Final Report

Alternative Systems Analysis

Steelstacks Performing Arts Center

Bethlehem, Pa

4/7/2011

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Steelstacks Performing Arts Center

Bethlehem, Pa

Project Team

Architect: Spillman Farmer Architects

MEP Engineer: Brinjac Engineering

Structural Engineer: Barry Isett & Associates

Civil Engineer: French & Parrello

Mechanical Systems

- Mini Split System with 3 roof top Condensing units.
- Split system serving AHU for Blast furnace room
- 6 Gas-fired roof top units
- Gas-fired water tube hot water Boiler
- 4 roof top energy recover units

Electrical Systems

- 200 KW 480/277V 3-phase generator
- 3000 AMP 3-phase main breaker with tvss (transient voltage surge suppression)
- 10 transformers inside of building
- 480/277V pad mount transformer from utility

Structural System

- Concrete footings ranging fro 2' 4" to 4' 2" in depth with Precast foundation walls
- 8" thick reinforced concrete floor system with metal deck
- 8" reinforced CMU interior wall system
- Steel joist and girder grid

Project Information

Building Owner: Artquest

Function Type: Preforming Arts Center

Size: 67,000 square feet

Stories: 4 above grade

Cost: $26 million

Dates of Construction: January 10, 2010 to February 26. 2011 (estimated)

Architecture

Steelstacks is a dynamic art center built on the old Bethlehem Steel site, the building flawlessly integrates itself into the campus. The building consist of music cafes and theaters as well as multipurpose room that overlooks the existing blast furnaces of Bethlehem Steel.

Lighting System

The Steel Stacks building has many different lighting elements due to the wide range of activities it can accommodate. It has a combination of color changing spotlights (LED), along with recessed fluorescent lights, and pendent lights. It also has an array of outside building lights to allow for the building to glow.

Michael Dean Mechanical

http://www.engr.psu.edu/ae/thesis/portfolios/2011/mbd5032/index.html

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Acknowledgments

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Executive Summary

The Steelstacks Performing Arts Center is a very unique building. The design for this building is very unique because it is a multi-purpose venue with 2 cinemas, a nightclub/cafe, banquet facility, full kitchen plus several concessions and bars, an open common area, and outdoor patio. Each space has very different design conditions which presented very interesting considerations.

The primary factor of importance for the owner was thermal comfort for those visiting the Center, as well having comparable electricity consumption. Thermal comfort was very important because an uncomfortable visit could hurt the audience viewing experience which in turn could hurt the reputation of the building.

The Steelstacks building is conditions by roof top units as well as one interior air-handling unit with an outdoor condenser unit. The units basically serve each of the large areas. This was done so that each space could run independently of each other. This was essential in the design because the building needs to be able to cost effective at full capacity as well as just holding small gatherings.

In order to optimize the building systems, analysis were performed in order to lower the building energy consumptions. Designs were done to flatten the loads of the building as well as overall consumption. Ground Source Heat Pump (GSHP) was investigated to handle both the cooling load and heating loads. A complete changeover from air-cooled system to a ground loop was implemented with the same decentralized system, but rather with heat pumps instead of RTUs. Also thermal storage was looked into to account for the large peak loads. A solar analysis was done on the building for the plausibility of the addition of a solar heating system. A study into how that would help with the total hot water and heating load was then looked into. Initial cost, maintenance cost as well as payback period was looked out to determine the best choice system.

After investigation into all of these choices there were pros and cons to each system. The solar system was the least effective of the group, the system had a hard time overcoming the large initial cost, while only needing to heat for the building during the winter months. An ice storage system had a very positive effect on the energy use of the Steelstack building but once again it could only be used for a limited amount of time during the year. The thermal storage system had a lot lower cost so the payback period was much more reasonable and this would be a valuable asset to the building. The GSHP system provided itself to be a very valuable advantage to the building and would easily payback in a reasonable time and then continues to save the building owner a considerable amount of money.

The GSHP presented itself to be the best choice of system for the owner over the term of the building. With a building of this nature, the owner is planning on running regularly throughout the year. The relatively low upkeep cost as well as running at a uniform efficiency throughout the year makes the GSHP the best choice of system.

Mechanical System Overview

Introduction

Steelstacks is a four story, 67,000 square foot performing arts center that is designed to be the signature center for the Artsquest organization. This multi-purpose venue contains two cinemas, a nightclub/café, banquet facilities, a full kitchen along with several concession stands, bars, an open common area and an outdoor patio system. The building north façade is completely glass, which allows for beautiful views of the existing blast furnaces from the former Bethlehem Steel plant. While having a full glass façade enhances the architecture of the building, it greatly alters the mechanical design considerations for the building. With LEED in mind, great measures were gone through to assure that this building was designed efficiently and in a sustainable manner.

Design Objectives and Requirements

The Steelstacks building was designed with a few main objectives in mind. The first of which was to design an energy efficient building that met LEED certification with a very structured budget. As well as achieving some type of LEED certification, the designers also need to meet all ASHRAE Standards that were applicable. From this the building had to meet energy, ventilation, temperature, and humidity requirements. While having these in mind, the design that became the most logical to use was having each major zone of the building to have its own air-handling with energy recovery units on areas which have high occupancy densities.

Site and Budget

The Steelstacks is on a very unique site which affected everything from the architecture to the mechanical systems. It is located on what was previously the Bethlehem Steel plant from the late 1800’s till about 2001. In an effort to minimize the economic impact the closing had on the Lehigh Valley, a plan was made to revitalize the south side of Bethlehem. A major redevelopment has ensued with the addition of a casino, hotel, and Museum of Industrial History. The revitalizing continued when the concept of Steelstacks emerged. Along with this performing arts center there are plans for outdoor amphitheater and community centers. In the years to come this site plans on hosting Musikfest, which is an annual festival held in Bethlehem that brings thousands of visitors from across the country. The site had great effects on the architecture of the building, a slab to roof window is placed on the north wall of the building to give views of the Blast Furnaces, and steel beams are exposed as well mechanical ductwork as homage to the original site.

System Initial Cost

A piece by piece breakdown of the mechanical system cost was not available for use in this project. A cost of 2.5 million dollars is the overall cost of the mechanical system thought. With the building being 67,000 square feet, we get a cost of $38.81 per square foot of building space. The mechanical equipment totals 9.62% of the total building cost.

Lost space

The Steelstacks building is very efficient in placing mechanical spaces. On floors one, two, and three the mechanical lost space is less than 3% on all floors. The lost space on these floors is for small mechanical rooms, or duct chases. The fourth floor houses all of the major mechanical equipment. I have included all the mechanical space outside of the building as well (roof). Normally this would not count as wasted space because it does not count for square footage of the building, but it was decided to be counted because it stored such a large amount of the mechanical equipment. If this were to not be counted the percentage loss would be 1.95%.

Floor	Lost Space(ft^2)	Percentage Loss
1st	290	1.45%
2nd	470	2.57%
3rd	135	0.64%
4th	6205	44.27%
Total	**7100**	**9.68%**

Table 1-Lost space per floor

Energy sources

This information was not readily available for this area. The electricity and gas cost below were found using the regional suppliers of energy. Other available energy sources are not know but can be assumed to be minimal because of the prior use on the site and because the site is still in the infancy stage of development.

Electricity

Electric demand charge	$6.25
Electric Consumption charge	$0.14/kWh

Gas

Consumption charge	S1.25/therm

Design Air conditions

The Steelstacks building is located in Bethlehem, PA. The design outdoor air conditions for Bethlehem, PA were taken from the ASHRAE Fundamental 2005. The coldest weather month is January and the warmest is July. The values obtained are shown below.

ASHRAE Values	Summer Design Cooling- 0.4%	Winter Design Heating- 99.6%
OA Dry Bulb (F)	90.7	6.6
OA Wet Bulb(F)	73.4	-
IA Temperature	75	70
Clearness Number	1	1
Ground Reflectance	0.2	0.2

Table 2-Design Conditions from ASHRAE

Equipment Summaries

The Steelstacks building utilizes a fairly simple conditioning system. It consists of six rooftop units (RTUs) that serve almost the entire building. Each of these systems serves a very specific area; this is done so that the building can be controlled according to what type of event is going on. There is also one Air Handling Units (AHU) that serves exclusively the Blast Furnace Room. The Blast Furnace Room is the one of the highlight areas of this building; it is a multipurpose room that can host events from concerts to banquets.

	Supply Air(CFM)	Supply Fan Power(HP)	Exhaust Fan Power (HP)	Enthalpy Wheel Power (HP)	Cooling Coil Cap (MBH)	Gas Fired Cap (MBH)
RTU-1	6800	5	-	-	191.1	199
RTU-2	1650	1	-	1.18	39.9	52.5
RTU-3	3020	2	-	3.62	79.3	126.7
RTU-4	23485	25	-	7.24	457.4	117.5
RTU-5	17500	20	10	10.86	443.3	790
RTU-6	3000	1.5	0.5	-	113.4	126.7
AHU-1	5300	7.5	0	-	291.2	378.8

Table 3-Existing Mechanical Equipment summary

RTU-1- This unit serves the kitchen area on the third floor and the areas relating to this area such as storage areas.

RTU-2- This unit serves exclusively the Small Cinema on the first floor.

RTU-3- This unit serves the Large Cinema on the first floor

RTU-4- This unit serves the Creative Commons area, this area has portions of it that are two stories high. The Creative Commons is an area for people to gather, it boast views of the blast furnaces as well as sitting areas and places to relax

RTU-5- This unit serves the Musikfest Café that is on the third floor and is two floors high. It also serves the mezzanine level that overlooks the Café. This area will hold concerts and musical events, with the VIP area located on the Mezzanine as well as bar. This area also overlooks the blast furnaces to the north.

RTU-6- This unit is the most diverse unit, it serves most of the remaining space in the building that require conditioned air. Areas include offices, retail areas, corridors, green room, and some storage areas.

AHU-1- This unit is used to condition the Blast Furnace room.

Enthalpy wheel-There is a total of four enthalpy wheels associated with the conditioning systems for the Steelstacks building. The wheels are placed on systems that serve areas with high population density. This is because these areas require a high ventilation rate. So an enthalpy wheel is can recoup some of the energy that would otherwise be thrown back into the environment.

The natural gas boilers are located on the fourth floor of the building in the mechanical room. It is a Lochinvar Intelli-Fin system with 89.9% steady state combustion efficiency. This boiler provides hot water to AHU-1, which is the indoor only indoor unit (all others are roof top packaged units boilers included). In addition to the supplying this one air handling unit it also provides hot water to the terminal unit hot water re-heat boxes located in the smaller rooms throughout the building.(offices, green rooms ect.)

Unit	Total Gas (MBH)	Net Output (MBH)	GPM	Temperature
B-1	1000	880	90	180

Table 4-Boiler Information

Pumps play a minor role in the Steelstacks building but it is still an important role. Their role is limited because of the rooftop units being packaged units that have a condenser and a boiler in it. The only area that requires pumped fluid to it is the AHU-1 which serves the Blast furnace room and is not a roof top unit and terminal re-heat boxes located in few rooms.

