na)	0
Non-HVAC Components	
Electric (kWh)	6,636,561
Natural Gas (Therm)	0
Fuel Oil (na)	0
Propane (na)	0
Remote HW (na)	0
Remote Steam (na)	0
Totals	
Electric (kWh)	9,725,819
Natural Gas (Therm)	44,603
Fuel Oil (na)	0
Propane (na)	0
Remote HW (na)	0
Remote Steam (na)	0
Remote CW (na)	0

Table 3. Annual Emissions

Component	TRY STREET TERMINAL BLDG
CO2 (lb)	0
SO2 (kg)	0
NOx (kg)	0

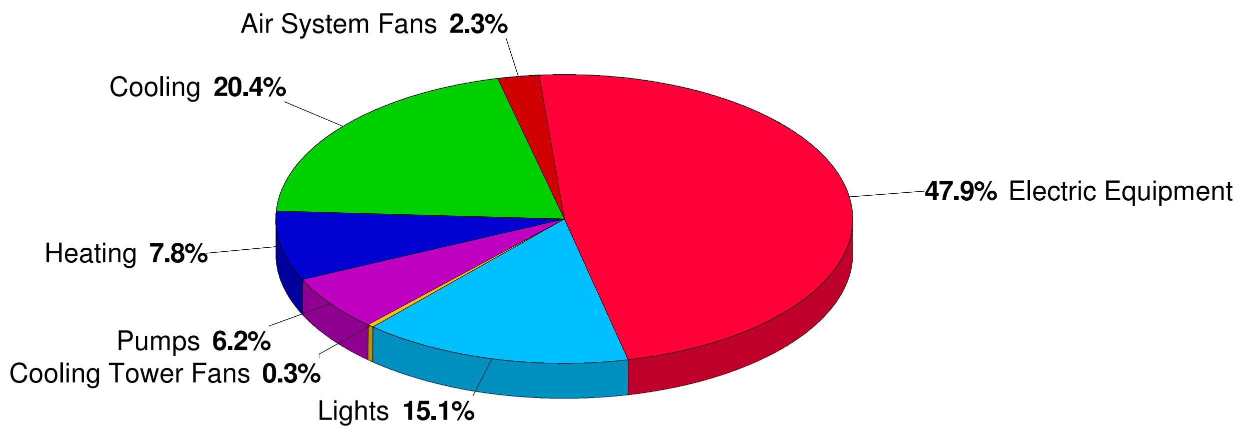
Table 4. Annual Cost per Unit Floor Area

Component	TRY STREET TERMINAL BLDG ($/ft²)
HVAC Components	
Electric	1.601
Natural Gas	0.423
Fuel Oil	0.000
Propane	0.000
Remote HW	0.000
Remote Steam	0.000
Remote CW	0.000
HVAC Sub-Total	**2.024**
Non-HVAC Components	
Electric	3.438
Natural Gas	0.000
Fuel Oil	0.000
Propane	0.000
Remote HW	0.000
Remote Steam	0.000
Non-HVAC Sub-Total	**3.438**
Grand Total	**5.462**
Gross Floor Area (ft²)	167920.4
Conditioned Floor Area (ft²)	167920.4

Note: Values in this table are calculated using the Gross Floor Area.

Table 5. Component Cost as a Percentage of Total Cost

Component	TRY STREET TERMINAL BLDG (%)
HVAC Components	
Electric	29.3
Natural Gas	7.8
Fuel Oil	0.0
Propane	0.0
Remote HW	0.0
Remote Steam	0.0
Remote CW	0.0
HVAC Sub-Total	**37.1**
Non-HVAC Components	
Electric	62.9
Natural Gas	0.0
Fuel Oil	0.0
Propane	0.0
Remote HW	0.0
Remote Steam	0.0
Non-HVAC Sub-Total	**62.9**
Grand Total	**100.0**



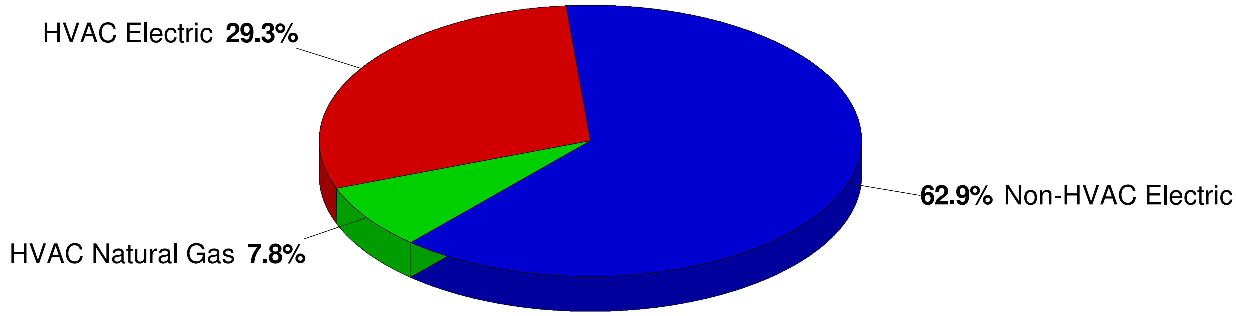
1. Annual Costs

Component	Annual Cost ($)	($/ft²)	Percent of Total (%)
Air System Fans	21,335	0.127	2.3
Cooling	187,220	1.115	20.4
Heating	71,185	0.424	7.8
Pumps	56,924	0.339	6.2
Cooling Tower Fans	3,201	0.019	0.3
HVAC Sub-Total	**339,865**	**2.024**	**37.1**
Lights	138,214	0.823	15.1
Electric Equipment	439,187	2.615	47.9
Misc. Electric	0	0.000	0.0
Misc. Fuel Use	0	0.000	0.0
Non-HVAC Sub-Total	**577,402**	**3.439**	**62.9**
Grand Total	**917,266**	**5.463**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area .... **167920.4** ft²
Conditioned Floor Area .... **167920.4** ft²

