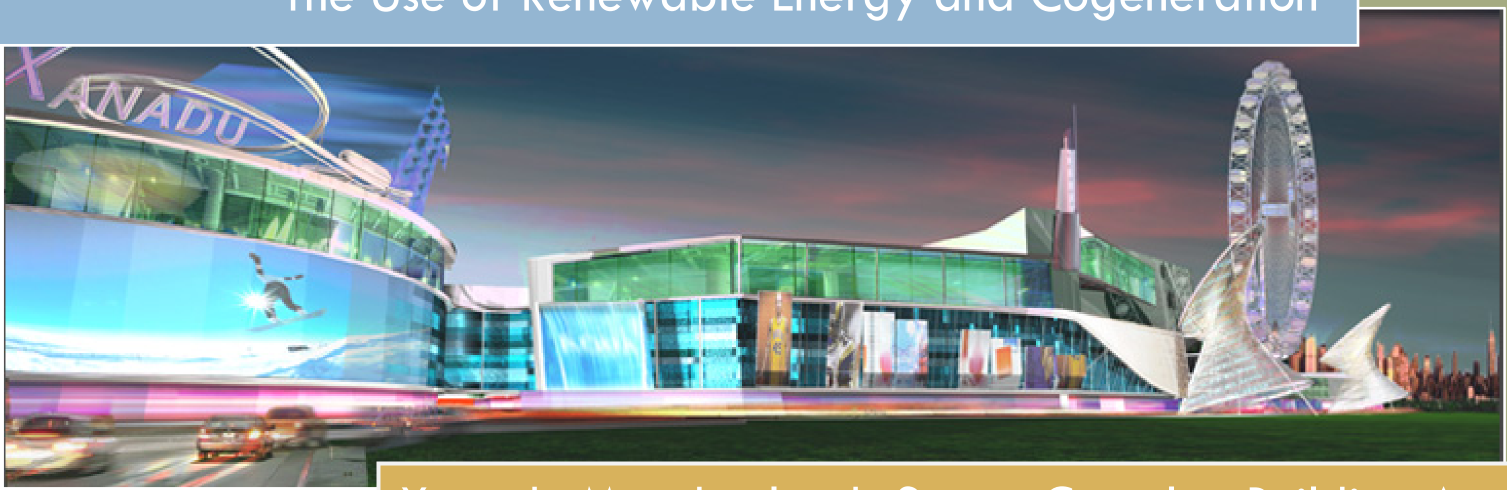
From Liability to Asset

The Use of Renewable Energy and Cogeneration



Xanadu Meadowlands Sports Complex Building A
East Rutherford, New Jersey

Prepared For:
Dr. James D. Freihaut, PhD
Department of Architectural Engineering
The Pennsylvania State University

Prepared By:
Jason M. Sambolt
Mechanical Option
April 9, 2008

Sports Complex
Building A

The Players

Owner:	Colony Capital
Architect:	Rockwell Group
Structural:	McNamara / Salvia Inc.
MEP:	E & S Construction Engineers
Electrical:	B & R Electrical Services
Consulting:	Acer Snowmec Consultants Ltd.
General Contractors:	Turner
	Whiting-Turner

Architecture

Building A of the Meadowlands Xanadu complex is designated as the sports district. All sports related retail stores and activities will be housed in this building. Building A has essential two sections; the south side of Building A will contain all the sporting good stores and restaurants while the north side of the building will house the Snowdome ski resort.

Electrical / Lighting

The complex is powered by a 480/277 Volt, three phase, four wire service. The power supply will be stepped down by 480 to 280/120 Volt transformers provided by individual tenants. The retail section's lighting is comprised of recessed metal halide down lights with 150 Watt T6 Cool White lamps. The ski resorts lighting is comprised of pendant mounted weatherproof metal halide globe fixtures with a 250 Watt lamp. The ski resort lighting is connected to a uninterrupted power supply for emergencies.

Statistics

Location:	East Rutherford, New Jersey
Building A Size:	553,000 square feet
Construction Dates:	June 2004 - November 2008
Overall Project Cost:	$2,000,000,000 base price
Delivery Method:	Design-Bid-Build

Mechanical

The retail section of Building A is served by four rooftop air handeling units. The units only provide air to the common areas of the building while tentants will be responsible for their own system. The indoor ski resort is served by a single large air handeling unit. An under-floor gylcol cooling system will maintain near freezing tempeatures year round to maintain the quality of snow.

Structural

The foundation consists of 30 to 60 foot piles to anchor the structure into the swampy surroundings. The skeleton of the building is comprised of W-shape steel beams, columns and girders.

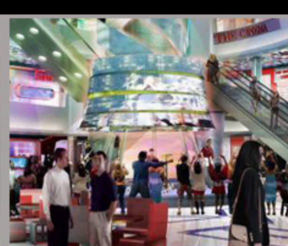
Indoor Ski Resort

The indoor ski resort will be the first in the United States. It will produce snow daily allowing for skiing all year round. The ski resort can also be converted for concerts and half pipe competitions.