Description	Capacity(GPM)	Head	HP	RPM
Primary Heating	57	15	1/2	1150
Secondary Heating	100	40	2	1750
AHU-1 Freeze Protection	5	10	1/3	1750

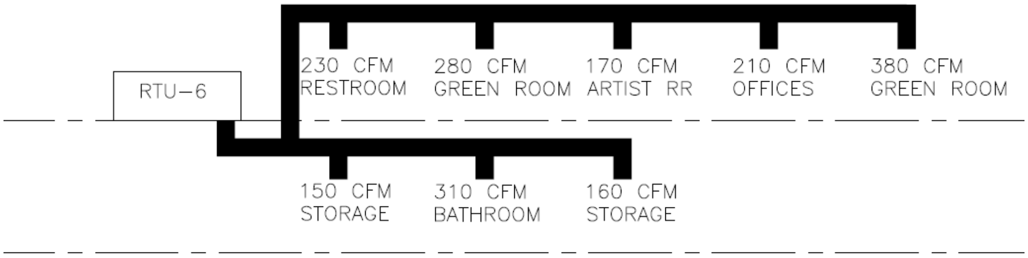
Table 5-Pump summary

System Operations

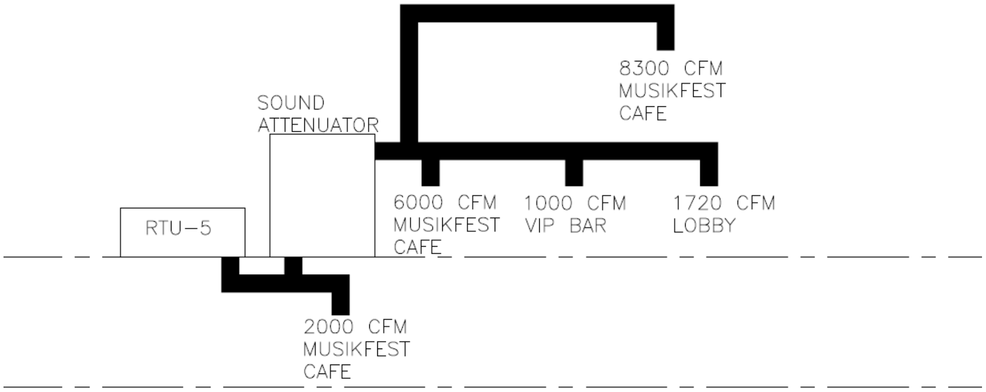
Air Side

The air system in the Steelstacks building is very simple. As previously stated each zone is independently served by an appropriately sized and configured unit. Certain units contain energy recovery units if there is high occupancy. The systems are variable speed drive motors, so they can supply appropriate levels to cooling and heating to the rooms. Each unit has economizer settings that will adjust the outside air damper to different levels depending on the outside and indoor air conditions, as well as the occupancy levels.

Below are schematics of two of the 7 total conditioning units. These are the only one really necessary to show because all other units serve just one area such a cinema.



Schematic 1-RTU-6 air distribution layout



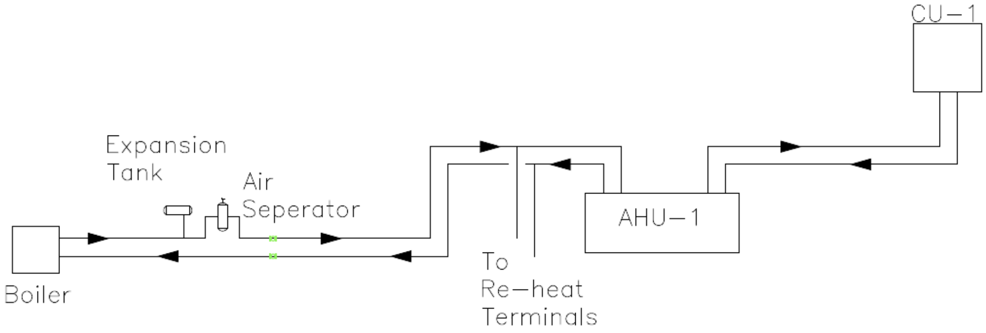
Schematic 2-RTU-5 air distribution layout

Water side

Once again this is a very straightforward system. Due to the fact that every system is independently run, the system has little built in redundancy and therefore is rather simple in nature. The packaged units are run completely self-sustained, so the only unit that requires chilled and hot water from an outside source is air handling unit supplying air to the Blast furnace rooms as well as the terminal re-heat boxes. This unit is inside for two main reasons, the first being that the mechanical space on the roof was not big enough to house it. Also the duct length required to go from the rooftop mechanical space to the blast furnace room is great.

The chilled water comes from and outside condensing unit which serves exclusively this air handler. These condensers along with all of the other components of the Mechanical system are system controlled either on-site or they can be remotely altered. This allow for altercations and real-time viewing of how the system is operating. This allows for on the fly changes that can greatly reduce the amount of energy use in the building.

Also there are a few condensing units that are considered part of a mini-split system. This system supplies the same rooms that have the terminal reheat boxes. There are a total of three condensing units for this system ranging in size from 6.2 tons to 16.6 tons. Since this system is a packaged unit again, all the heat exchanging is done internally and cold water is run from these units directly to their corresponding AC unit.



Schematic 3- AHU-1 water layout

Relevant Data from Previous Reports

Technical Reports I & II both provided information that is relevant to this report. The areas that crossover are areas that directly correlate to ASHRAE 62.1 and 90.1 and some Building Load Analysis.

Ventilation Requirements

The Steelstacks building has many diverse areas of usage within the building. This required an area specific ventilation calculation. The procedure described in ASHRAE 62.1 was performed to gain an understanding on each zone ventilation requirements. The varieties of different zones included in the building were cinemas, multipurpose, cafeteria, offices.

A total of 6 zones were checked for compliance with the minimum airflow rates. The maximum Z_p values come from zones that seemed to have a very high occupancy rates. These values could be estimated a little high due to using ASHRAE standards for occupancy rather than what the designers used because they probably have a better understanding of what the room will be used for.

Below in the graph I have summarized the minimum air flow requirements set forth by ASHRAE, it can be seen that even with the minor mishaps in calculating the zones with high occupancy all the units seem to be working in compliance of the 62.1. The one zone that is not in compliance is the kitchen, this can be rationalized by the lack of knowledge I have into the specifications of all the cooking equipment and the desired airflows for these areas.

Unit	Designed Max CFM	Designed Min OA	ASHRAE 62.1 Min OA	Compliance
RTU-1	6800	660	1630	NO
RTU-2	1575	1575	1428	YES
RTU-3	3050	2955	2752	YES
RTU-4	23485	5175	3699	YES
RTU-5	17500	10670	4171	YES
RTU-6	3000	660	421	YES
AHU-1	5300	3630	1854	YES

Table 6-Compliance check on existing equipment

Heating and Cooling Loads

Trace 700 Version 6.2 was used to simulate building block load conditions for the

Steelstacks building. Trace was chosen over the other software packages due to the ease of use as well as the familiarity with the program. Each zone was modeled with their appropriate system for heating, cooling, and supply air. These results were then compared to the designed values and appropriate rational was inferred to why there were such inconsistencies. After an initial run of the software I had great differences in cooling and heating loads in the areas of with the greatest amount of occupancy. I realized that I had greatly overestimated the amount of people that would be in the zones and did and appropriate correction on this. After the corrections were made I got a much more accurate reading on the heating and cooling levels of the Steelstacks building.

	Heating Load (MBH)		**Cooling Load (tons)**		**Supply Air cfm/sf**	
	Modeled	Designed	Modeled	Designed	Modeled	Designed
RTU-1	314	199	22.9	17.8	3858	6800
RTU-2	79	52.5	11.4	4.9	1582	1650
RTU-3	131	126.7	12.6	9.71	1927	3050
RTU-4	875	117.5	53.1	55	13111	23485
RTU-5	355	790	51.7	51.47	16564	17500
RTU-6	32	126.7	1.7	11.9	423	3000
AHU-1	157	378.8	23.4	24.25	9862	5300
Total	1943	1791.2	176.8	175.03	47327	60785
Percent Difference	7.8		1.0		28.4	

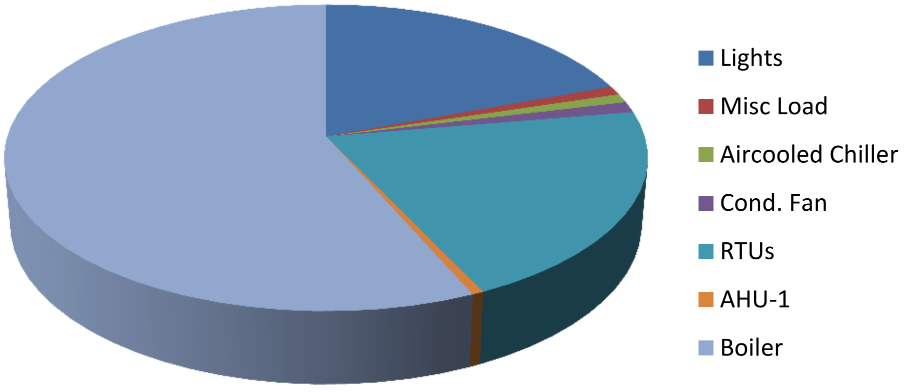
Table 7-Comparison of Designed and Modeled conditions

Annual Energy Use

All of the equipment efficiencies and sizes were taken from the design drawing and the energy consumptions were calculated and reported below.

Equipment	Utility	Unit	Total
Lights	Electric	kWh	373086
	Peak	kW	42.6
Misc. Loads	Electric	kWh	17955
	Peak	kW	2.1
Air-cooled Chiller	Electric	kWh	17805
	Peak	kW	156.9
Cond. Fan	Electric	kWh	21806
	Peak	kW	17.1
RTU-1	Electric	kWh	32766
	Peak	kW	3.7
RTU-2	Electric	kWh	6553
	Peak	kW	0.8
RTU-3	Electric	kWh	13107
	Peak	kW	1.5
RTU-4	Electric	kWh	163831
	Peak	kW	18.7
RTU-5	Electric	kWh	131065
	Peak	kW	15
RTU-6	Electric	kWh	49149
	Peak	kW	5.6
AHU-1	Electric	kWh	9830
	Peak	kW	1.1
Boiler	Gas	therms	3698
	Peak	therms/Hr	2.8

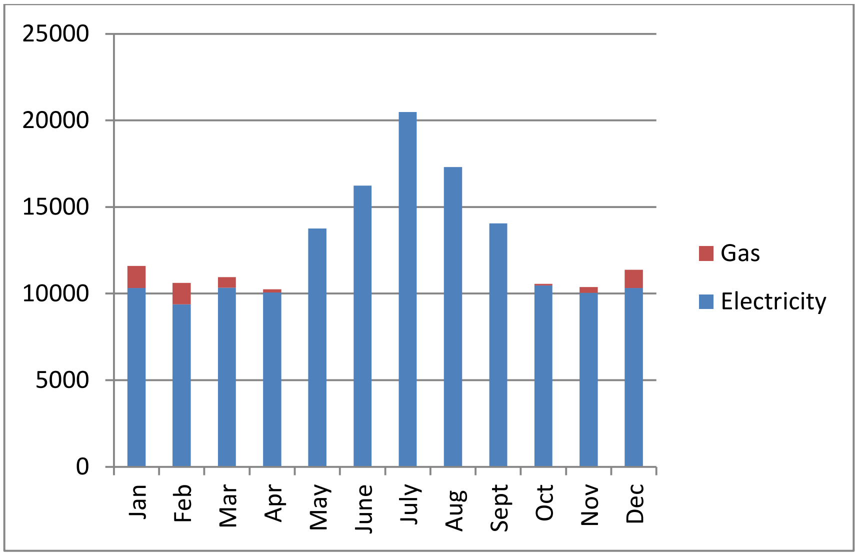
Table 8-Electricity consumption



Graph 1-Energy breakdown

This pie chart above was done by converting all of the values to the same units. From this comparison it is very apparent that the boiler and the fans for each of the units are the main areas for energy consumption.