Annual Energy Costs - TRY STREET TERMINAL BLDG

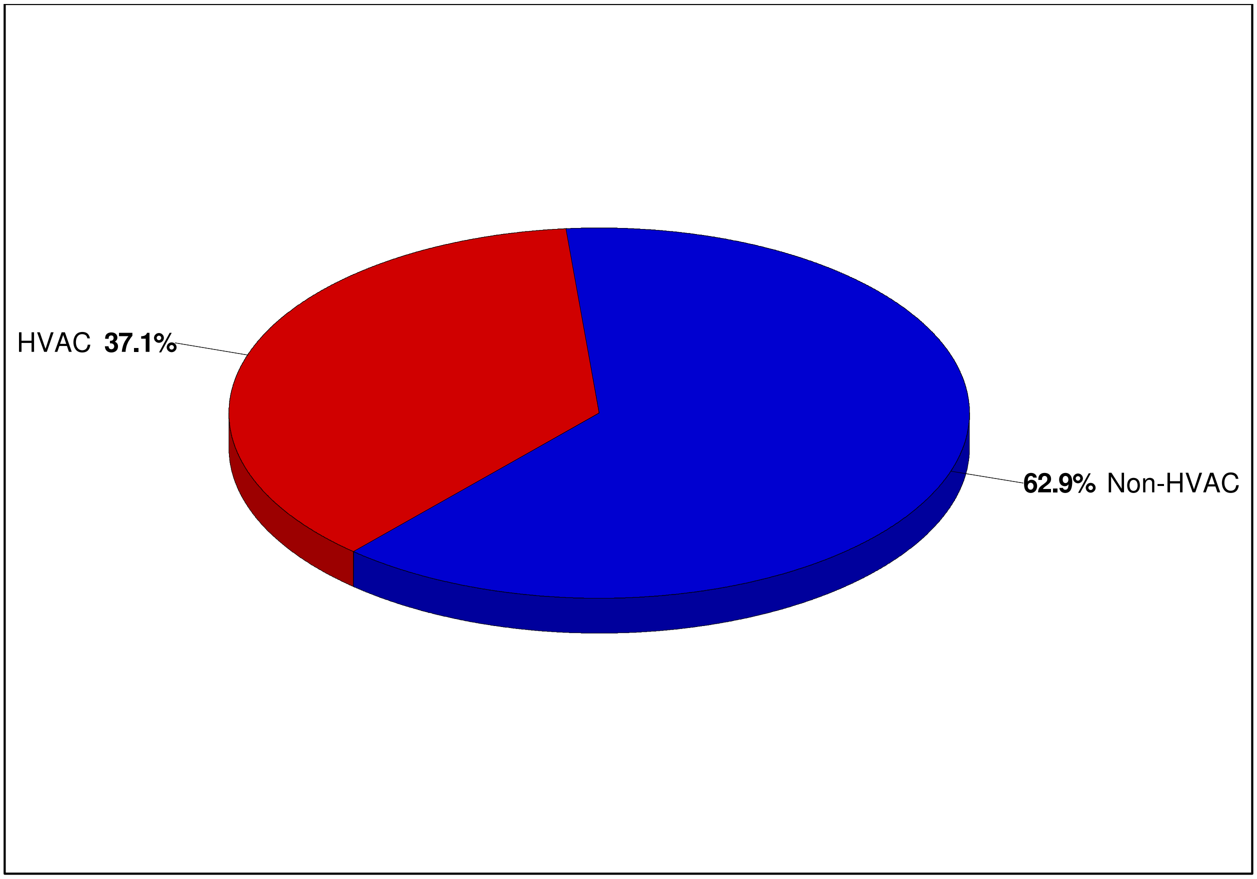


1. Annual Costs

Component	Annual Cost ($/yr)	($/ft²)	Percent of Total (%)
HVAC Components			
Electric	268,765	1.601	29.3
Natural Gas	71,097	0.423	7.8
Fuel Oil	0	0.000	0.0
Propane	0	0.000	0.0
Remote Hot Water	0	0.000	0.0
Remote Steam	0	0.000	0.0
Remote Chilled Water	0	0.000	0.0
HVAC Sub-Total	**339,863**	**2.024**	**37.1**
Non-HVAC Components			
Electric	577,381	3.438	62.9
Natural Gas	0	0.000	0.0
Fuel Oil	0	0.000	0.0
Propane	0	0.000	0.0
Remote Hot Water	0	0.000	0.0
Remote Steam	0	0.000	0.0
Non-HVAC Sub-Total	**577,381**	**3.438**	**62.9**
Grand Total	**917,243**	**5.462**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area .... **167920.4** ft²
Conditioned Floor Area .... **167920.4** ft²



1. Annual Costs

Component	Annual Cost ($/yr)	($/ft²)	Percent of Total (%)
HVAC	339,865	2.024	37.1
Non-HVAC	577,402	3.439	62.9
Grand Total	**917,266**	**5.463**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area .... **167920.4** ft²
Conditioned Floor Area .... **167920.4** ft²

1. Annual Coil Loads

Component	Load (kBTU)	(kBTU/ft²)
Cooling Coil Loads	24,195,590	144.090
Heating Coil Loads	4,320,715	25.731
Grand Total	**28,516,303**	**169.820**

2. Energy Consumption by System Component

Component	Site Energy (kBTU)	Site Energy (kBTU/ft²)	Source Energy (kBTU)	Source Energy (kBTU/ft²)
Air System Fans	836,725	4.983	836,725	4.983
Cooling	7,342,464	43.726	7,342,464	43.726
Heating	4,463,724	26.582	4,463,724	26.582
Pumps	2,232,486	13.295	2,232,486	13.295
Cooling Towers	125,523	0.748	125,523	0.748
HVAC Sub-Total	**15,000,921**	**89.334**	**15,000,921**	**89.334**
Lights	5,420,538	32.280	5,420,538	32.280
Electric Equipment	17,224,220	102.574	17,224,220	102.574
Misc. Electric	0	0.000	0	0.000
Misc. Fuel Use	0	0.000	0	0.000
Non-HVAC Sub-Total	**22,644,758**	**134.854**	**22,644,758**	**134.854**
Grand Total	**37,645,678**	**224.188**	**37,645,678**	**224.188**

Notes:
1. 'Cooling Coil Loads' is the sum of all air system cooling coil loads.
2. 'Heating Coil Loads' is the sum of all air system heating coil loads.
3. Site Energy is the actual energy consumed.
4. Source Energy is the site energy divided by the electric generating efficiency (100.0%).
5. Source Energy for fuels equals the site energy value.
6. Energy per unit floor area is based on the gross building floor area.
   Gross Floor Area .... **167920.4** ft²
   Conditioned Floor Area .... **167920.4** ft²

Energy Budget by Energy Source - TRY STREET TERMINAL BLDG

EXISTING BLDG_WSHP6 04/15/2007
Penn State 09:11AM

1. Annual Coil Loads

Component	Load (kBTU)	(kBTU/ft²)
Cooling Coil Loads	24,195,590	144.090
Heating Coil Loads	4,320,715	25.731
Grand Total	**28,516,303**	**169.820**