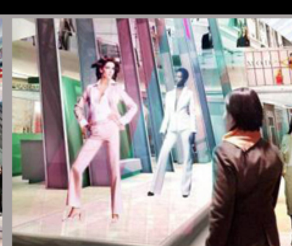
Five Districts

Sports

Food



Entertainment



Fashion

Education

Jason M. Sambolt

Mechanical Option

http://www.engr.psu.edu/ae/thesis/portfolios/2008/jms917/

Acknowledgements

The Penn State University Architectural Engineering Faculty

Thesis Advisor: James D. Freihaut, Ph.D.

Project Sponsor: Turner Construction Company

Sponsor Liaison: Steve Annesse

Structural Help: Steven Reichwein
Linda M. Hanagan, Ph.D., P.E.

And my family for all their support.

Table of Contents

Figures

Tables

Executive Summary

The Xanadu Sports Complex Building A is comprised of a retail section and an indoor ski resort called the Snowdome. Through the analysis found in previous technical reports areas of design improvement were found. Through the analysis the main areas of concern were found to be in the ventilation systems of both the retail section and indoor ski resort and the large amount of energy needed to run such a building. The contributing factor to these concerns can be linked to the use of the Building Officials and Code Administrators (BOCA) 1996 code.

The goal of the mechanical redesign is to address concerns voiced by the community questioning the impact this project will have on the environment. On October 13, 2004 four environmental advocacy groups filed a lawsuit through the New Jersey Appellate Court which requested the halt of construction. This lawsuit, among other lawsuits and financial uncertainties, has greatly delayed the construction ultimately increasing the project budget by $700 million. These factors create a large liability to the owner. The publicized lawsuit also creates poor public relations with the local community who has come to question the reasoning of an indoor ski resort.

In order to alleviate some of the burden these liabilities inherently present, an environmentally friendly mechanical system redesign will be explored. Through the use of a local landfill providing landfill gas, an engine on the complex site can produce energy to power Building A. In addition to the engine producing electricity on-site, waste heat from the combustion process can also be used to provide steam to provide heating and cooling to the building through the use of an absorption chiller/heater.

The introduction of the new mechanical system equipment will affect other building systems. The changes required due to the redesign will be addressed to fully analyze the feasibility of the new mechanical system. A structural analysis of the building's roof will be used to determine whether or not reinforcing will be needed to support the new equipment. The electrical system will also be analyzed to determine whether feeders, panel boards, and the main distribution lines need to be resized in order to provide the proper capacity to the new equipment.

The goals of the system redesign are to reduce the environmental impact the indoor ski resort and retail section will create, save the owner money, create positive public relations, and benefit the local community. In short, the redesign will attempt to turn a large liability into an asset to all.

Building Design Background

Building A of the Meadowlands Xanadu complex is designated as the sports district. All sports related retail stores and activities will be housed in this building. Building A has essentially two sections; the south side of Building A will contain all retail stores while the north side of the building will house the Snowdome indoor ski resort.

The retail section of Building A will contain a wide variety of sporting goods stores, a restaurant, and night clubs. The majority of leasable space will be used for retail sales; however, these retail spaces are not included in the current contract. Therefore, for these types of spaces an analysis will not be applicable. All work in retail spaces, night clubs, the ski resort lodge, and the restaurant will be fit out by the tenant near the end of construction.

The north section of Building A will house The United States' first indoor ski resort named the Snowdome. During normal operation the slopes will be comprised of snow laying flat over the distance of the run. However, during special events the slopes can be made into quarter pipes, and jumps can be added for competitions. Aside from skiing and snowboarding competitions the Snowdome is planned to be used for concerts, fashion shows, and parties with a wintery touch. The Snowdome will house 160,000 square feet of cold side space and will include a novice ski slope at 330 feet long by 120 feet wide and an advanced ski slope at 780 feet long and 150 feet wide. During times of normal operation the peak occupancy load is expected to be 300; while during special events the space is designed to provide enough fresh air for 999 people.

Figure 1 below shows the occupancy categories break down for the building.