From this model the total energy cost was calculated. The total energy cost per year was \$154,998, and \$2.31/ft^2 which seems to be on the high side, the energy rates could be a little off, but I am not immediately sure for this error. Below is a graph of the cost for both electricity and gas for each month during the year. The gas cost is very low on this graph but the area it represents is very true. It shows that the main usage is in the winter months, the boiler is the only element of the system that is uses gas and that is just an auxiliary boiler for what the heat pumps cannot handle.



Graph 2-Energy Cost per month

LEED Analysis for the Mechanical System

The Leadership in Energy and Environmental Design was created by the United States Green Building Council in order to promote sustainable design for both owners and design team. Points are awarded on a scale of how much the improvement will reduce energy consumptions or be friendlier to the environment. Steelstacks was designed with LEED in mind, but due to the ever changing construction and schedule of the building the designer and owner are reluctant to release anything because nothing is set in stone yet. The section will go over the two main areas of LEED that relate to mechanical systems; Energy and Atmosphere (EA) and Indoor Environmental Quality (IEQ).

Energy and Atmosphere

EA Prerequisite 1: Fundamentals of Commissioning and Building Energy Systems-Achieved

This is to make sure the building is installed and operated as designed. The Steelstacks building is not finished construction yet but plans are in place to make sure this system is running appropriately.

EA Prerequisite 2: Minimum Energy Performance-Achieved

This is to establish minimum levels of energy efficiency throughout the building. This building was designed with LEED as a goal, so his was definitely looked at.

EA Prerequisite 3: Fundamental Refrigerant Management-Achieved

Zero use of chlorofluorocarbons (CFCs) refrigerants was used in this building.

EA Credit 1: Optimize Energy Performance-3 Points

These are points given for the amount of energy saved in the designed building over the baseline building. The major factors in this were the windows, the SHGC of the windows that were installed were much lower than the minimum required in ASHRAE 90.1. Other small differences factored in to make a energy reduction of 16% which achieves 3 Points

EA Credit 2: On-site Renewable Energy

This is to promote the use on-site energy use. There is a possibility for the addition of a solar panel array on the roof of the building, but as of right now it is being put on hold due to cost.

EA Credit 3: Enhanced Commissioning

As of right now in the construction process this is not applicable. The commissioning is semi-ongoing and the detail of it is unknown, so it is unclear if this will be achieved.

EA Credit 4: Enhanced Refrigerant Management-2 Points

Reduce the total refrigerant impact. A calculation is associated with this credit and any value less the 100 receives 2 points. The Steelstacks building had a very low value (35) for this due to the mechanical design and received the points

EA Credit 5: Measurement and Verification

The building is still under constructions so this is not yet known if this credit will be sought after.

EA Credit 6: Green Power

This credit is to encourage the use of grid-source, renewable energy technologies on a net zero pollution basis. Steelstacks does not plan to buy green energy.

Indoor Environmental Quality

IEQ Prerequisite 1: Minimum Indoor Air Quality Performance-Achieved

This sets minimum indoor air quality performance to enhance indoor air quality in buildings. The Steelstacks meets and exceeds Sections 4 through 7 of ASHRAE 62.1-2007, Ventilation for Acceptable Indoor Air Quality.

IEQ Prerequisite 2: Environmental Tobacco Smoke (ETS) Control-Achieved

To prevent or minimize the building occupants and surfaces to exposure of indoor tobacco smoke. The Steelstacks building is a non-smoking building so this achieved.

IEQ Credit 1: Outdoor Air Delivery Method-1 Point

This is to provide capacity for ventilation system monitoring to help promote occupant comfort. CO_2 sensors will be installed in the highly populated spaces in the building to allow for proper ventilation.

IEQ Credit 2: Increased Ventilation

This credit is to provide additional outdoor air ventilation to improve indoor air quality. This could be done at the Steelstacks building. The building has the option of running on 100% outdoor air, and has the control system to accompany this idea. But for now this will not be implemented because of energy consumption.

IEQ Credit 6.1: Controllability of Systems-Lighting-1 Point

This credit is to provide that a high level of lighting control by individual occupants or groups of multi-occupant spaces. The lighting system is very diverse at the Steelstacks, because it has to provide lighting for a variety of events from comedians to rock bands to formal gatherings. All of which can be adjusted to suite the occupant.

IEQ Credit 6.2: controllability of Systems- Thermal Comfort-1 Point

This is intended to provide a high level of thermal comfort system control by individual of groups in multi-occupant spaces. The Steelstacks provides exactly this, it has thermostats in all of the offices and green rooms, as well as having numerous sensors in the larger spaces to allow for regional heating and cooling.

IEQ Credit 7.1: Thermal Comfort-Design-1Point

This is to provide a comfortable thermal environment that promotes occupant productivity and well-being. The Steelstacks meets ASHRAE Standards 55-2004 so this credit is achieved.

IEQ Credit 7.2: Thermal Comfort-Verification

This credit is to provide for the assessment of building occupant thermal comfort over time. The owner of the building will decide if there will be verification on this if the building is going for a LEED certification. This will be decided at the end of construction.

Water Efficiency

WE Prerequisite 1: Water Use Reduction-Achieved

This is to increase water efficiency within buildings to reduce the burden o municipal water supply and wastewater systems. Many different ideas were implemented to achieve this credit of at least a 20% aggregate reduction in the baseline building.

WE Credit 3: Water Use Reduction-2 Points

This credit is to further increase water efficiency within the building to reduce the burden on municipal water supply. The Steelstacks building will have at the minimal a 30% reduction in water over the baseline building which will achieve at least 2 points.

Evaluation of Current System

The system chosen to condition the Steelstacks building is a very convention system used very effectively for this use. This type of system has been used in similar buildings for many years and has proven to be adequate.

The construction cost of the mechanical system is about 9% of the building total cost. This is a somewhat low value for this type of building. This can be attributed to the ease of access to the rooftop units as well as most of the ductwork is left exposed which leaves for easier installation.

The operating cost of the Steelstacks Building is somewhat high; this could be for a couple of things. The calculated cost of operating the building was \$4.63/ft^2 annually. The use of the building leads to high cost, because of late night activities which call for lots of lighting as well as condition of the air in coldest parts of the day. Another reason the calculated cost could be high is the validity of cost of energy. The cost was estimated from researched values and is not exact to this specific building.

With the current mechanical system in place a few issues could come up. Although the system is very simple and may have very little tinkering over the course of the building lifecycle, it does not have the ability to alter the loads of the building or account for high load periods. Therefore in times when a load is considerably higher or lower in certain spaces, the cost goes proportionally. But for normal conditions as set out by the load calculations the system should run with rather ease.

One finding that deemed itself to be very interesting was the amount of sensors placed throughout the inside and outside of the building. These were then sent to the main control system to evaluated different criteria so that the building would run most efficiently. Sensors capacity ranged from temperature to CO_2, to humidity.

Proposed Alternative System

While the Steelstacks is currently a very efficient design, there may be a design that could better suit this build and improve the overall performance of the building and the long term investment for the owner. In order to determine the best solution for this building, a few alternative design elements will be evaluated. Ground Source Heat Pumps will be looked into to reduce coil loads. Solar energy sources will be looked into analysis into feasibility and payback will be evaluated, also thermal energy storage will be implemented to see if this is a valued system. The systems will be evaluated on a basis of initial cost as well as cost savings to determine a payback period and the most effective system.

Ground Source Heat Pumps

Loads on Steelstacks building current system will be compared after the implementation of a Ground Source Heat Pump (GSHP) option. The GSHP system will allow for the reduction of loads overall operation of the building.

The Steelstacks building is located on the redeveloped site of the former Bethlehem Steel Plant; there is a vast amount of usable space for the GSHP system. Different methods of looping are considered for this project because the site of the property has many unexplored underground systems. Back up boilers will be used but the system will be sized appropriately so that the boilers will not have to pick up too much excess load.

System requirements will be have to be looked into for the comparison of this type of system. The sizing of different equipment as well as looking into a location for the well field will be looked into for this evaluation.

Solar Energy

Solar Energy can be a great way to reduce the thermal loads on a building. The installation of solar energy system can lower cost of heating domestic water as well as heating loads during the winter. The simple idea of this type of system is that thermal energy collectors can be placed on or near the building and that the energy can either immediately be put to use in the building or be put into a storage tank to be used for future loads.

For this study only a water heating system with tanks storage and auxiliary energy source will be investigated. The reason that this system will be studied is because preliminary research has made it very clear that this is the most efficient system for this type of building.

Thermal Energy Storage

Thermal storage can be a great addition to most buildings to reduce peak loads on a building. By reducing the peak loads on a building, system equipment can be reduced, and initial cost on the building can be reduced. The main idea behind thermal storage is that a reservoir can be chilled or warmed during the night while either off-peak electrical rates are less expensive. Also there are little inefficiencies in the system that cools the fluid in the tank, this is because the system can run at full efficiency, and part load inefficiencies do not affect the system then.

Adding thermal storage to the Steelstacks building would greatly reduce on peak cooling hours. The addition of thermal storage could actually cover the entire energy consumed by cooling loads for certain days due to the nature of the this building; some days the building may only be hosting a small gathering or concert and the thermal storage could cut the load needed by convention cooling out completely.

There are two types of available thermal storage, ice storage and chilled water storage. Both of these systems will be evaluated for use in the Steelstacks building. System requirements will be looked into when evaluating this system such as space requirements, and efficiencies for both ice and chilled water storage.

Ground Source Heat Pump System

The ground source heat pump system (GSHP) uses the nearly constant temperature of the ground to condition the internal spaces of the building. Holes are drilled into the ground ranging from 100-500 feet to extract or reject energy into the ground. This is considered vertical looped system, other systems such as horizontal loop and open looped systems will not be looked into in this study due to space and load consideration.

Ground source heat pumps work in the same manner that an air-sourced heat pump would work, except that the exchange is between the ground instead of air. The interaction between the system and the ground occurs with a refrigerant cycling through polyethylene pipes.

Ground source heat pumps should be a very effective system for the Steelstacks building not only because of the general advantages but because of the use of the building. This building can be used at all hours of the day and 365 days a year, so a system that has low operating cost such as GSHP does will be very efficient.

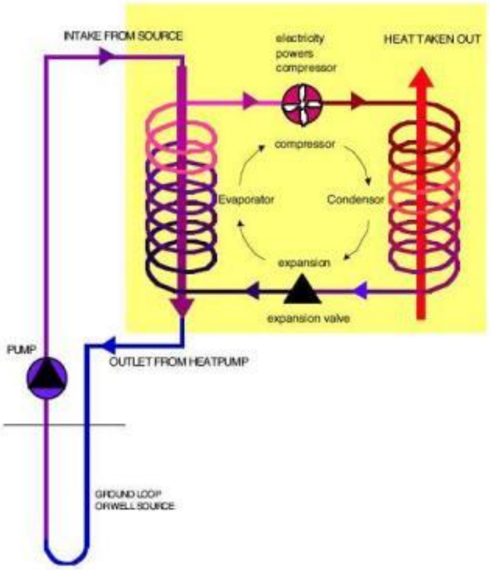


Figure 1-Schematic of basic GSHP

Preliminary analysis

The primary concern with the installation of GSHP system is land space. The system needs and ample amount of ground to run the looping through. Below is a figure that shows the area of the surrounding the Steelstacks building. The area directly between the Steelstacks building and the blast furnaces will be a big open plaza, which will work very well for a geothermal site because nothing will have to be excavated for a plaza, limiting the possibility of any damage to the system during the construction period. The area to the right of the building on the map is also a possible site for the underground system. This area is just an open space between the Steelstacks building and the future site of another building.