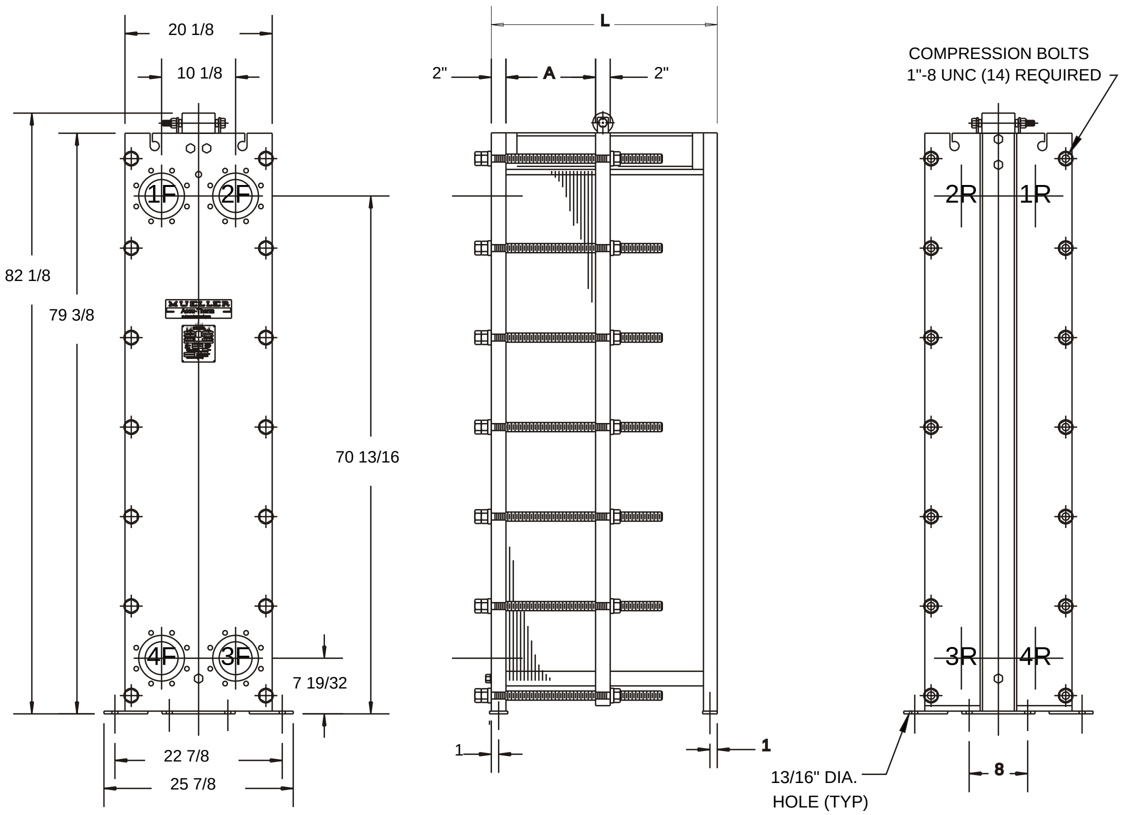
2. Energy Consumption by Energy Source

Component	Site Energy (kBTU)	Site Energy (kBTU/ft²)	Source Energy (kBTU)	Source Energy (kBTU/ft²)
HVAC Components				
Electric	10,540,548	62.771	10,540,548	62.771
Natural Gas	4,460,294	26.562	4,460,294	26.562
Fuel Oil	0	0.000	0	0.000
Propane	0	0.000	0	0.000
Remote Hot Water	0	0.000	0	0.000
Remote Steam	0	0.000	0	0.000
Remote Chilled Water	0	0.000	0	0.000
HVAC Sub-Total	**15,000,842**	**89.333**	**15,000,842**	**89.333**
Non-HVAC Components				
Electric	22,643,950	134.849	22,643,950	134.849
Natural Gas	0	0.000	0	0.000
Fuel Oil	0	0.000	0	0.000
Propane	0	0.000	0	0.000
Remote Hot Water	0	0.000	0	0.000
Remote Steam	0	0.000	0	0.000
Non-HVAC Sub-Total	**22,643,950**	**134.849**	**22,643,950**	**134.849**
Grand Total	**37,644,792**	**224.182**	**37,644,792**	**224.182**

Notes:
1. 'Cooling Coil Loads' is the sum of all air system cooling coil loads.
2. 'Heating Coil Loads' is the sum of all air system heating coil loads.
3. Site Energy is the actual energy consumed.
4. Source Energy is the site energy divided by the electric generating efficiency (100.0%).
5. Source Energy for fuels equals the site energy value.
6. Energy per unit floor area is based on the gross building floor area.
   Gross Floor Area .... **167920.4** ft²
   Conditioned Floor Area .... **167920.4** ft²

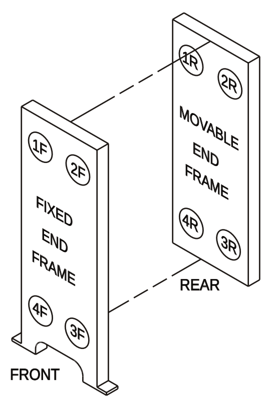
APPENDIX – MECHANICAL DEPTH

Accu-Therm®
Plate Heat Exchangers



FRONT VIEW **SIDE VIEW** **REAR VIEW**

PORT LOCATIONS

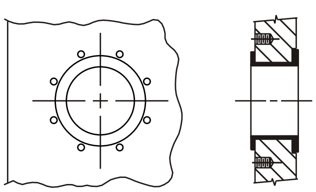


STANDARD MATERIALS
OF CONSTRUCTION

END FRAMES. . . . . SA-515-70, SA-516-70 OR EQUIV
PLATE HANGER . . . . TYPE 304 S/S
COMPRESSION BOLTS (ZINC PLATED) SA-193-B7
COMPRESSION NUTS (ZINC PLATED) SA-194-2H
CONNECTION STUDS (ZINC PLATED). SA-193-B7
CONNECTION NUTS (ZINC PLATED). SA-193-2H
SHROUD (OPTIONAL) . . . . ALUMINUM
PAINT. . . . . CORROSION RESISTANT PAINT

DIMENSIONS ARE FOR REFERENCE USE ONLY.
ACTUAL PRODUCTION DIMENSIONS ARE SUBJECT TO CHANGE.

REFER TO COMPUTER PRINTOUT FOR VARIABLE DIMENSIONS AND COMPLETE PLATE, GASKET AND CONNECTION SPECIFICATIONS.



STANDARD CONNECTION
4" STUDDED PORT

MUELLER®

MODEL AT60
FRAME TYPE B-20

REV DATE 3/08/05

Annual Cost Summary

Table 1. Annual Costs

Component	TRY STREET TERMINAL BLDG ($)
Air System Fans	18,554
Cooling	129,843
Heating	30,234
Pumps	75,128
Cooling Tower Fans	0
HVAC Sub-Total	**253,758**
Lights	116,318
Electric Equipment	439,187
Misc. Electric	0
Misc. Fuel Use	0
Non-HVAC Sub-Total	**555,505**
Grand Total	**809,263**

Table 2. Annual Cost per Unit Floor Area

Component	TRY STREET TERMINAL BLDG ($/ft²)
Air System Fans	0.131
Cooling	0.919
Heating	0.214
Pumps	0.532
Cooling Tower Fans	0.000
HVAC Sub-Total	**1.796**
Lights	0.823
Electric Equipment	3.108
Misc. Electric	0.000
Misc. Fuel Use	0.000
Non-HVAC Sub-Total	**3.931**
Grand Total	**5.727**
Gross Floor Area (ft²)	141317.0
Conditioned Floor Area (ft²)	141317.0

Note: Values in this table are calculated using the Gross Floor Area.