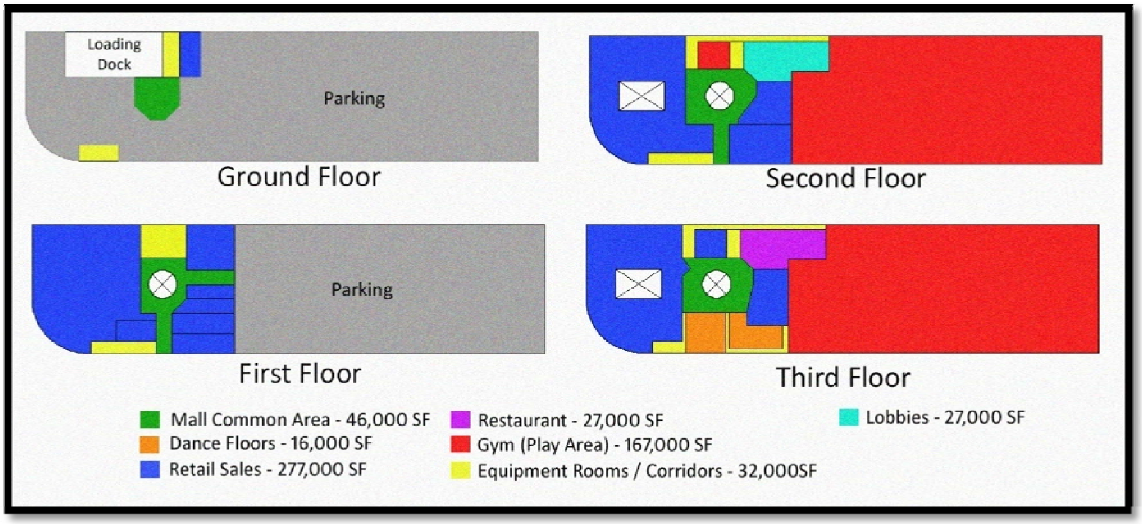


Figure 1: Building A Occupancy Category Distributions

Electrical System Background

The complex is powered from existing high voltage electrical lines that run parallel to the adjacent New Jersey Turnpike. The high voltage lines feed a set of transformers on the west side of the building that will supply power to that side of the building, while another set of transformers are located on the east side to provide power to the east side of the building. These transformers will step the 26.4 Kilovolt service to a 480/277 Volt, three phase, four wire service that will run to various electrical rooms on the ground floor. The electrical service covered in the current contract will provide power to the air handling units and will be stepped down by 480 to 280/120 Volt transformers to power the lighting in the common areas. There will also be unfinished electrical rooms that will provide a place for the individual tenants 480 to 280/120 Volt transformers which will be added at the tenant's expense towards the end of construction.

Also located on the west side of the building next to the transformers is a backup generator. This emergency generator is rated at 1000 Kilowatts, three phase, four wire, 277/480 volts and will provide electricity to building A in the event of a power failure.

Lighting System Background

The majority of retail section's lighting is comprised of recessed metal halide down lights with 150 Watt T6 Cool White lamps. The only lighting fixtures included in this contract are those in the common areas and back of house rooms. All lighting in leasable spaces will be provided by the tenants near the end of construction.

The Snowdome indoor ski resort's lighting is comprised of pendant mounted weatherproof metal halide globe fixtures with a 250 Watt lamp. It is important for the ski resort to be very well lit since skiers need to make split decisions at fast speeds. For this reason, a power outage and consequently lighting failure can result in injuries. To assure the safety of skiers, the ski resort lighting is connected to an uninterrupted power supply.

Structural System Background

The foundation consists of 30 foot concrete piles on the east side of the building while 60 foot piles are used on the west side to anchor the building. The large piles are necessary due to the fact that the surrounds are classified as wetlands and can create swampy conditions. The skeleton of the building is comprised of a wide range of W-shape steel beams, columns, and girders. All floors are composed of poured concrete slabs on composite metal decking. From the metal decking the load is carried to the beams located directly below the decking, then to the girders that direct the load to the columns and then eventually to the concrete piles.

Fire Protection System Background
The entire Xanadu Sports Complex will be fully equipped with a fire alarm and sprinkler system. Throughout Building A wall mounted pull boxes, audible alarms, and strobe lights are located in easy to see areas. At the sound of the alarm guests will be directed to fire exit stairways that will only be used in the event of an emergency. There are three of these dedicated exit stairways in the retail section of the building and there is one more located at the top of the slope in the indoor ski resort. In addition to the fire protection system all floors, exit stairways, mechanical shafts, exit corridors, and columns have a two hour fire rating.

Transportation System Background
For the retail section of Building A, two sets of escalators located on every floor in the central atrium will be the means of vertical transportation. Not far from the escalators are a set of elevators that will also provided access to every floor of stores. As mentioned in the fire protection section there are also exit stairways, however they will only be used in the event of an emergency. In the Snowdome, a roof mounted chair left will provide quick access to the top of the main slope while a rope pull will provide access to the top of the smaller slope.

Mechanical Systems Existing Conditions

Design Conditions

The entire Xanadu Sports Complex including the mechanical system was designed to comply with Building Officials and Code Administrators (BOCA) 1996. Chapter 28 of the BOCA 1996 code covers the provisions of a building's mechanical system. The mechanical section covers topics such as acceptable pipe material, insulation requirements, and plenum sizes; however, prescriptive methods for designing ventilation systems and acceptable comfort levels are not present in the code. It is evident that the BOCA 1996 code is nowhere near as detailed as the current International Mechanical Code (IMC) regulations.

The design outdoor conditions used for the load calculations and energy analysis were obtained using the ASHRAE Fundamentals Handbook 2005, and the weather data files were obtained from TRACE 700. The ASHRAE Handbook lists the closest city, Newark, New Jersey, as having a design summer temperature of 91°F DBT and a 73°F WBT. A winter design temperature of 14°F DBT was used and WBT was not used due to the fact that Trace assumes dry winter conditions for certain climate zones. Other weather factors assigned by Trace are clearness factors of 0.99 and a ground reflectance value of 0.2.