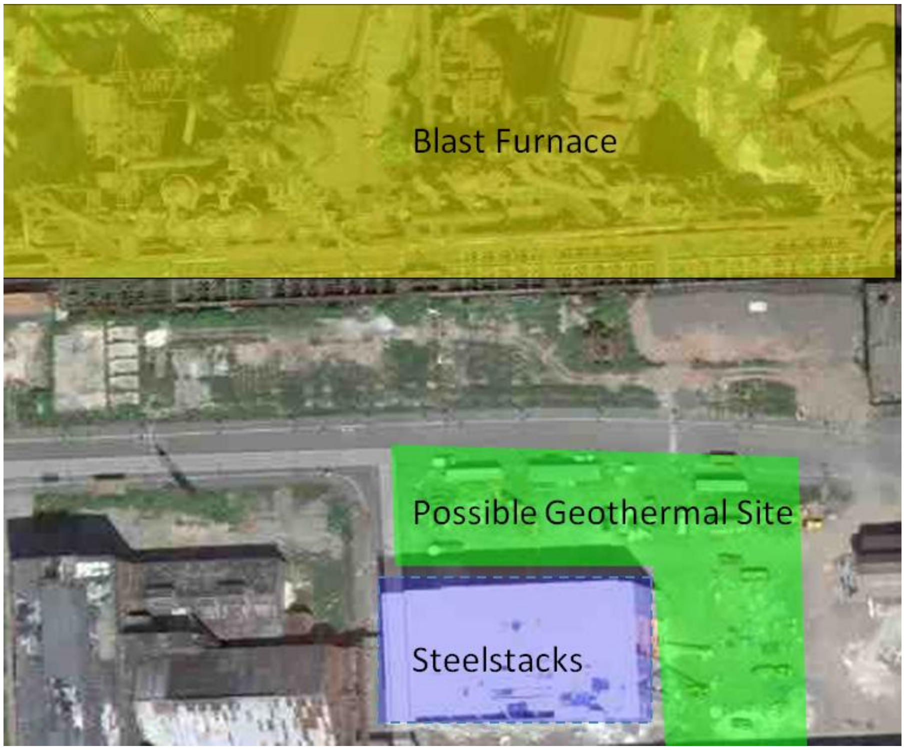
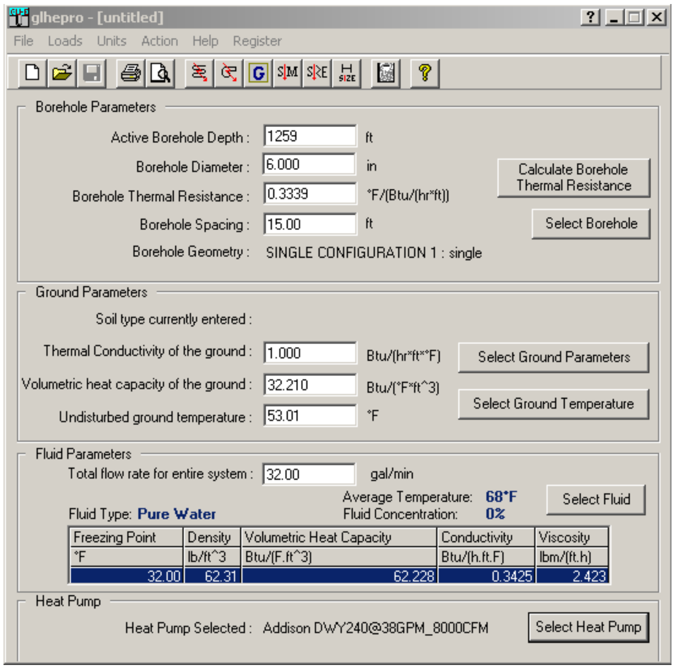


Figure 2-Graphic of possible site for geothermal bore field

The next step to determin if this area would be a feasable spot for the boreholes was to use a program called GLHEPRO v4.0. This program takes parameteres from inputed data about site and selected heat pums and tells you the calculated sized of boreholes needed. For this program I just used a “single line configuration”, the reason for this is because it would then output the depth of the borehole needed if I only had one borehole. I can than use that depth to decide how I would want to break that length up (ex. 1200 ft total, 3 x 400ft holes, or 4 x 300ft holes, or 6 x 200ft holes). I picked the heat pump size based on the loads of the existing equipment . Below is the main screen of GLEPRO which allows you to set up all the parameteres of the well system. The following screen is the selection screen of the heat pump.



Borehole Parameters

Active Borehole Depth : 1259 ft
Borehole Diameter : 6.000 in
Borehole Thermal Resistance : 0.3339 °F/(Btu/(hr*ft))
Borehole Spacing : 15.00 ft
Borehole Geometry : SINGLE CONFIGURATION 1 : single

Ground Parameters

Soil type currently entered :
Thermal Conductivity of the ground : 1.000 Btu/(hr*ft*°F)
Volumetric heat capacity of the ground : 32.210 Btu/(°F*ft^3)
Undisturbed ground temperature : 53.01 °F

Fluid Parameters

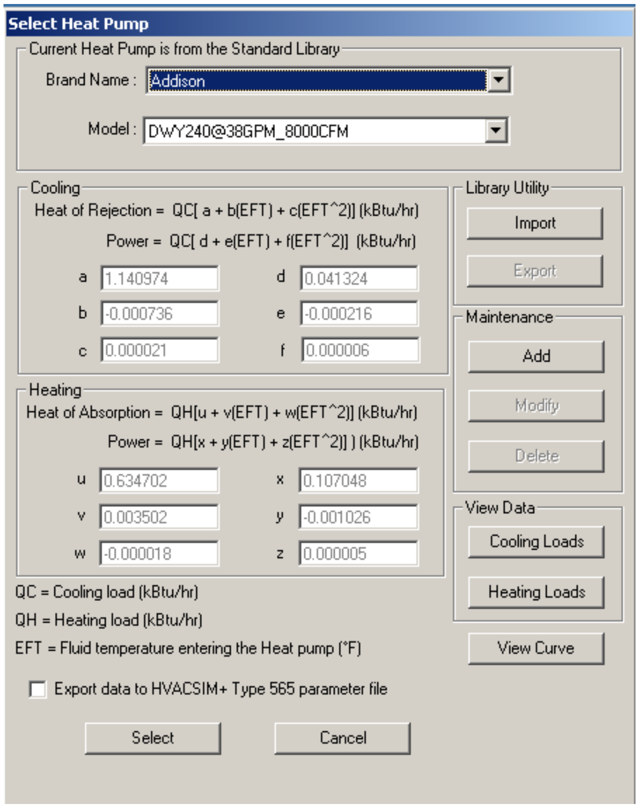
Total flow rate for entire system : 32.00 gal/min
Average Temperature: 68°F
Fluid Concentration: 0%
Fluid Type: Pure Water

Freezing Point °F	Density lb/ft^3	Volumetric Heat Capacity Btu/(F.ft^3)	Conductivity Btu/(h.ft.F)	Viscosity lbm/(ft.h)
32.00	62.31	62.228	0.3425	2.423

Heat Pump

Heat Pump Selected : Addison DWY240@38GPM_8000CFM

Figure 3-glhepro input page



Current Heat Pump is from the Standard Library

Brand Name : Addison

Model : DWY240@38GPM_8000CFM

Cooling

Heat of Rejection = QC[a + b(EFT) + c(EFT^2)] (kBtu/hr)

Power = QC[d + e(EFT) + f(EFT^2)] (kBtu/hr)

a 1.140974
d 0.041324
b -0.000736
e -0.000216
c 0.000021
f 0.000006

Heating

Heat of Absorption = QH[u + v(EFT) + w(EFT^2)] (kBtu/hr)

Power = QH[x + y(EFT) + z(EFT^2)]) (kBtu/hr)

u 0.634702
x 0.107048
v 0.003502
y -0.001026
w -0.000018
z 0.000005

QC = Cooling load (kBtu/hr)
QH = Heating load (kBtu/hr)
EFT = Fluid temperature entering the Heat pump (°F)

☐ Export data to HVACSIM+ Type 565 parameter file

Figure 4-glhepro pump selection page

After taking all the data for the various heat pump systems, I decided to go with a depth of 300 ft. per borehole which comes to a total of 85 total bore holes. Below is a graphical representation of what the configuration would roughly be under the ground. There is a minimum distance of 15 feet between boreholes. This image confirms that there is ample amount of space for a geothermal field.

Figure 5-Schematic of bore hole positions with proper spacing

Modeling

The Ground source heat pump system was modeled in Trace700. Heat pumps were sized to the same specification as the existing rooftop units (capacity and fan size). They were modified from air source heat pumps to ground source as well as not having a boiler backup.

Energy savings

A GSHP system relies on the relatively constant temperature of the ground. The ground is warmer than the air in the winter and cooler in the summer. Having the constant temperature will create a larger change in temperature compared to the air, which will make for a very efficient system. Therefore the energy savings was considerable with the GSHP. The yearly consumption went from 1,002,387 kWh per year to 846,175 kWh per year which is a saving of 15.6% per year compared to the existing system. The graph below shows how the GSHP system is more efficient in every month of the year then the existing system.

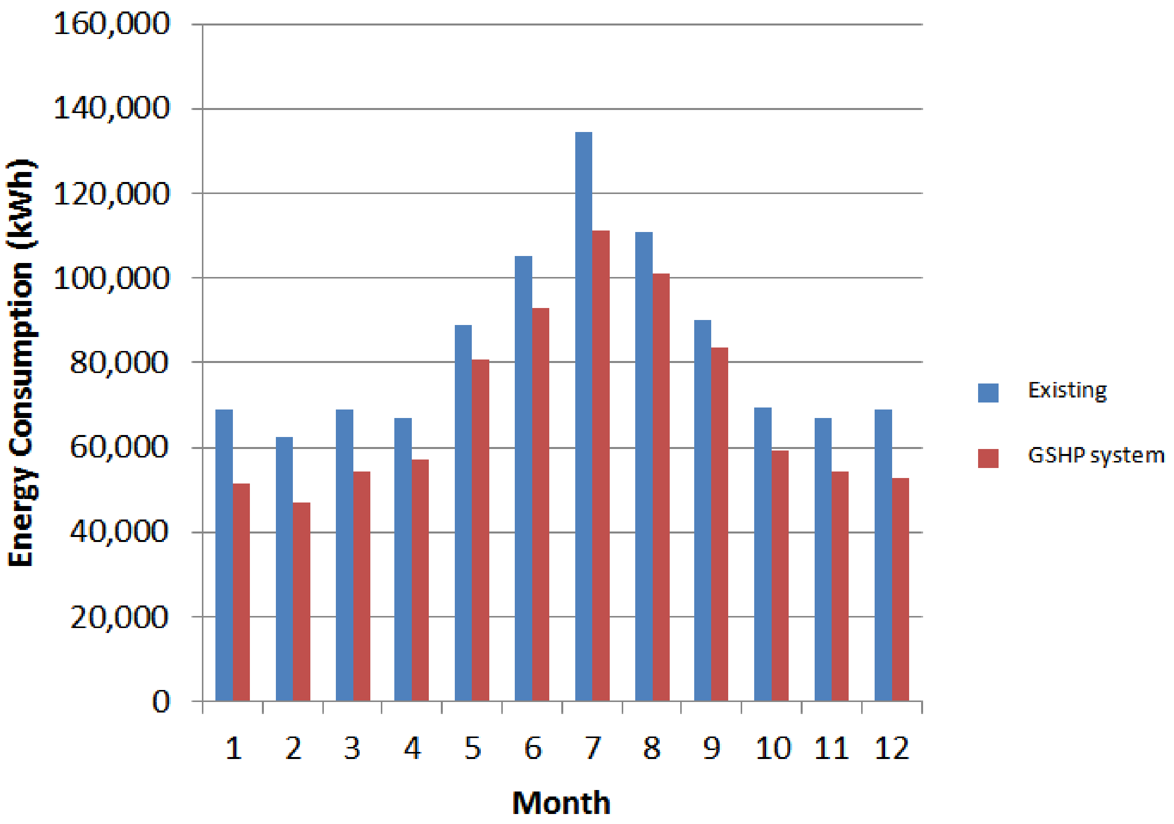


Figure 6-Energy consumption of existing system vs. GSHP system.