Table 3. Component Cost as a Percentage of Total Cost

Component	TRY STREET TERMINAL BLDG (%)
Air System Fans	2.3
Cooling	16.0
Heating	3.7
Pumps	9.3
Cooling Tower Fans	0.0
HVAC Sub-Total	**31.4**
Lights	14.4
Electric Equipment	54.3
Misc. Electric	0.0
Misc. Fuel Use	0.0
Non-HVAC Sub-Total	**68.6**
Grand Total	**100.0**

Table 1. Annual Costs

Component	TRY STREET TERMINAL BLDG ($)
HVAC Components	
Electric	223,635
Natural Gas	30,126
Fuel Oil	0
Propane	0
Remote HW	0
Remote Steam	0
Remote CW	0
HVAC Sub-Total	**253,762**
Non-HVAC Components	
Electric	555,486
Natural Gas	0
Fuel Oil	0
Propane	0
Remote HW	0
Remote Steam	0
Non-HVAC Sub-Total	**555,486**
Grand Total	**809,248**

Table 2. Annual Energy Consumption

Component	TRY STREET TERMINAL BLDG
HVAC Components	
Electric (kWh)	2,570,522
Natural Gas (Therm)	18,900
Fuel Oil (na)	0
Propane (na)	0
Remote HW (na)	0
Remote Steam (na)	0
Remote CW (na)	0
Non-HVAC Components	
Electric (kWh)	6,384,899
Natural Gas (Therm)	0
Fuel Oil (na)	0
Propane (na)	0
Remote HW (na)	0
Remote Steam (na)	0
Totals	
Electric (kWh)	8,955,420
Natural Gas (Therm)	18,900
Fuel Oil (na)	0
Propane (na)	0
Remote HW (na)	0
Remote Steam (na)	0
Remote CW (na)	0

Table 3. Annual Emissions

Component	TRY STREET TERMINAL BLDG
CO_2 (lb)	0
SO_2 (kg)	0
NO_x (kg)	0

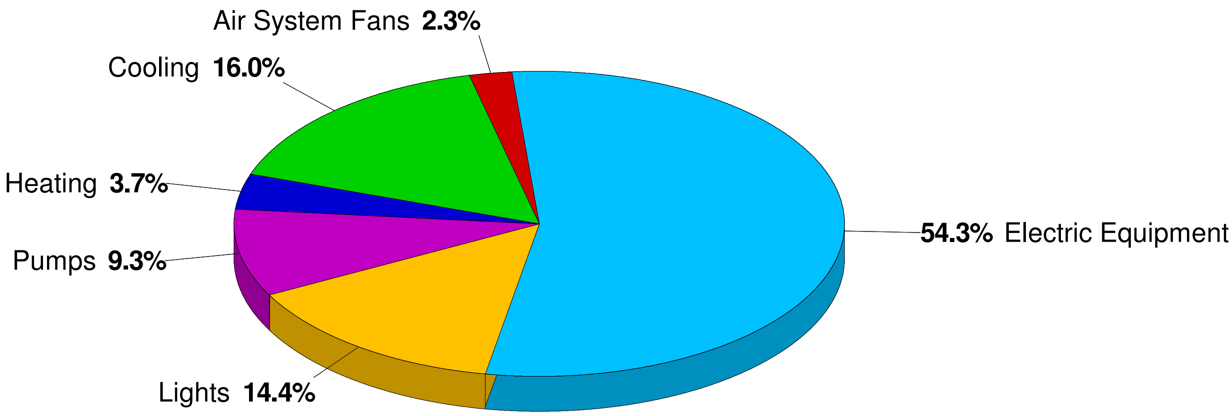
Table 4. Annual Cost per Unit Floor Area

Component	TRY STREET TERMINAL BLDG ($/ft²)
HVAC Components	
Electric	1.583
Natural Gas	0.213
Fuel Oil	0.000
Propane	0.000
Remote HW	0.000
Remote Steam	0.000
Remote CW	0.000
HVAC Sub-Total	**1.796**
Non-HVAC Components	
Electric	3.931
Natural Gas	0.000
Fuel Oil	0.000
Propane	0.000
Remote HW	0.000
Remote Steam	0.000
Non-HVAC Sub-Total	**3.931**
Grand Total	**5.727**
Gross Floor Area (ft²)	141317.0
Conditioned Floor Area (ft²)	141317.0

Note: Values in this table are calculated using the Gross Floor Area.

Table 5. Component Cost as a Percentage of Total Cost

Component	TRY STREET TERMINAL BLDG (%)
HVAC Components	
Electric	27.6
Natural Gas	3.7
Fuel Oil	0.0
Propane	0.0
Remote HW	0.0
Remote Steam	0.0
Remote CW	0.0
HVAC Sub-Total	**31.4**
Non-HVAC Components	
Electric	68.6
Natural Gas	0.0
Fuel Oil	0.0
Propane	0.0
Remote HW	0.0
Remote Steam	0.0
Non-HVAC Sub-Total	**68.6**
Grand Total	**100.0**



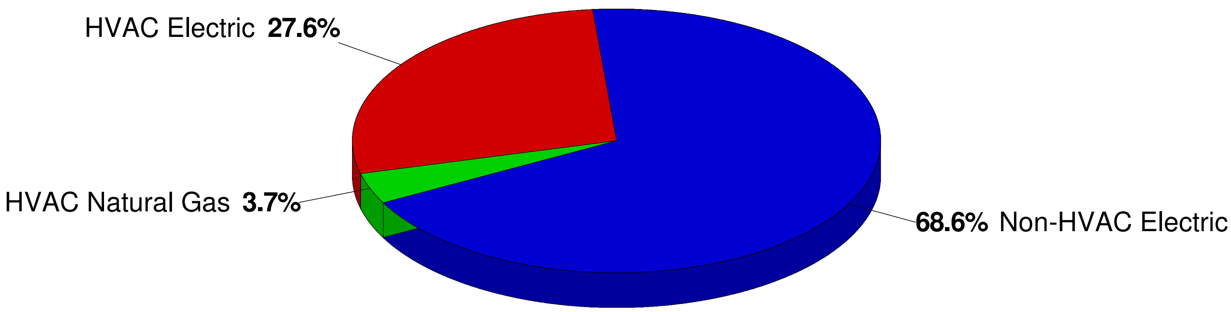
1. Annual Costs

Component	Annual Cost ($)	($/ft²)	Percent of Total (%)
Air System Fans	18,554	0.131	2.3
Cooling	129,843	0.919	16.0
Heating	30,234	0.214	3.7
Pumps	75,128	0.532	9.3
Cooling Tower Fans	0	0.000	0.0
HVAC Sub-Total	**253,758**	**1.796**	**31.4**
Lights	116,317	0.823	14.4
Electric Equipment	439,187	3.108	54.3
Non-HVAC Sub-Total	**555,505**	**3.931**	**68.6**
Grand Total	**809,263**	**5.727**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area .... **141317.0** ft²
Conditioned Floor Area .... **141317.0** ft²