The indoor design conditions for the retail section of Building A were not available from the design engineer. For this reason an assumption was made, and the design dry bulb temperature was set at 72°F. While the retail design conditions were not available, the indoor ski resort's conditions were. In the Snowdome during normal day operation, temperatures must be maintained between 30°F and 32°F. However, at night fresh snow is made on a daily schedule, and temperatures must be cooled to approximately 24°F to ensure proper snow making.

As with many of the other design considerations, the design engineer was not available to provide information regarding design considerations; however, a look at the site reveals a problem with the introduction of uncontaminated air to the building. Figure 2 below provides an aerial photo of the site before construction began. The red silhouette represents Building A while the grey silhouette represents the rest of current construction. Figure 2 shows how close the complex is to the New Jersey Turnpike Interstate 95 and Route 120, which are both heavily trafficked on a daily basis. For this reason it is important to avoid introducing highly contaminated air though the building's ventilation system.

Figure 2: Aerial Photo of Complex Site Previous to Construction

Retail Mechanical System

The air side mechanical system for the retail section of Building A uses four roof top air handling units that serve all the common areas of the building. In Building A common spaces are comprised of walkways to the different stores and restaurants, restrooms, back of house rooms, and a large central area that will create a large atrium for all the levels of shopping. All tenant spaces will not have any mechanical work done at this time and will be finished by the leaser towards the completion of the building. All four common area rooftop units are controlled by variable frequency drives with two running modes: occupied mode during normal operating hours and unoccupied mode during the nighttime. A programmable time clock will control when the occupied or unoccupied mode begins to run. A thermostat will control the cycling of the supply fan and energize the electric heating coil to maintain the nighttime setback temperature during the unoccupied mode. During the occupied mode the supply fan will operate continuously. The use of an economizer to maximize atmospheric cooling will also be implemented for all four of the rooftop units.

RTU-1 serves the first and second floor common areas on the east side of the building, and RTU-2 serves the first and second floor common areas on the west side of the building. Both units supply 16,100 cfm of air each with 1,496 cfm of that supply air being outside air. Each unit's cooling coil has a capacity of approximately 38 tons and an electric heating coil capacity of 150 kilowatts. RTU-3 and RTU-4 serve the third floor common areas. Both of these units supply 31,000 cfm of air each with 3,037 cfm of that supply air being outside air. Each unit's cooling coil has a capacity of approximately 78 tons and an electric heating coil capacity of 190 kilowatts. A graphical representation of the atrium's ventilation system can be seen in Figure 3.

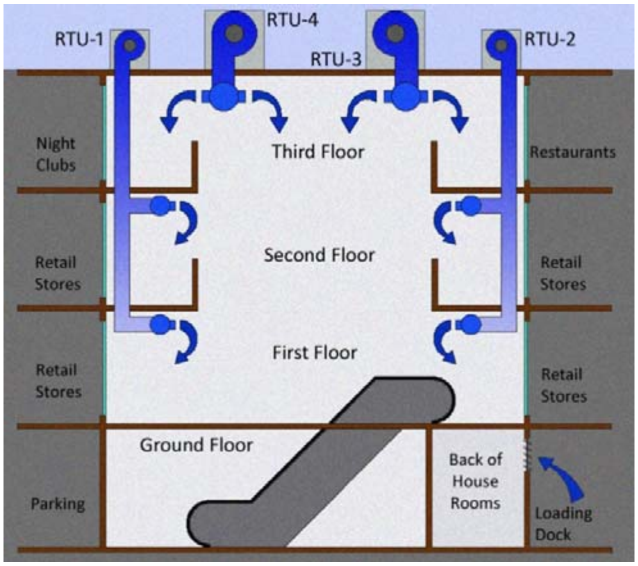


Figure 3: Retail Ventilation

In addition to the rooftop units, wall mounted electric unit heaters are used in mechanical spaces, entrance vestibules, and exit stairways to maintain thermal comfort. To ensure fresh air enters the back of house rooms, exhaust fans are installed to negatively pressurize the rooms. With the use of exhaust fans, fresh air that has been supplied to the walkways on the floor will be drawn to the rooms with negative pressure. Small air condition units are also used in elevator machine rooms and the main ground floor entrance to supply cooling when needed.

Snowdome Mechanical System

The challenge of an indoor ski resort is to ensure that snow can be maintained year round and to maintain a highly controlled environment. During normal day operation, temperatures must be maintained between 30°F and 32°F. However, at night fresh snow is made on a daily schedule, and temperatures must be cooled to approximately 24°F to ensure proper snow making. The Xanadu Snowdome plans to achieve ideal conditions by using cooled supply air, under floor glycol piping, recirculation coolers, and snow guns to provide the best skiing conditions every day of the year.