Cost Analysis

Initial cost for the GSHP system was a tricky task to calculate. The Heat Pumps were estimated using RSMeans Mechanical cost data. There will be obvious variation from this estimated cost because of manufactures not having the exact sizes that are called out and as well as some inaccuracies associated with RSMeans.

Name	Capacity (ton)	Bore Holes	Estimated Cost*	
			GSHP	Existing
GSHP-1	22.9	11	$31,000	$22,200
GSHP-2	11.4	5	$19,040	$10,600
GSHP-3	12.6	6	$19,760	$10,600
GSHP-4	53.1	26	$51,040	$39,600
GSHP-5	51.7	25	$49,940	$39,600
GSHP-6	1.7	1	$5,310	$2,025
GSHP-7	23.4	11	$31,000	$22,200
Total	176.8	85	$207,090	$146,825

Table 9-Cost comparison for existing system and GSHP system

The cost difference for the system equipment for changing from the existing system to a GSHP system is $60,265. The GSHP system will eliminate the use of a boiler for space heating. The cost of the 1,000 MBH boiler was $17,025. This system cost due not include fans for distributing the air to the building because these will be kept the same so the prices will be the same. The cost of the boring and piping for the vertical loops will be the most expensive part of the GSHP system. From previous data an estimate of $3000 per bore hole for a 300 foot deep hole is an appropriate estimate. Having 85 bore vertical loops, this comes to a total of $255,000 for bore holes and bore hole piping. This comes to first cost increase $298,240.

The GSHP system reduced energy cost considerably due to the constant temperature of ground which eliminated any back-up boilers as well increased efficiencies. The energy savings per year was $23,495. This savings has a simple payback of 10.6 years. The below graph shows what the payback would be for various increases in electricity cost.

Increase percentage	Payback period
0	10.6
5	9
10	7.5
15	6.6
20	6.2
25	5.7

Table 10-Payback period

Recommendation

Ground source heat pumps would be a very valuable addition to the Steelstacks building. The payback period is one that is rational for this type of business. Also, the use of the building makes the GSHP system very profitable. The notion that this building is going to be used throughout the night, which during the winter would create the highest heating loads, a GSHP system neutralizes that load some by having a constant ground temperature and having relatively constant system efficiencies.

Solar Energy

Solar Energy is a very effective way to save money on energy usage on a building. Solar energy is collected during the day and then either store or put directly to use in the building. A basic water heating system with water tank storage and auxiliary energy source was chosen because this system allows independent control of the solar collector-storage loop on the one hand and storage auxiliary loop on the other hand, as solar heated water can be added to the storage at the same time that hot water is removed from the tank to handle the building loads.

Design conditions

In the initial stages of thermal the orientation of the building and solar array are the primary concerns for design of the system. The Steelstacks building is located in Bethlehem, Pa which has a latitude of 40.626^{o} (Φ). This value will have a great effect on the slope of collectors. Typical solar collectors have an angle that is roughly 15^{o} larger then there latitude value. For this research, different values of tilt angle will be looked into find the reach an appropriate tilt angle.

Looking at the location of the Steelstacks building, there are two possible locations for the solar collectors to be installed. The first possibility is on the roof of the building. The roof of the building has 15,690 ft^2 available for a possible collector. This idea would be ideal, except the architect of the building has reservations about roof placement because he believes it will take away from the building exterior. The second possible site for the collectors is in a green space behind the Steelstacks building and another existing building. This location is far from view for visitors to the building as well an unobscured view to the south. The drawback of this location is that there would be more piping and valving needed for the water travel that distance. The system though would have much more room to expand if necessary.

The roof top unit serves to be the best space, due to its location. An architectural breadth will be investigated to alter the exterior of the building to effectively hide the solar panels on the roof.

Figure 7-Site possibilities for Solar Collectors

Process

The thermal process of the solar collector system is very simple. A solar array of collectors is placed so that they have direct access to sunlight. During the day, collectors will get very hot and as fluid passes through them the water will increase in temperature. This fluid is then sent to the hot water tank. The heat is exchanged in the hot water tank and then sent back to the solar collectors. From there the thermal energy goes to two possible locations, some of the thermal energy goes to the domestic hot water tank to supply water to the bathrooms and kitchen. This loop has an auxiliary heater to increase the water temperature if needed to the prescribed 120°F for hot water. The other loop is for space heating. This loop goes to the individual space heating equipment to serve the space. This look can have auxiliary heating depending on how the solar collector array is sized.

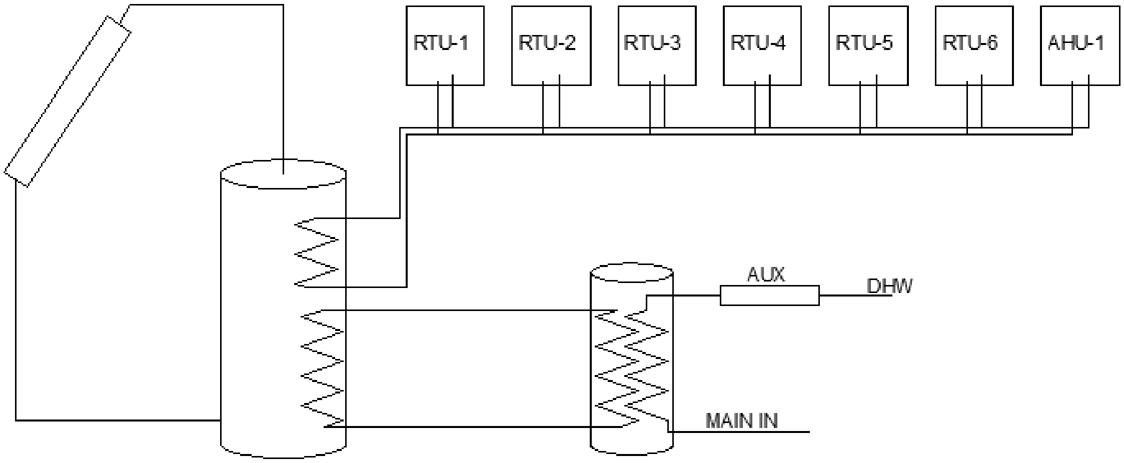


Figure 8-Schematic of Solar Water heating system.

The type of space heating that this system will provide is still a forced air system. The hot fluid will go then from the storage tank to the coils in the existing units and the air will be forced into the spaces as it does now. The only difference is the process of heating the fluid; traditionally this was done completely by boilers now it is done mostly by solar heating and some supplemental boiler use.

Calculations & Sizing

The results for this were carried out by TRNSYS software in combination with excel and hand calculations. TRNSYS was used to calculate the total savings per year based on inputted values of collector area and storage tank size. This alone could not properly size the system though, other considerations into cost were essential for the sizing of this system.

The first step in this process was to find the overall load (UA) on the building during the winter months. This was done using the highest design conditions. The equation below was used to calculate this and this parameter was put directly into the software package.

$$UA = \frac{\dot{q}_H}{T_{DH} - T_{OA}}$$

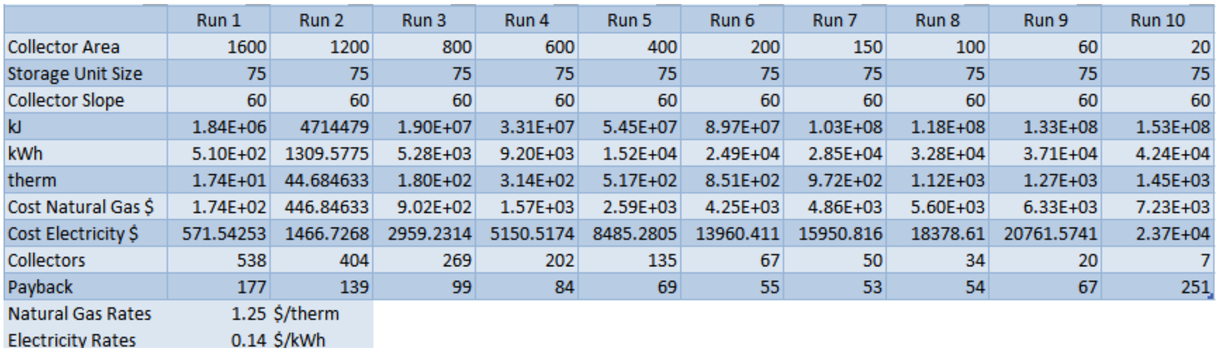
$\boldsymbol{\dot{q}_H}$- hour load of the largest heating use (from TRACE software)

$\boldsymbol{T_{DH}}$-heating design set point

$\boldsymbol{T_{OA}}$-outside air temperature at when heating design occurs.

First the collectors were sized to support the full load of the building. This was an unreal estimation because most systems are sized to accommodate at a maximum of 75% of the building load because after this threshold it does not make economic sense for the water heating system to be that large. An estimation was also done to cover the recommended 75% of the load.

From this step, different values of collector size and storage size were inputted to find the appropriate sizes based on annual savings and payback period. The outputs from TRNSYS were put into an excel file and quickly gave rough estimated of panels and payback. Below is the output of various sizes and estimated payback. The table below shows only a few of the referenced material.



	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10
Collector Area	1600	1200	800	600	400	200	150	100	60	20
Storage Unit Size	75	75	75	75	75	75	75	75	75	75
Collector Slope	60	60	60	60	60	60	60	60	60	60
kJ	1.84E+06	4714479	1.90E+07	3.31E+07	5.45E+07	8.97E+07	1.03E+08	1.18E+08	1.33E+08	1.53E+08
kWh	5.10E+02	1309.5775	5.28E+03	9.20E+03	1.52E+04	2.49E+04	2.85E+04	3.28E+04	3.71E+04	4.24E+04
therm	1.74E+01	44.684633	1.80E+02	3.14E+02	5.17E+02	8.51E+02	9.72E+02	1.12E+03	1.27E+03	1.45E+03
Cost Natural Gas $	1.74E+02	446.84633	9.02E+02	1.57E+03	2.59E+03	4.25E+03	4.86E+03	5.60E+03	6.33E+03	7.23E+03
Cost Electricity $	571.54253	1466.7268	2959.2314	5150.5174	8485.2805	13960.411	15950.816	18378.61	20761.5741	2.37E+04
Collectors	538	404	269	202	135	67	50	34	20	7
Payback	177	139	99	84	69	55	53	54	67	251
Natural Gas Rates	1.25	$/therm								
Electricity Rates	0.14	$/kWh								