Annual Energy Costs - TRY STREET TERMINAL BLDG

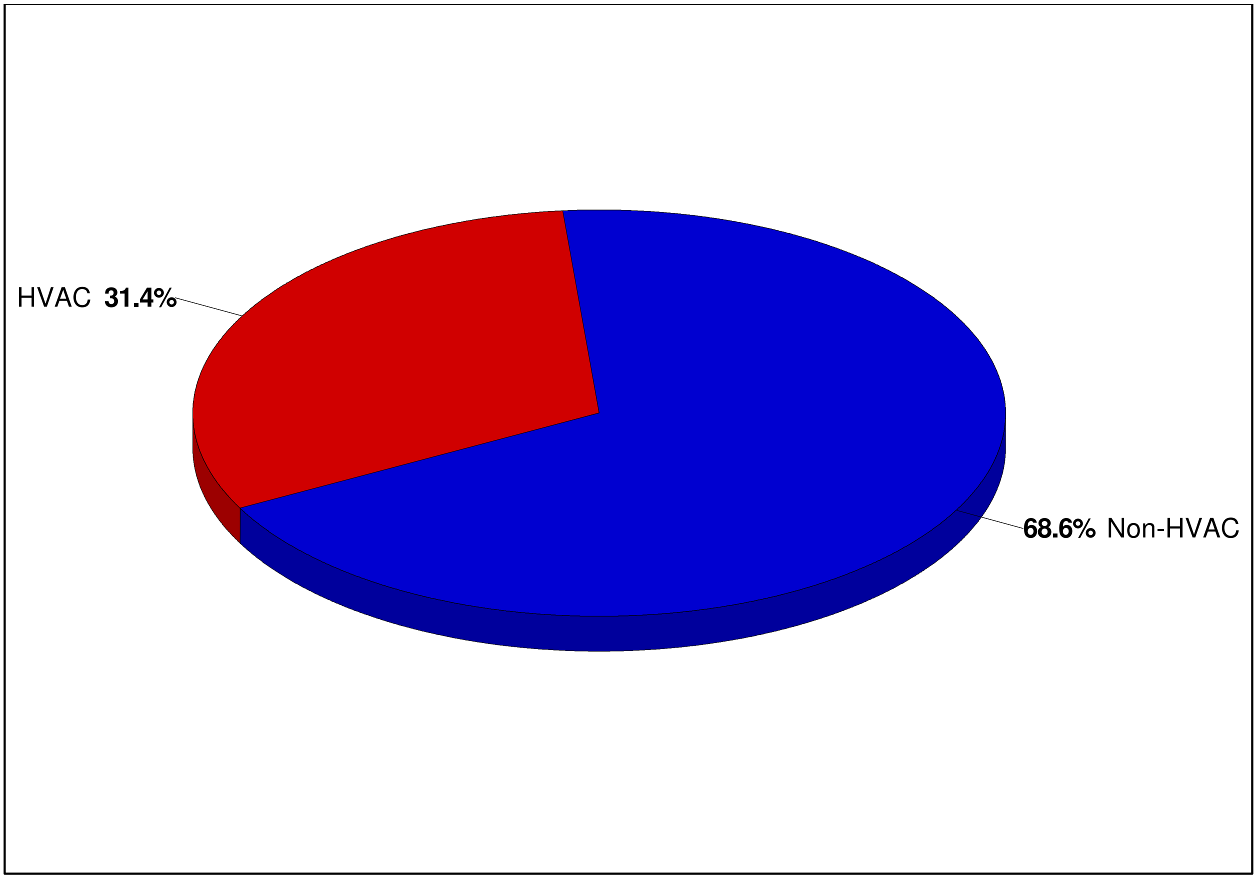


1. Annual Costs

Component	Annual Cost ($/yr)	($/ft²)	Percent of Total (%)
HVAC Components			
Electric	223,635	1.583	27.6
Natural Gas	30,126	0.213	3.7
HVAC Sub-Total	**253,762**	**1.796**	**31.4**
Non-HVAC Components			
Electric	555,486	3.931	68.6
Natural Gas	0	0.000	0.0
Non-HVAC Sub-Total	**555,486**	**3.931**	**68.6**
Grand Total	**809,248**	**5.727**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area .... **141317.0** ft²
Conditioned Floor Area .... **141317.0** ft²



1. Annual Costs

Component	Annual Cost ($/yr)	($/ft²)	Percent of Total (%)
HVAC	253,758	1.796	31.4
Non-HVAC	555,505	3.931	68.6
Grand Total	**809,263**	**5.727**	**100.0**

Note: Cost per unit floor area is based on the gross building floor area.

Gross Floor Area .... **141317.0** ft²
Conditioned Floor Area .... **141317.0** ft²

1. Annual Coil Loads

Component	Load (kBTU)	(kBTU/ft²)
Cooling Coil Loads	23,738,400	167.980
Heating Coil Loads	2,135,980	15.115
Grand Total	**25,874,384**	**183.095**

2. Energy Consumption by System Component

Component	Site Energy (kBTU)	Site Energy (kBTU/ft²)	Source Energy (kBTU)	Source Energy (kBTU/ft²)
Air System Fans	727,645	5.149	727,645	5.149
Cooling	5,092,232	36.034	5,092,232	36.034
Heating	1,894,203	13.404	1,894,203	13.404
Pumps	2,946,381	20.849	2,946,381	20.849
Cooling Towers	0	0.000	0	0.000
HVAC Sub-Total	**10,660,461**	**75.436**	**10,660,461**	**75.436**
Lights	4,561,784	32.281	4,561,784	32.281
Electric Equipment	17,224,220	121.884	17,224,220	121.884
Misc. Electric	0	0.000	0	0.000
Misc. Fuel Use	0	0.000	0	0.000
Non-HVAC Sub-Total	**21,786,004**	**154.164**	**21,786,004**	**154.164**
Grand Total	**32,446,465**	**229.601**	**32,446,465**	**229.601**

Notes:
1. 'Cooling Coil Loads' is the sum of all air system cooling coil loads.
2. 'Heating Coil Loads' is the sum of all air system heating coil loads.
3. Site Energy is the actual energy consumed.
4. Source Energy is the site energy divided by the electric generating efficiency (100.0%).
5. Source Energy for fuels equals the site energy value.
6. Energy per unit floor area is based on the gross building floor area.
   Gross Floor Area .... **141317.0** ft²
   Conditioned Floor Area .... **141317.0** ft²