The Snowdome ventilation system is comprised of a single 30,000 cfm air handling unit with 15,000 cfm of the supply air being outside air. The unit uses a main common intake system with one primary and two secondary cooling coils. The air is pre-cooled by means of a thermal wheel and then cooled down to above freezing by the primary cooling coil. The air is then cooled below freezing by the secondary coils which are fed by a cold glycol system. A hot glycol system line is also fed to the secondary coils and will only be used when the coils need to be defrosted. The system is fully variable in volume, achieved by using inverters on the fans, to suit the current occupancy.

Two 222 ton electric screw chillers operating at 1.5°F leaving glycol temperature provide the cold glycol to the air handling unit's coils, under floor piping matrix, recirculation coolers, and snow guns. Both chillers operate in conjunction with an evaporative condenser located on the roof of the Snowdome mechanical mezzanine which houses all the mechanical equipment.

Mounted along the ceiling of the Snowdome are recirculation coolers and snow guns. Both devices will be run using the cold glycol system during normal operation. However, when the devices need to be defrosted, the cold glycol system will be shut off, and the hot glycol system will be turned on for defrosting. The snow guns also require compressed air for the use of snow making; therefore, a compressed air line will be provided to each snow gun.

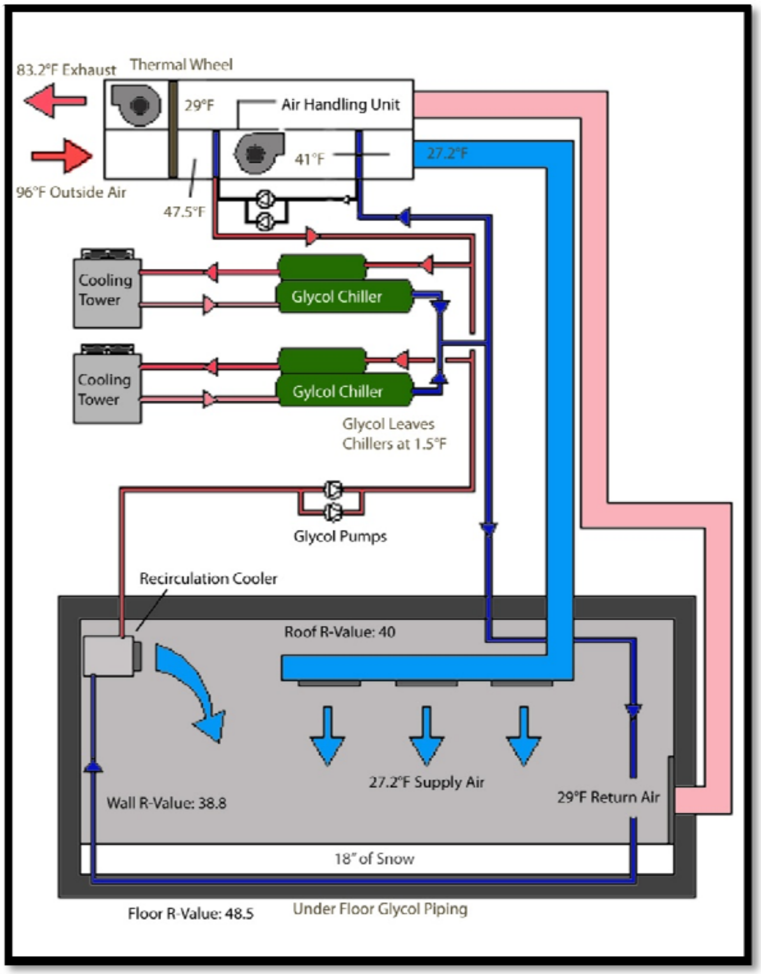


Figure 4: Snowdome Mechanical System

Retail Rooftop Air Handling Units

The control logic for all four rooftop units serving the retail sections of Building A are the same. A programmable time clock will ensure the supply fan operates continuously during the hours the stores are open. The units have three set cycles: occupied, unoccupied, and morning warm-up.

During the occupied cycle the fan will operate continuously. When the outside air enthalpy sensor E1 reads a value less than the return air enthalpy sensor E2, dampers D1, D2, and D3 will modulate to maximize atmospheric cooling. The supply air temperature sensed by T3 will then be maintained to the design setpoint by modulating the electric heat coil EHC or energizing the direct expansion cooling coil DXCC. The supply air temperature will be set at 55°F, however, is adjustable. During the unoccupied cycle the fan and electric heating coil will maintain a setback temperature of 55°F. During morning warm-up dampers D1 and D3 will remain closed. Damper D2 will remain open, and the fan will operate with the electric heating coil until temperature sensor T5 reaches 65°F. At this time the system will return to the occupied cycle. Figure 5 below provides a schematic for a typical retail rooftop unit.