Table 11-table showing inputted values from TRNSYS to calculating simple payback

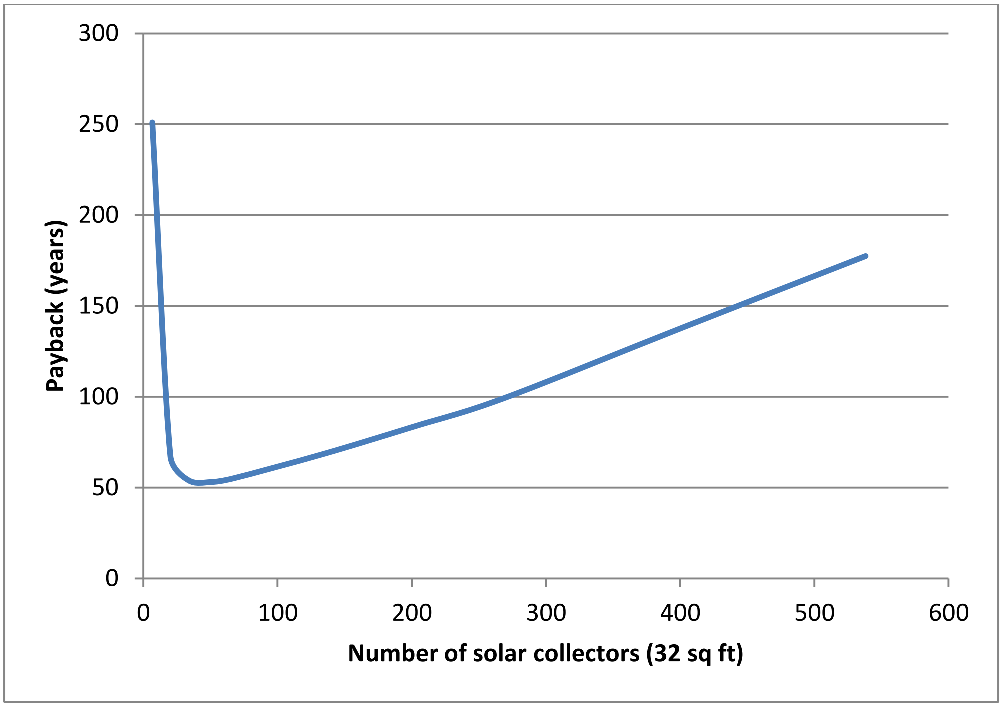
Cost Comparison

Solar collector systems have a very high initial cost; the idea is that the cost can quickly be offset by the large savings in energy. For this building the collectors that were chosen from Suntrac Solar. The efficiency and characteristics of their panels' best describes the characteristics of my modeled system. They provide 8 feet by 4 feet panels which cost $1,950; the installation cost of these panels is estimated at around 4,000 dollars, which includes pipes and valves and any necessary storage or pumps. This will bring the total to $5,950 per panel. The cost per panel greatly decreases with the size of the solar collector area because fittings, valves and other solar supplies are only need once. For the purposed of estimation, $2,275 per panel will be used. This number was calculated by using online information as well as RSmeans.

For this system 538 panels are needed to sustain the total heating load for the building. This amount of panels does not make sense economically because the payback period would be too large. (~177 years). This system would also occupy all off the available space on the roof of the building

For the system sized to handle 75% of the load, the results were very similar, they payback periods was close to 85 years, and no further investigation was pursued in this design.

The most economical system in terms of payback cost and annual savings had a total of 50 panels. The chart below helps visualized the size and payback considerations taken into account for choosing the appropriate system. This system is not so oversized that it becomes inefficient during the summer months. The payback on this system is much more reasonable then the full load system but yet still a little high to be considered for installation. The simple payback period is 49.5; no further investigation into payback period was done because this value is way too high.



Graph 3-Payback vs. collector area

The main reason for this is because that the large majority of this system will only be used for less than half of the year. The heating part of this system will be used for approximately five or six months. During these months the ROI(return on investment) will be very high because it greatly reduce full loads, but during the summer months were the only load on the solar collectors will be the load for washing dishes and hands, the collector will be way oversized therefore decreasing your payback period.

Collector Cost w/installation & storage	$113,750
Boiler downsize	($9,825)
Total	$103,925

Table 12-Solar Cost

Altered System

A quick analysis was done to see if the system would be plausible if it was sized in a simplified way. The space heating was completely taking out of the problem and the system was sized to just accommodate the hot water needs of the building. This was a much more efficient system. The payback period was lower but further investigation was not pursued because this would not be a plausible option though because of the inconsistency in the venue. The initial payback period was not low enough for the system to be fully applicable for this building.

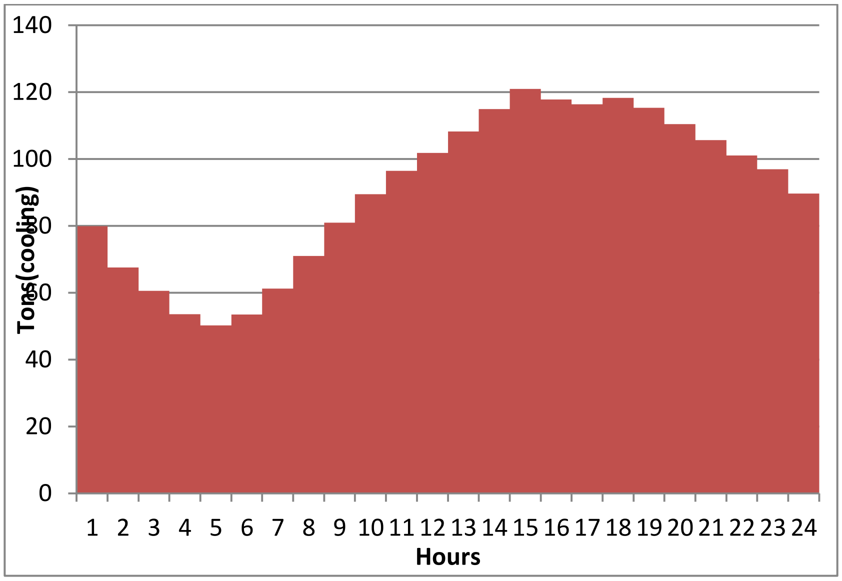
Thermal Storage

Thermal storage is a very simple idea to reduce energy cost of a building. It simply works by storing thermal energy in either chilled water or ice in the off-peak hours and uses the stored energy during the day when loads are higher and on-peak prices do the same. This practice is often called load leveling because it levels the load on the equipment throughout the day.

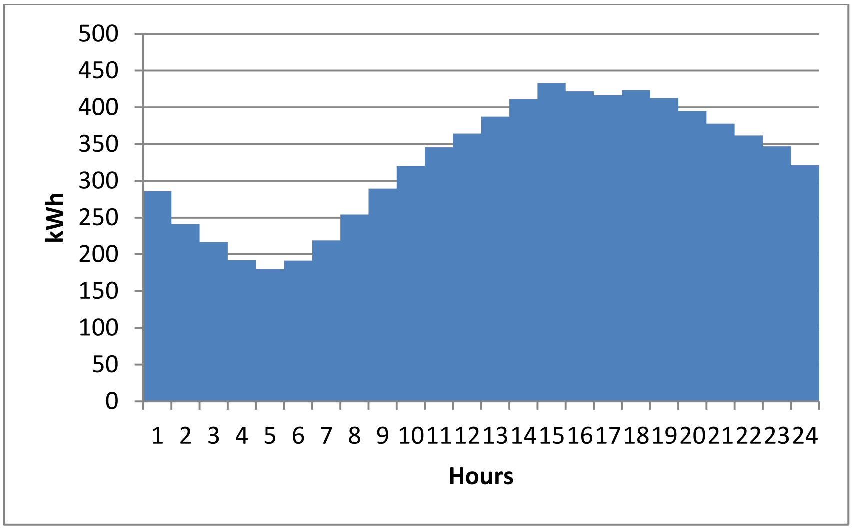
Modeling

The initial step to finding if thermal storage was an appropriate idea for the Steelstacks building, a computer model done on Trane Trace software was performed. Trace did an analysis of the building loads for all hours of the year. The mechanical load was only taken into consideration for this analysis.

Below in figures a plot of the energy consumption by hour on the peak day of the year for the packaged units. This will be used to appropriately size the thermal storage system with the process of peak shaving. The peak profile will be used to find out what hours thermal storage will be used and when it will be charged.



Graph 4-The cooling load on the building throughout the year in tons of cooling



Graph 5-The total cooling load on the building throughout the year in kWh

After looking at the graphs it is easy to see when the main load on the building will be. The building load peaks around 4 p.m. and it hits its minimum at around 5 a.m. This is rationalized by the use of the building. Most of the occupancy loads will be from the early evening till late in the night. The peak thermal load will be in the middle of the day till late evening, with both of these profiles (occupancy and solar), overlapping around in the early evening till about 8 p.m. which is when the highest loads are.

Chilled vs. Ice storage

Initially the idea of researching both chilled water and ice storage was to determine what system would be most effective. Each system had there advantages and disadvantages. The ice storage would be a more effective choice because it requires less space because ice holds more thermal energy then chilled water. The disadvantage of ice storage was that the efficiency of the chiller is lowered due to the high energy required to freeze water.

For this study, only chilled water will be looked into, this is because space is not a large concern for this project; the idea is to have the most energy efficient building.

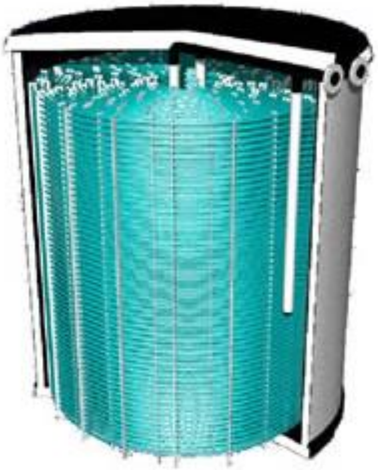
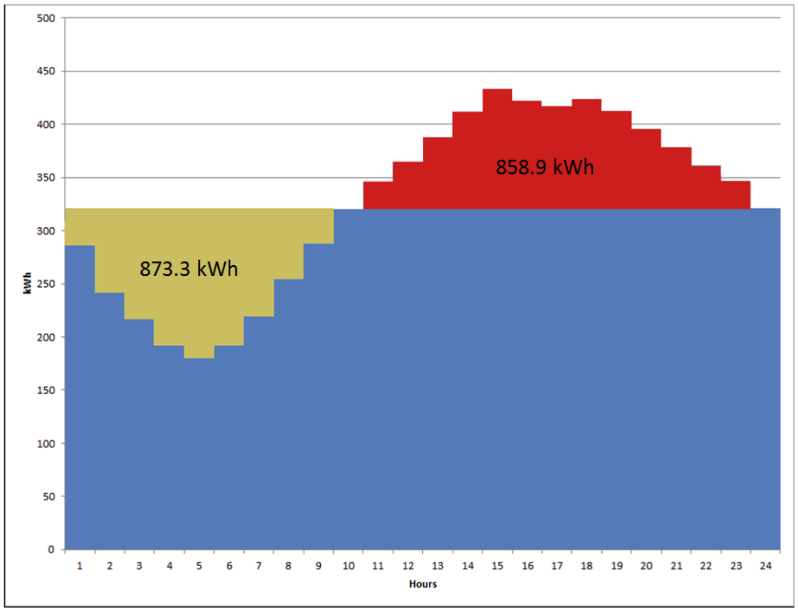


Figure 9-Thermal storage tank

Cost Savings

The cost savings for the thermal storage was a little different the normal consumption savings. Thermal storage biggest savings was in the demand rate in the electrical cost. The difference between peak and off-peak savings for the electricity rate was around 4 cents (14 cents on peak and 9.8 cents off peak). Peak shaving allowed the mechanical system to run very consistently throughout the day and lower the highest load times. Since my demand price was 6.25 dollars a kWh, this could get very expensive without thermal storage.

The thermal storage was on used for the summer months, May through September; during the winter months it did not make economic sense to run the thermal storage through the night because the peak loads during the day did not exceed the load to run the plant during operational hours.



Graph 6-Showing that the stored energy will be able to supplement the excess

In the above figure is a graphical representation of how the energy is going to be saved and used by using thermal storage. The idea is that air-cooled chillers will run at 325 kWh constantly, when the load is more than satisfied by that load the extra load will go into thermal storage. When the load cannot be satisfied by running at 325 kWh, the thermal storage will be used to satisfy the load. The above graphical representation shows that thermal storage will more than satisfy the peak loading. The thermal storage would need to be sized to accommodate 873 kWh of cooling or 248 ton-hours of cooling.