Energy Budget by Energy Source - TRY STREET TERMINAL BLDG

1. Annual Coil Loads

Component	Load (kBTU)	(kBTU/ft²)
Cooling Coil Loads	23,738,400	167.980
Heating Coil Loads	2,135,980	15.115
Grand Total	**25,874,384**	**183.095**

2. Energy Consumption by Energy Source

Component	Site Energy (kBTU)	Site Energy (kBTU/ft²)	Source Energy (kBTU)	Source Energy (kBTU/ft²)
HVAC Components				
Electric	8,770,619	62.063	8,770,619	62.063
Natural Gas	1,889,973	13.374	1,889,973	13.374
Fuel Oil	0	0.000	0	0.000
Propane	0	0.000	0	0.000
Remote Hot Water	0	0.000	0	0.000
Remote Steam	0	0.000	0	0.000
Remote Chilled Water	0	0.000	0	0.000
HVAC Sub-Total	**10,660,592**	**75.437**	**10,660,592**	**75.437**
Non-HVAC Components				
Electric	21,785,276	154.159	21,785,276	154.159
Natural Gas	0	0.000	0	0.000
Fuel Oil	0	0.000	0	0.000
Propane	0	0.000	0	0.000
Remote Hot Water	0	0.000	0	0.000
Remote Steam	0	0.000	0	0.000
Non-HVAC Sub-Total	**21,785,276**	**154.159**	**21,785,276**	**154.159**
Grand Total	**32,445,868**	**229.596**	**32,445,868**	**229.596**

Notes:
1. 'Cooling Coil Loads' is the sum of all air system cooling coil loads.
2. 'Heating Coil Loads' is the sum of all air system heating coil loads.
3. Site Energy is the actual energy consumed.
4. Source Energy is the site energy divided by the electric generating efficiency (100.0%).
5. Source Energy for fuels equals the site energy value.
6. Energy per unit floor area is based on the gross building floor area.
   Gross Floor Area .... **141317.0** ft²
   Conditioned Floor Area .... **141317.0** ft²

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RETScreen® International

Clean Energy Project Analysis Software

Ground-Source Heat Pump Project Model

Click Here to Start

- Description & Flow Chart
- Colour Coding
- Online Manual

Worksheets

- Energy Model
- Heating & Cooling Load
- Cost Analysis
- Greenhouse Gas Analysis
- Financial Summary

Features

- Product Data
- Weather Data
- Cost Data
- Currency Options
- Sensitivity Analysis

Clean Energy
Decision Support Centre
www.retscreen.net

- Training & Support
- Internet Forums
- Marketplace
- Case Studies
- e-Textbook

Partners

UNEP NASA GEF

RETScreen® Energy Model - Ground-Source Heat Pump Project

Training & Support

Site Conditions		Estimate	Notes/Range
Project name		**Commercial System**	See Online Manual
Project location		**Pittsburgh, PA**	
Available land area	m²	4,383	
Soil type	-	Heavy soil - damp	
Design heating load	kW	357.1	Complete H&CLC sheet
Design cooling load	kW	1,159.9	

System Characteristics		Estimate	Notes/Range
Base Case HVAC System			
Building has air-conditioning?	yes/no	Yes	
Heating fuel type	-	**Natural gas**	
Heating system seasonal efficiency	%	80%	55% to 350%
Air-conditioner seasonal COP	-	3.0	2.4 to 5.0
Ground Heat Exchanger System			
System type	-	Groundwater	
Design criteria	-	Cooling	
Typical land area required	m²	226	
Pumping depth	m	15	
Wellbore depth	m	20	
Maximum well flow rate	L/s	50	0.5 to 60.0
Required groundwater flow rate	L/s	33	
Number of supply wells required	-	1	
Heat Pump System			
Average heat pump efficiency	-	User-defined	See Product Database
Heat pump manufacturer		Trane - high eff.	
Heat pump model			
Standard cooling COP	-	4.75	
Standard heating COP	-	3.60	
Total standard heating capacity	kW	845.5	
	million Btu/h	2.885	
Total standard cooling capacity	kW	1,150.0	
	million Btu/h	3.924	
Supplemental Heating and Heat Rejection System			
Suggested supplemental heating capacity	kW	0.0	
	million Btu/h	0.000	
Suggested supplemental heat rejection	kW	0.0	
	million Btu/h	0.000	

Annual Energy Production		Estimate	Notes/Range
Heating			
Electricity used	MWh	101.7	
Supplemental energy delivered	MWh	0.0	
GSHP heating energy delivered	MWh	**233.8**	
	million Btu	797.6	
Seasonal heating COP	-	2.3	2.0 to 5.0
Cooling			
Electricity used	MWh	561.4	
GSHP cooling energy delivered	MWh	**2,362.7**	
	million Btu	8,061.6	
Seasonal cooling COP	-	4.2	2.0 to 5.5
Seasonal cooling EER	(Btu/h)/W	14.4	7.0 to 19.0
			Complete Cost Analysis sheet

Version 3.1

NRCan/CETC - Varennes

RETScreen® Heating and Cooling Load Calculation - Ground-Source Heat Pump Project

Site Conditions		Estimate	Notes/Range
Nearest location for weather data		Pittsburgh, PA	See Weather Database
Heating design temperature	°C	-16.1	-40.0 to 15.0
Cooling design temperature	°C	33.0	10.0 to 40.0
Average summer daily temperature range	°C	11.0	5.0 to 15.0
Cooling humidity level	-	Medium	
Latitude of project location	°N	40.5	-90.0 to 90.0
Mean earth temperature	°C	12.8	Visit NASA satellite data site
Annual earth temperature amplitude	°C	14.0	5.0 to 20.0
Depth of measurement of earth temperature	m	15.0	0.0 to 3.0

Building Heating and Cooling Load		Estimate	Notes/Range
Type of building	-	Commercial	
Available information	-	Descriptive data	
Building floor area	m²	13,120	
Number of floors	floor	10	1 to 6
Window area	-	Above average	
Insulation level	-	High	
Occupancy type	-	Continuous	
Equipment and lighting usage	-	Moderate	
Building design heating load	kW	357.1	
	million Btu/h	1.218	
Building heating energy demand	MWh	233.8	
	million Btu	797.6	
Building design cooling load	kW	1,159.9	
	ton (cooling)	329.9	
Building cooling energy demand	MWh	2,362.7	
	million Btu	8,061.6	Return to Energy Model sheet

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RETScreen® Cost Analysis - Ground-Source Heat Pump Project