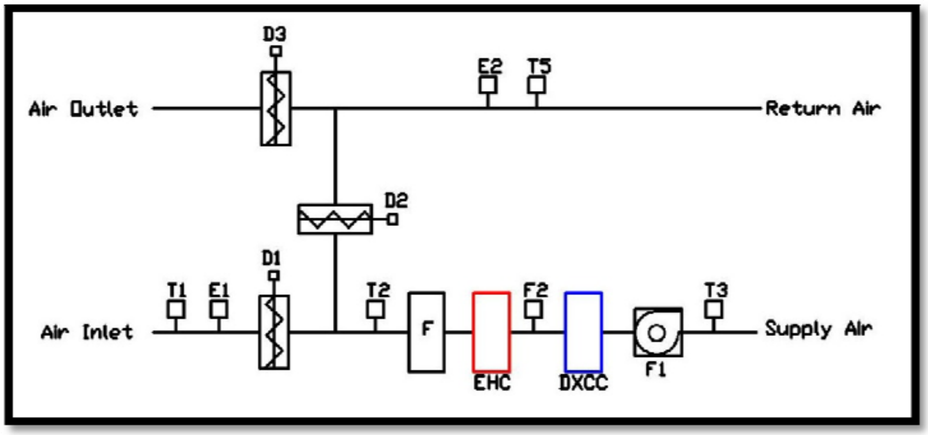


Figure 5: Schematic of a Typical Retail Rooftop Air Handling Unit

Snowdome Air Handling Unit

The Snowdome's ventilation system is comprised of a main common intake system with one primary and two secondary cooling coils. The air is pre-cooled by means of a thermal wheel TW and then cooled to just above freezing by the primary cooling coil C1. The air is then cooled to below freezing temperatures by either one of the secondary coils C2a or C2b, which are fed by the main cold glycol system. The system is fully variable in volume to suit the occupancy which is achieved by inverters on the fans.

During normal operation the system will operate on a time control from the BAS and in conjunction with the occupancy of the Snowdome. The fresh air supply will be varied from a minimum set point which will be controlled by a carbon dioxide sensor. The system will ensure that the carbon dioxide level is maintained below 1000 parts per million. The signal from the sensor will be sequenced with the exhaust fan inverter to maintain the correct pressure. The unit will provide ventilation during regular operating hours and while the snow plows are grooming the snow at night. To ensure proper indoor air quality the unit is equipped with two sets of filters: a panel-type pre-filter PF and a main set of bag filters SF. The differential pressure transducers DPTs across the filters will indicate a dirty filter condition. Coil C2a will be used as a duty coil and will only shutdown for a defrosting cycle or if a problem arises with the coil, at which point coil C2b will take the cooling responsibility. The coil temperature sensor T4 will sense the coil temperature, and as long as it stays at its design temperature, dampers D1, D2, and D3 will remain open. However, if temperature sensor T4 detects a problem with coil C2a then dampers D1, D2, and D3 will close and dampers D4, D5, and D6 will open to allow the coil C2b to cool the air. At this point the cold glycol valve MV3 will close to stop the glycol flow to coil C2a, and the valve MV5 will open to allow the cold glycol to flow into coil C2b.

Temperature sensor T3 will ensure that the temperature leaving the first coil is maintained at 41°F by modulating the temperature of the entering cold glycol. The glycol temperature sensor T10 will ensure that the glycol temperature never falls below 30°F. If T10 reads a temperature of 30°F, it will override the control of valve MV1 to allow the temperature to rise above 30°F. The off coil temperature of cooling coil C2a will be sensed by temperature sensor T6 which will control the modulation of the three-way valve MV2 on the primary cold glycol circuit.

Since coils C2a and C2b operate below freezing temperatures ice buildup will need to be addressed with a defrost cycle. The defrost cycle will be initiated through the use of a time channel within the BAS but will also be checked for loss of air flow through the DPT. Once it has been determined that the defrost cycle should be initiated, the cold glycol valves MV3 and MV4 will close along with dampers D1, D2, and D3. The heater ACH between dampers D2 and D3 will energize to prevent the freezing of the damper blades. At this point the hot glycol valves MV7 and MV8 will open. The cold and hot glycol valves will have end switches to provide a closed signal and will ensure that both valves are never open simultaneously. On the completion of the defrost cycle the hot glycol valves MV7 and MV8 will close, and the coil will remain switched off until required. Also the heater ACH will remain on until the coil is charged again. Figure 6 below provides a schematic for the Snowdome air handling unit while Figure 7 provides a schematic for the glycol connections to the unit's coils.