The total savings from changing to a thermal storage system is $7,627. This calculation was done by Trane Trace which account for both reduction in peak load and on and off peak consumption charges.

Addition equipment is need for ice storage, obviously the tanks will be addition equipment as well as a certain amount of valves and control device to allow the system to switch from producing thermal storage the retrieving it. The average for thermal storage is $60-80 per ton hour required. That would put the cost of just the tanks at $19,840. This value does not account for any addition piping or controls. The piping distance is very low because the tanks will be placed outside very close to the tanks. The price for the piping, pipe insulations and valves is $12,285. These values were taken from RSMeans catalog.

One missing piece of information about this system is that the value of saving represents the total amount of savings is for the entire building. There are seven units that serve then entire system. This study is assuming that one single tank could be used to serve all the systems. This assumption would require a control system that is very effective. The building is already outfitted with a BMS (Building Management System) which is very integrated into the whole building design. The main assumption is that this system has the capacity to handle this task of both putting the unused chillers to use in storing thermal energy and when system need thermal energy it can pull the required amount.

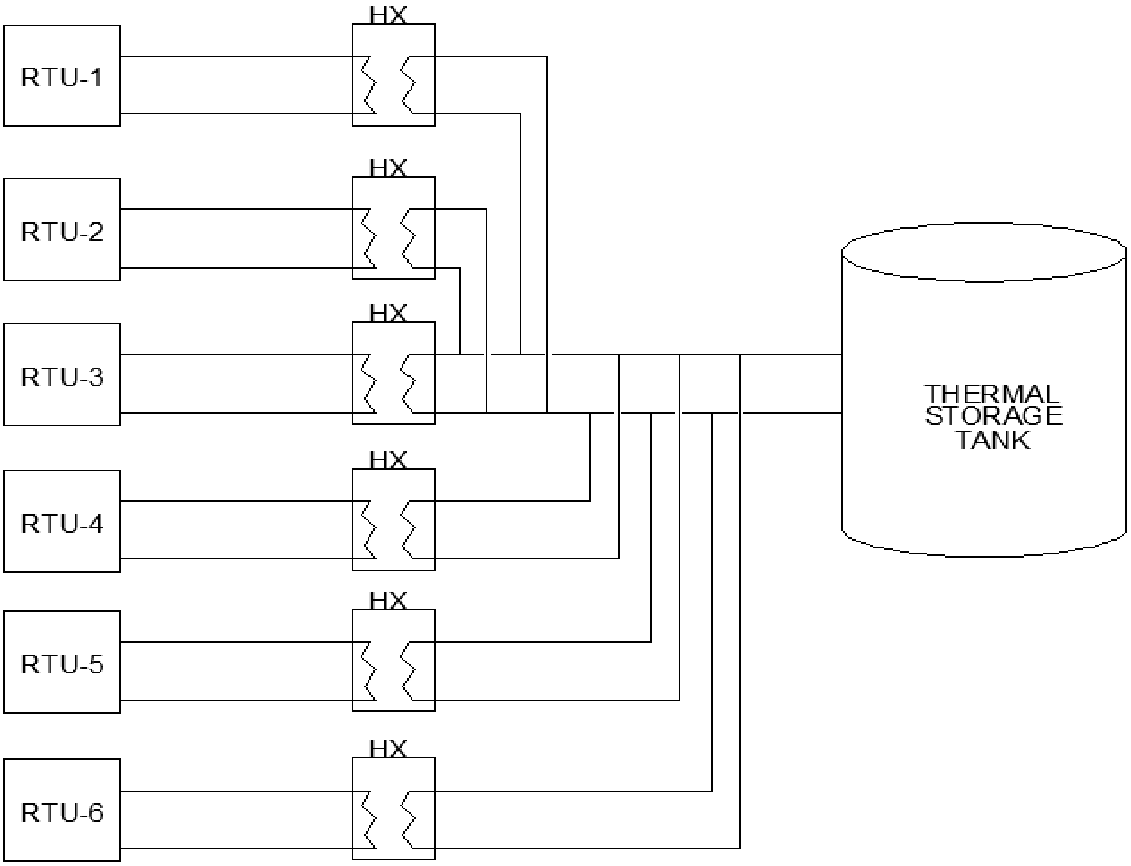


Figure 10-Thermal Storage Schematic

The payback of this designed ice storage system is very short. The simple payback period comes out to 4.2 years. This value could be increased with any drawbacks to the above mention idea. Only two different changes in payback were calculated because of the short payback time.

Increase percentage	Payback period
0	4.2
5	3.9
10	3.5

Table 13-Payback estimates

Recommendation

The recommendation for the Steelstacks building for a thermal storage system would be a definite 'yes'. The system has proven to reduce the high demand cost in this area of electricity. Another thing that would have to be looked into with the owner is the ability to control the amount of thermal storage made. Because this building primary use is for concerts, cultural events, and movie showing, there is a good possibility that the building will not always be in full use. The ice storage system was designed to account for full load every day. If the BMS system could be programed to make certain amounts of thermal storage depending on the next days anticipated load, the payback period would be decreased greatly.

Another consideration to look into for this system is the amount of time during the year it can be used. The sizing calculations were made for the peak load for the whole year and the cost savings was based on all the savings happening in the winter months. Therefore the annual saving could greatly vary with the outdoor conditions as well as the anticipated consumption of the building.

Acoustical Study

``One problem that was very eye-popping to me when I took my initial visit to the Steelstacks building was that the RTU units had no vibration control. The units were simply placed on an elevated surface with nothing preventing the vibration of the unit to go directly into the building. This creates a lot of uncertainty because of this building being a performing arts center. Background noise in this type of venue could be very dramatic to the audiences viewing pleasure.

Figure 11- This is a picture taken from the sight showing the lack of any type of vibration control.

Upon further investigation into this problem, it was apparent that some type of neoprene isolation device was specified in the drawings but not installed for some reason.

An investigation into what effect this omission will have and what noise will transmit through the walls and down into the Musikfest café. The first step to find the effects of this mistake was to find the T_{60} time of the room. This value is the amount of time it takes for 60 decibels to decay in the room. The values are below; a different value is associated with every bandwidth. The values associated with this room are rather high for this type of venue. There are two reasons for this: the first is that an assumption for the amount of people in there was low and two, because no chairs were assumed. Each was done for a respective reason.

The estimate for people was on the low end so that a worst case scenario could be evaluated. If the people count was closer to 3500, the T_{60} time would definitely decrease and the effect of the roof top units may not be noticed. Another assumption was that there were no chairs in the performing center. This center is a multifunctional venue, the setup can vary from an open pit to a table and chairs arrangement. Again this assumption was used to allow for the highest T_{60} time. Both of these assumptions are very plausible to happen at the same time.

		α at different Hz				
Surface	Surface ft^2	125	250	500	1000	2000
Ceiling	7280	0.25	0.28	0.31	0.17	0.16
Floor	7280	0.2	0.21	0.21	0.37	0.6
North Wall	2900	0.35	0.25	0.18	0.12	0.07
East Wall	1125	0.28	0.215	0.22	0.15	0.145
South Wall	2900	0.21	0.18	0.18	0.18	0.22
West Wall	1125	0.21	0.25	0.06	0.07	0.09
People	2500	0.35	0.35	0.42	0.46	0.5
		Volume	182000			
	T_{60}	125	250	500	100	2000
		4.631812	4.716753	4.730249	4.72712	3.714674

Table 14- Calculations of the varying T_{60} times of different frequencies

Once the T_{60} time was calculated, an examination into seeing if this number was reasonable was explored. Upon initial investigation it seemed very high, even with the numerous assumptions that were made. If the T_{60} times were correct that would mean that a lot of drowning out would occur during a performance which would make it hard to hear. This situation is not very typical for a performing arts center. The reason this sacrifice was made in this building was because of the essential view to the blast furnaces through the floor to ceiling windows as well as the architectural design of the building. The exposed beams on the ceiling as well as the raw nature of the concrete walls were something that is carried throughout the building. This not necessary appropriate for a performing arts center but was essential for the design of the building. The design of the building was compensated with a state of the art sound amplification system to allow for all sound to reach the audience at the same time and reduce the drowning out feeling of the building.

From all the gathered knowledge it is very apparent that this room would be very susceptible to outside noise entering the building. If a sound or vibration were to come into the building it would linger in the room and could become a very large annoyance. Another very important attribute would be that the closest wall to the outdoor mechanical space is the VIP and Suite section, the people sitting here would have paid a lot of money for these seats and if a constant humming would be coming from the wall it could greatly decrease the satisfaction with their experience. Below in the figure the relationship to the Mechanical Room and the VIP/Suite section is very apparent.

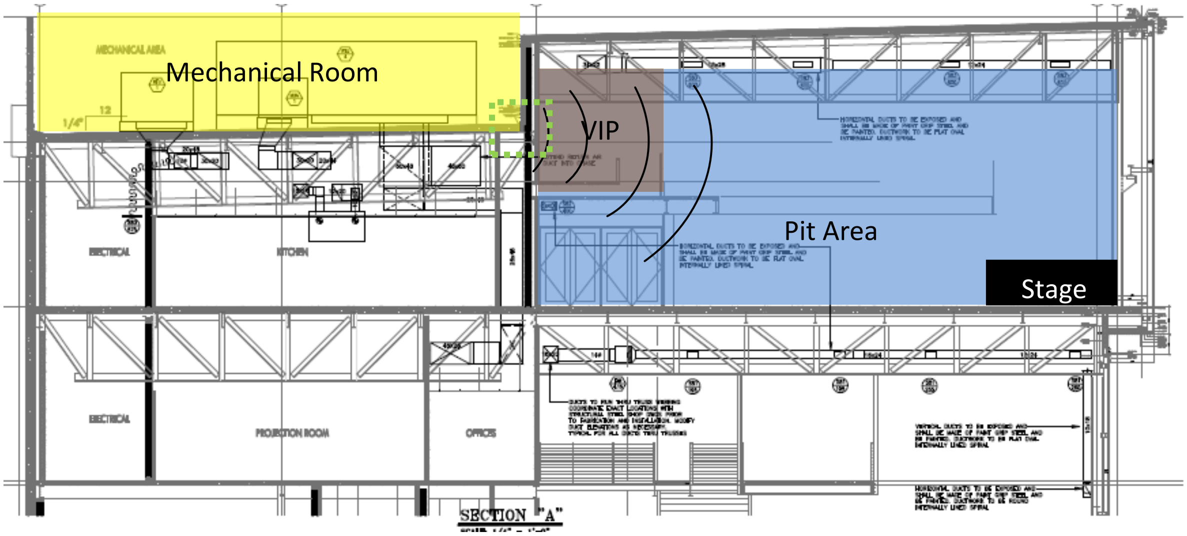


Figure 12- A cross section of the building layout, showing the relation of the mechanical room to the performing center.

Solutions

Once it was apparent that some sort of isolation was needed to prevent the possibility of noise disturbances coming into the room, two possible solutions were investigated. The first idea is to isolate each piece of equipment separately with some type of neoprene pads or acoustical curb package. The other idea was to completely isolate the roof from the wall of the Performing center.

The neoprene pad or curb package would be a very easy fix for this problem. Neoprene pads act as spring and dampen the impending vibration of the roof top units. Numerous levels of neoprene can be applied to account for different levels of vibration per the equipment specification. The only problem with neoprene in an outdoor environment is that over time it has the tendency to dry rot or decay in climates with high weather changes.

Figure 13- An example of multiple levels of neoprene padding.