Type of analysis: Pre-feasibility | Currency: $ | Cost references: Enter new 1

Initial Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
Feasibility Study							
Other - Feasibility Study	Cost	0	$ -	$ -			
Sub-total:				**$ -**	0.0%		
Development							
Other - Development	Cost	0	$ -	$ -			
Sub-total:				**$ -**	0.0%		
Engineering							
Other - Engineering	Cost	0	$ -	$ -			
Sub-total:				**$ -**	0.0%		
Energy Equipment							
Heat pumps	kW cooling	1,150.0	$ 100	$ 115,000			$200 - $570
Well pumps	kW	17.4		$ -			$425 - $3,400
Circulating pumps	kW	19.5	$ 850	$ 16,617			$250 - $1,900
Circulating fluid	m³	0.00	$ 2,600	$ -			$2,400 - $5,300
Plate heat exchangers	kW	1,150.0	$ 20.00	$ 23,000			$7.00 - $20.00
Trenching and backfilling	m	0	$ -	$ -			$4.00 - $9.00
Drilling and grouting	m	40	$ 12.00	$ 480			$11.00 - $38.60
Ground HX loop pipes	m	0	$ 2.50	$ -			$1.50 - $3.50
Fittings and valves	kW cooling	1,150.0	$ 12.00	$ 13,800			$8.00 - $20.00
Other - Energy Equipment	Credit		$ -	$ -			
Electric central heating system	Credit	1	$ 20,000	$ (20,000)			
Sub-total:				**$ 148,897**	86.8%		
Balance of System							
Supplemental heating system	kW	0.0	$ -	$ -			$35 - $110
Supplemental heat rejection	kW	0.0	$ -	$ -			$500 - $750
Internal piping and insulation	kW cooling	1,150.0	$ 20	$ 23,000			$20 - $70
Other - Balance of System	Cost	0	$ -	$ -			
Credit - Balance of System	Credit	1	$ 1,000	$ (1,000)			
Sub-total:				**$ 22,000**	12.8%		
Miscellaneous							
Training	p-h	14	$ 40	$ 560		1 - 16	$40 - $100
Contingencies	%	0%	$ 171,457	$ -		10% - 40%	
Sub-total:				**$ 560**	0.3%		
Initial Costs - Total				**$ 171,457**	100.0%		

Annual Costs (Credits)	Unit	Quantity	Unit Cost	Amount	Relative Costs	Quantity Range	Unit Cost Range
O&M							
Property taxes/Insurance	project	0	$ -	$ -			
O&M labour	m²	1,000	$ 2.50	$ 2,500			$1.00 - $3.00
Travel and accommodation	p-trip	0	$ -	$ -			
Other - O&M	Cost	0	$ -	$ -			
Credit - O&M	Credit	1	$ 3,500	$ (3,500)			
Contingencies	%	5%	$ 170,897	$ 8,545		2% - 15%	
Sub-total:				**$ 7,545**	13.1%		
Fuel/Electricity							
Electricity	kWh	**663,161**	**$ 0.087**	$ 57,695			
Incremental electricity load	kW	**-62.3**	**$ 120**	$ (7,479)			
Sub-total:				**$ 50,216**	86.9%		
Annual Costs - Total				**$ 57,761**	100.0%		

Periodic Costs (Credits)		Period	Unit Cost	Amount		Interval Range	Unit Cost Range
Heat pump compressor	Cost	10 yr	$ 5,000	**$ 5,000**			
Air-conditioner replacement	Credit	12 yr	$ 6,000	**$ (6,000)**			
				$ -			
End of project life	Credit	-	$ 2,000	**$ (2,000)**			*Go to GHG Analysis sheet*

RETScreen® Greenhouse Gas (GHG) Emission Reduction Analysis - Ground-Source Heat Pump Project

Use GHG analysis sheet? Yes   Type of analysis: Standard

Background Information

Project Information
Project name: Commercial System
Project location: Pittsburgh, PA

Global Warming Potential of GHG
1 tonne CH_4 = 21 tonnes CO_2 (IPCC 1996)
1 tonne N_2O = 310 tonnes CO_2 (IPCC 1996)

Base Case Electricity System (Baseline)

Fuel type	Fuel mix (%)	CO_2 emission factor (kg/GJ)	CH_4 emission factor (kg/GJ)	N_2O emission factor (kg/GJ)	Fuel conversion efficiency (%)	T & D losses (%)	GHG emission factor (t_{CO2}/MWh)
Natural gas	100.0%	56.1	0.0030	0.0010	45.0%	8.0%	0.491
Electricity mix	100%	135.5	0.0072	0.0024		8.0%	0.491

Base Case Heating and Cooling System (Baseline)

Fuel type	Fuel mix (%)	CO_2 emission factor (kg/GJ)	CH_4 emission factor (kg/GJ)	N_2O emission factor (kg/GJ)	Fuel conversion efficiency (%)	GHG emission factor (t_{CO2}/MWh)
Heating system						
Natural gas	100.0%	56.1	0.0030	0.0010	80.0%	0.254
Cooling system						
Electricity	100.0%	135.5	0.0072	0.0024	300.0%	0.164

Proposed Case Heating and Cooling System (Ground-Source Heat Pump Project)

Fuel type	Fuel mix (%)	CO_2 emission factor (kg/GJ)	CH_4 emission factor (kg/GJ)	N_2O emission factor (kg/GJ)	Fuel conversion efficiency (%)	GHG emission factor (t_{CO2}/MWh)
Heating system						
Electricity	100.0%	135.5	0.0072	0.0024	229.8%	0.214
Cooling system						
Electricity	100.0%	135.5	0.0072	0.0024	420.8%	0.117

GHG Emission Reduction Summary

	Base case GHG emission factor (t_{CO2}/MWh)	Proposed case GHG emission factor (t_{CO2}/MWh)	End-use annual energy delivered (MWh)	Annual GHG emission reduction (t_{CO2})
Heating system	0.254	0.214	233.8	9.45
Cooling system	0.164	0.117	2362.7	111.05
			Net GHG emission reduction t_{CO2}/yr	**120.50**

Complete Financial Summary sheet

RETScreen® Financial Summary - Ground-Source Heat Pump Project

Annual Energy Balance

Project name		Commercial System	Electricity required	MWh	663.2
Project location		Pittsburgh, PA	Incremental electricity load	kW	(62.3)
			Net GHG reduction	t_{CO2}/yr	120.50
Heating energy delivered	MWh	233.8			
Cooling energy delivered	MWh	2,362.7			
Heating fuel displaced	-	Natural gas	Net GHG emission reduction - 25 yrs	t_{CO2}	3,012.61

Financial Parameters

Avoided cost of heating energy	$/m³	0.060	Debt ratio	%	0.0%
GHG emission reduction credit	$/$t_{CO2}$	-	Income tax analysis?	yes/no	No
Retail price of electricity	$/kWh	0.087			
Demand charge	$/kW	120			
Energy cost escalation rate	%	2.0%			
Inflation	%	2.0%			
Discount rate	%	10.0%			
Project life	yr	25			