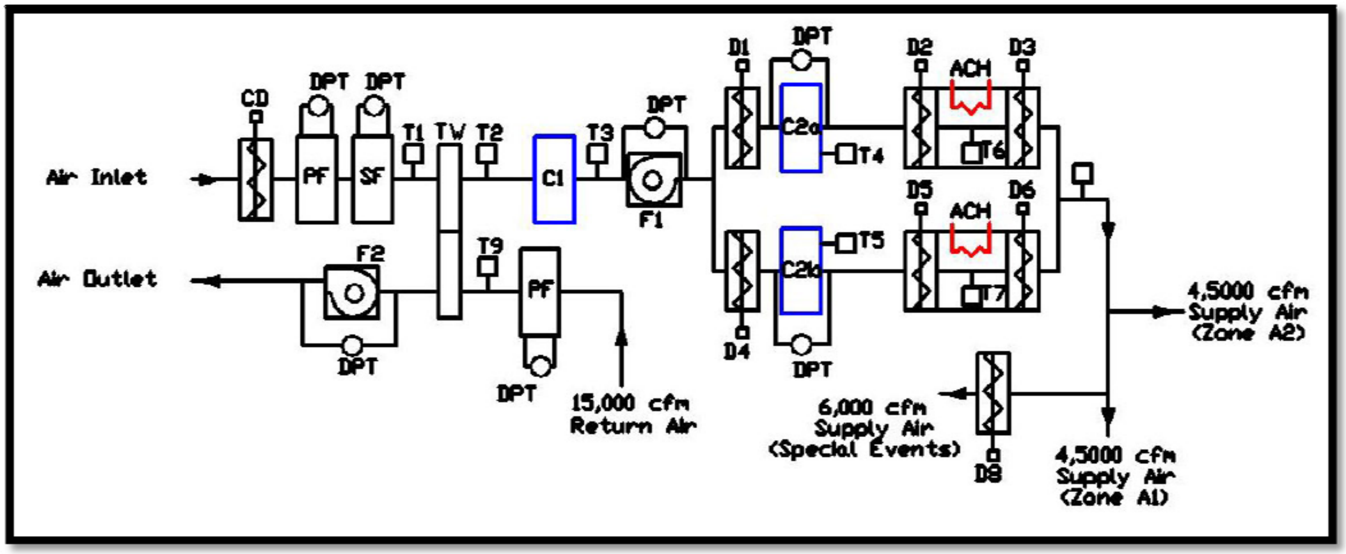


Figure 6: Schematic of the Snowdome Air Handling Unit

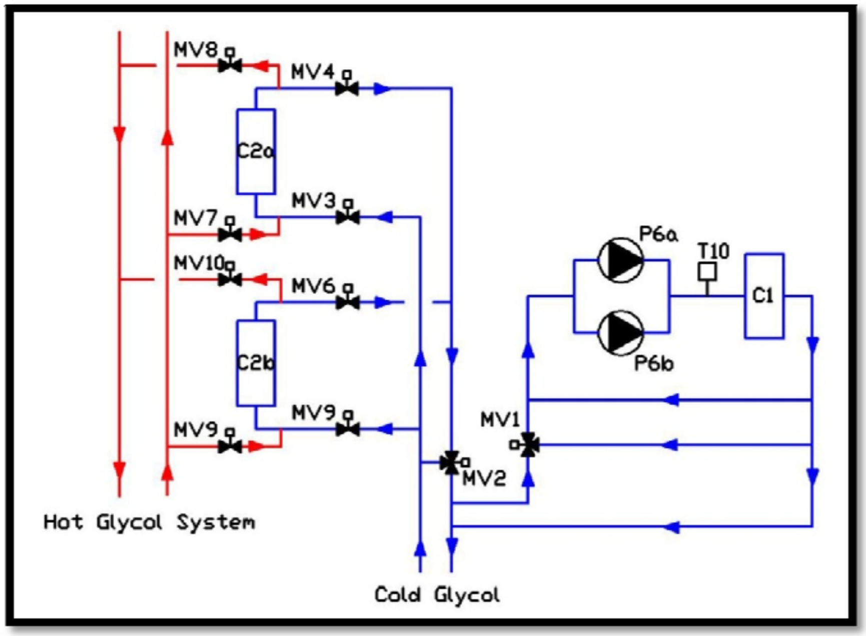


Figure 7: Schematic of the Snowdome Air Handling Unit Coil Connections

Snowdome Chillers and Main Cold Glycol Pumps

The Snowdome Glycol Chillers provide cold glycol to all the recirculation coolers, snowguns, under floor piping matrix, air handling unit cooling coils, and snowmaking tank. The chiller system will be on at all times to ensure proper temperatures are maintained in the skiing area. The return glycol temperature sensor T1 will enable the number of chillers to be controlled at low load. A separate output to the chillers will change the chiller operating at set points required by the system for snow making. The main glycol pumps will run in a duty/standby operation. A differential pressure switch located across each pump will sound an alarm on sensing a no flow condition through the duty pump, and the standby pump will begin to run. The system will monitor the hours of operation of each pump and share operating time between them. A time delay between the switching of the duty pump will occur to ensure that the system does not shut down. As mentioned earlier, the chillers should never shut down. The only time of shut down will occur under a manual control or a power failure. In a manual shut down the duty pump will continue to run for a prescribed period of time; however, if the system loses pressure, the pumps will shut down immediately. If a power failure occurs, the compressors will automatically restart once the power is restored. Figure 8 below provides a schematic for the chillers and main glycol pumps.