A curb package would be a better idea for this situation. A curb package would be a better solution for this climate and size of equipment. A curb system works as a system of springs and rigid beams to isolate the vibration. The roof top units would be placed on steel girders; these girders would be held up by a system of springs that are attached to the roof. The system the can vibrate freely without having any effect on the roof. The figures below show how the system works.

Figure 14-Schematic showing the isolation technique in curb isolation package, courtesy of VibroAcoustics

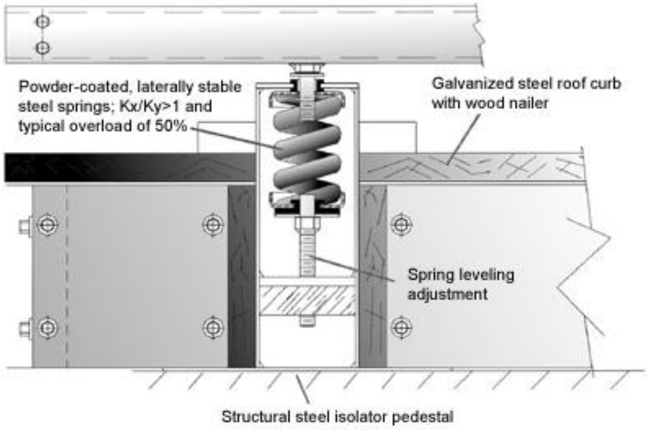


Figure 15-Vibration curb detail courtesy of Kinetics Noise

The other solution to isolate the sound from traveling into the performance space is to actually isolate the roof from the adjacent wall. As of right now the connection between the two spaces is very rigid, if this connection could act as sort of a free motion connect or rather a connection that could connect without such rigidity. The connection would actually dampen the vibration traveling through the wall. This is a very difficult task, and something that would needed to be done by a structural expert. Below is an example of how isolation would work between a floor and some type wall, this is not exactly how a system would work for my system but is does an ample job describing the process. But this task would more than likely not be pursued due to the complexity, along with the easier and cheaper solutions readily available.

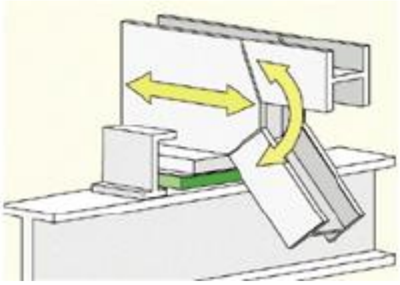


Figure 16-Example of structural vibration control

Architectural Breadth

An Architectural Breadth was pursued for the Steelstacks building for a few reasons. The major reason was because the addition of solar collectors on the roof took away from the original dynamic of the building. In meetings with the Architect it was very clear that no mechanical equipment was to be seen from the outside of the building. The existing mechanical equipment on the roof is placed in a pit within the roof system. This could not be done with the addition of solar collectors because it would have cut into the height of the third floor venues.

The idea behind the Architectural breadth is to extend the concrete system that is used throughout the building up another eight feet. This will do a few things; the first is that this will now hide the solar collectors from the public. From an Architectural standpoint it does something very unique to the large windows on the north side of the building. The concrete extension actually frames the large windows. It brings attention to the windows as being a frame maker. Originally the windows looked like windows from the outside. Once you were inside it was very clear that these window made for the beautiful views of the existing Blast Furnaces of the Bethlehem Steel Plant. With these additions I think it makes the building complete inside an out.

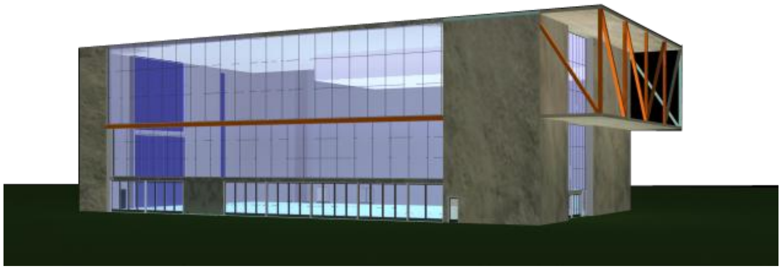


Figure 17-Existing Building

Figure 18-Rendering of Existing Building with solar panels installed and visible

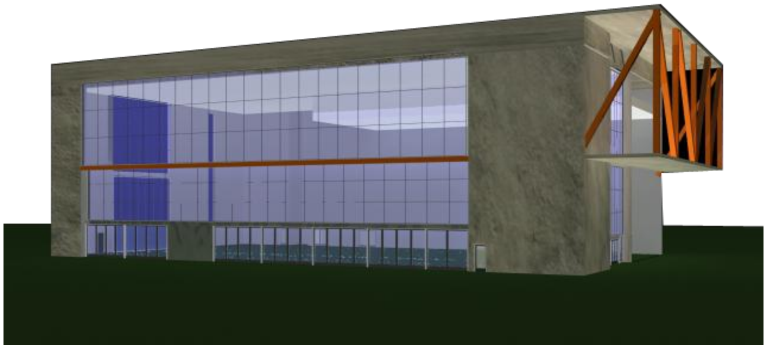


Figure 19-New Design Implemented on Building

Also, small changes were made the viewing deck. The roof was extended up to the eight foot extension. This change was made so that the extension did not look like it was an afterthought to cover the solar collectors; it also adds volume to the viewing deck.

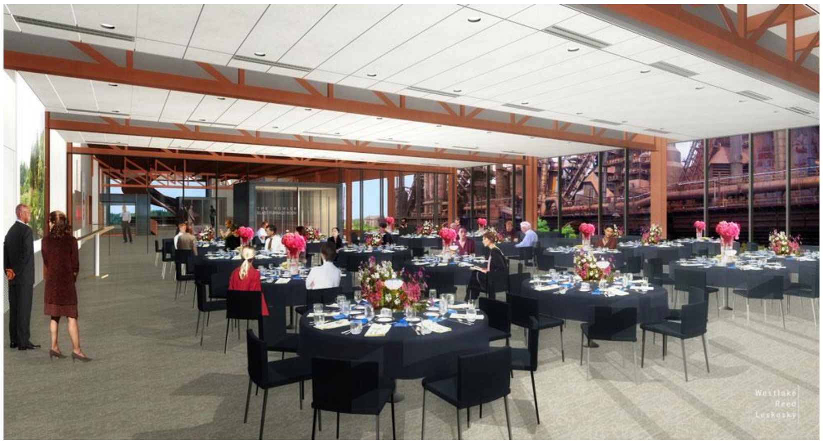


Figure 20-A rendering of the Blast furnace room that shows the views of the Bethlehem Steel Blast Furnaces, courtesy of Westlake Reed Leskosky

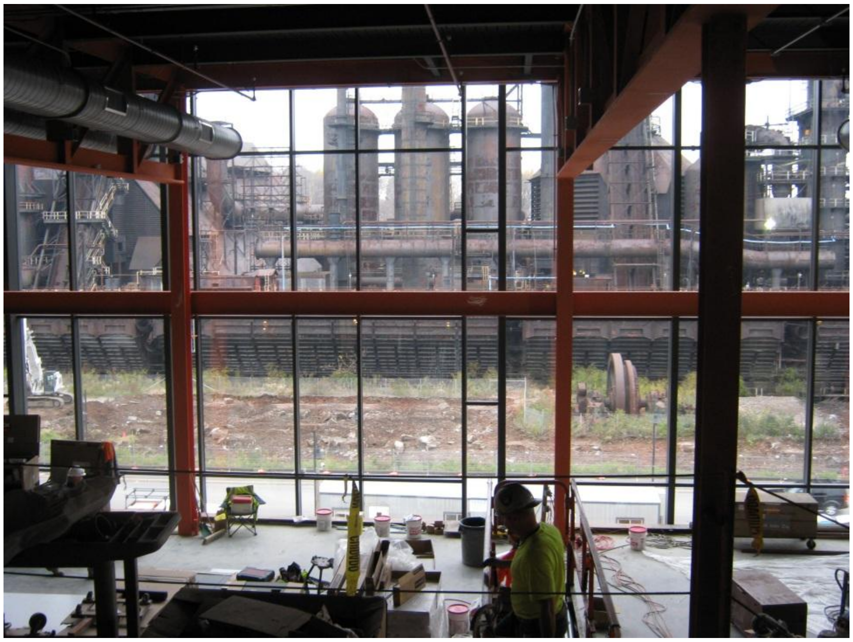


Figure 21- Picture from the Suites looking out to the Blast Furnaces and down onto pit area

The above rendering and picture exemplify the types of views that the audience or will see when attending the Steelstacks building. By changing the exterior of building slightly to accommodate for the addition solar panels on the roof, these view windows have now been framed form the outside. This will guide the audience into the building and give them a sense of the beauty of the views.

Conclusions and Final Recommendation

After looking at the performed analysis on the Steelstacks building, the one clear choice was Ground Source Heat Pumps. This system provided itself with an ample payback and the best long term, year round solution. The thermal storage system provided itself with a short payback time but since it could not be used year round and did not provide the owner with enough savings, the owner may not be interested in purchasing them for the return on investment. The solar collectors were not a good choice for this building. The solar collectors had trouble overcoming the large initial cost, while only being used at full capacity for the winter months of the year.

The GSHP system had an energy cost savings of $23,495. This takes a large amount out of the monthly energy cost. This will help with the day to day operations of the Center. The payback period on this system was estimated at 11.6 years at a minimum. This payback will be shorter based on the anticipated increase in electricity. Due to the low cost of maintenance associated with this system and the constant efficiency it becomes the clear choice for the Steelstacks building.

The thermal storage system is also a very plausible solution for Steelstacks. The payback period was lower than the GSHP system, but it did not provide itself the best solution due to the large savings as well as some inconsistencies in efficiency. If the owner were to have a larger budget on this project I would suggest this solution but due to the tight budget for construction and running of the building it is not the best choice.

The solar water and space heating system was not a good fit for the Steelstacks building. The system saved money each year, but the initial cost was not covered for 17 years, which is not a good return on investment for this type of building.

One possible solution that was not looked into in the depth of the report was a combination of these systems. Each system was researched and implemented as an individual entity. Possible improvements could have been made in the systems could work in unison of one another, and improve overall efficiencies.

References

Kavanaugh, S. P., *HVAC Simplified,* American Society of Heating, Refrigerating, and Air-Conditioning and Engineers (ASHRAE), Atlanta. www.ashrae.org

http://www.kineticsnoise.com/seismic/esr.html

"Isolated Curbs (VCR)." *Vibro-Acoustics*. Web. 05 Apr. 2011. <http://www.vibro-acoustics.com/products/vibration-isolation/curbs/isolated-curbs>.

SunTrac Solar | High Temperature Solar Hot Water. Web. 05 Apr. 2011. <http://www.energisticsystems.us/>.

"Solar Space Heating: Solar Space Heating Panels and Systems." *Solar Water Heaters | Solar Air Conditioning | PV Solar Panels | Solar Heating | Solar Thermal*. Web. 05 Apr. 2011. <http://www.solarpanelsplus.com/solar-space-heating/.>.

"For Commercial Buildings - Space Heating." *Florida Solar Energy Center*. Web. 05 Apr. 2011. <http://www.fsec.ucf.edu/en/consumer/solar_hot_water/commercial/space.htm>.

"Thermal Energy Storage Benefits." *Ice Thermal Energy Storage, Ice Rink - CALMAC*. Web. 05 Apr. 2011. <http://www.calmac.com/benefits/>.

"Energy Savers: Estimating a Solar Water Heater System's Cost." *EERE: Energy Savers Home Page*. Web. 05 Apr. 2011. <http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12910>.

"Energy Savers: Geothermal Heat Pumps." *EERE: Energy Savers Home Page*. Web. 05 Apr. 2011. <http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12640>.