Project Costs and Savings

Initial Costs				**Annual Costs and Debt**		
Feasibility study	0.0%	$	-	O&M	$	7,545
Development	0.0%	$	-	Fuel/Electricity	$	50,216
Engineering	0.0%	$	-			
Energy equipment	86.8%	$	148,897	**Annual Costs and Debt - Total**	**$**	**57,761**
Balance of system	12.8%	$	22,000			
Miscellaneous	0.3%	$	560	**Annual Savings or Income**		
Initial Costs - Total	100.0%	**$**	**171,457**	Heating energy savings/income	$	1,698
				Cooling energy savings/income	$	68,519
Incentives/Grants		$	-			
				Annual Savings - Total	**$**	**70,217**
Periodic Costs (Credits)						
Heat pump compressor		$	5,000	Schedule yr # 10,20		
Air-conditioner replacement		$	(6,000)	Schedule yr # 12,24		
		$	-			
End of project life - Credit		$	(2,000)	Schedule yr # 25		

Financial Feasibility

Pre-tax IRR and ROI	%	7.4%	Calculate GHG reduction cost?	yes/no	No
After-tax IRR and ROI	%	7.4%			
Simple Payback	yr	13.8	Project equity	$	171,457
Year-to-positive cash flow	yr	12.0			
Net Present Value - NPV	$	(36,432)			
Annual Life Cycle Savings	$	(4,014)			
Benefit-Cost (B-C) ratio	-	0.79			

Yearly Cash Flows

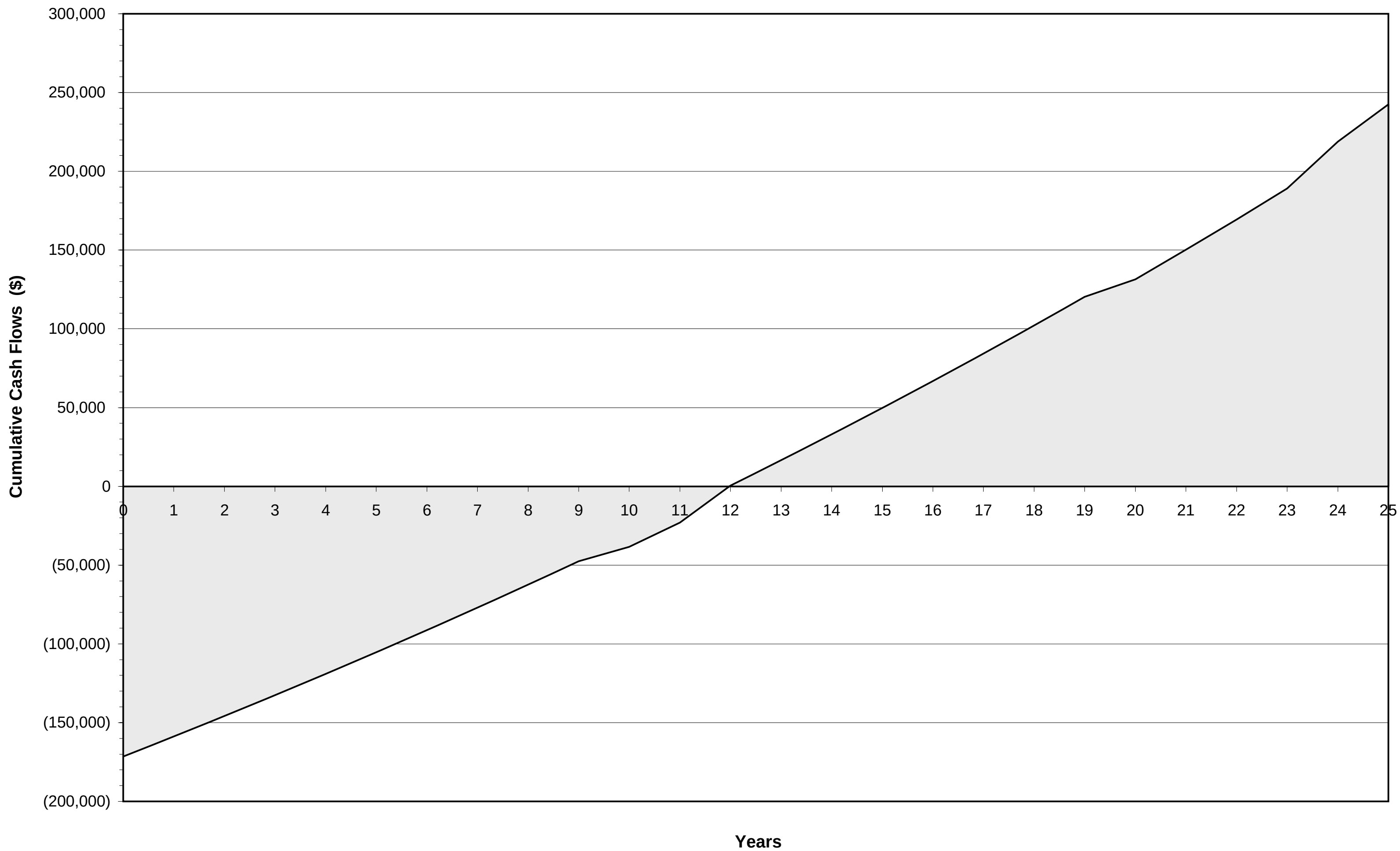
Year #	Pre-tax $	After-tax $	Cumulative $
0	(171,457)	(171,457)	(171,457)
1	12,706	12,706	(158,752)
2	12,960	12,960	(145,792)
3	13,219	13,219	(132,573)
4	13,483	13,483	(119,090)
5	13,753	13,753	(105,337)
6	14,028	14,028	(91,308)
7	14,309	14,309	(77,000)
8	14,595	14,595	(62,405)
9	14,887	14,887	(47,518)
10	9,089	9,089	(38,429)
11	15,488	15,488	(22,941)
12	23,407	23,407	467
13	16,114	16,114	16,581
14	16,436	16,436	33,017
15	16,765	16,765	49,782
16	17,100	17,100	66,882
17	17,442	17,442	84,324
18	17,791	17,791	102,115
19	18,147	18,147	120,262
20	11,080	11,080	131,342
21	18,880	18,880	150,222
22	19,258	19,258	169,479
23	19,643	19,643	189,122
24	29,686	29,686	218,808
25	23,717	23,717	242,526

Cumulative Cash Flows Graph

GSHP Project Cumulative Cash Flows
Commercial System, Pittsburgh, PA

Total Initial Costs: $ 171,457

Net average GHG reduction (t_{CO2}/yr): 120.50



IRR and ROI: 7.4%

Year-to-positive cash flow: 12 yr

Net Present Value: $ -36,432

RETScreen® Sensitivity and Risk Analysis - Ground-Source Heat Pump Project

Use sensitivity analysis sheet?	No

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