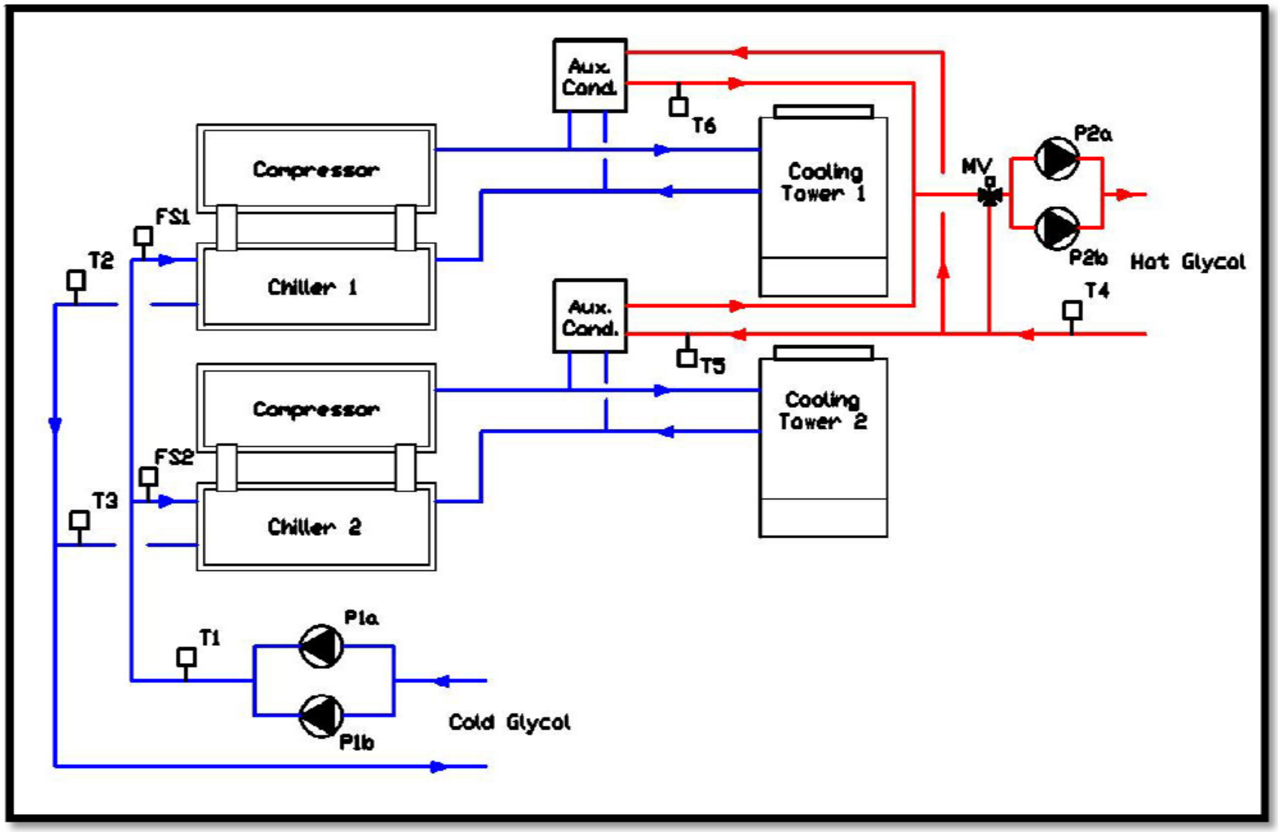


Figure 8: Schematic of Chillers and Main Glycol Pumps

Snowdome Recirculation Coolers

Thirteen ceiling mounted recirculation coolers will help maintain skiing conditions year round. The cooler fans will operate normally at all times, however, will shut off during the defrosting process. The controls for the coolers will also provide a sleep function which will stop individual coolers if cooling is not required in the zone served by the cooler for a preset time. This will help provide power savings during periods of low ambient temperatures and low occupancy.

During normal operation the cooler fans will run at a low speed which is controlled by the fan inverter. The fan speed will be increased by a modulating control function if temperature sensor T1 reads that the return air temperature rises above 32°F to increase the cooling duty. When the temperature falls back within the limit, the fans will revert to the low speed. The output of the cooling coil will be controlled by modulating the cold glycol supply flow. The return air temperature sensor T1 will send a signal to the controller which will modulate the three-way valve MV1 to provide the supply air temperature. Along the cold glycol supply line are temperature sensors that ensure the proper glycol temperature is maintained. If one of these sensors determine that the main cold glycol flow temperature has risen to high, all the recirculation cooler fans will shutdown in order to reduce the amount of heat produced.

At night during the snowmaking cycle, the cooler fans will run at full speed, and the return air set point will change to the lower 27°F air temperature. Also, since the system runs below freezing conditions a defrost cycle will periodically need to be run. This process is possible due to the hot glycol system. In order to defrost the coolers and still maintain skiing conditions, no more than three coolers will be defrosted at a time. In order to run the defrost cycle the cold glycol valve will close, and the fans will remain on to raise the temperature of the remaining glycol in the coil to room temperature. After a preset time the fans will shut down and the hot glycol valves MV2 and MV3 will open to allow the hot glycol into the coil. The coil temperature sensor T3 will read the coil temperature, and once the coil reaches a set temperature the defrost cycle will be shut off. Valves MV2 and MV3 will close and the cold glycol valve MV1 will open. Figure 9 below provides a schematic for the operation of a typical recirculation cooler.

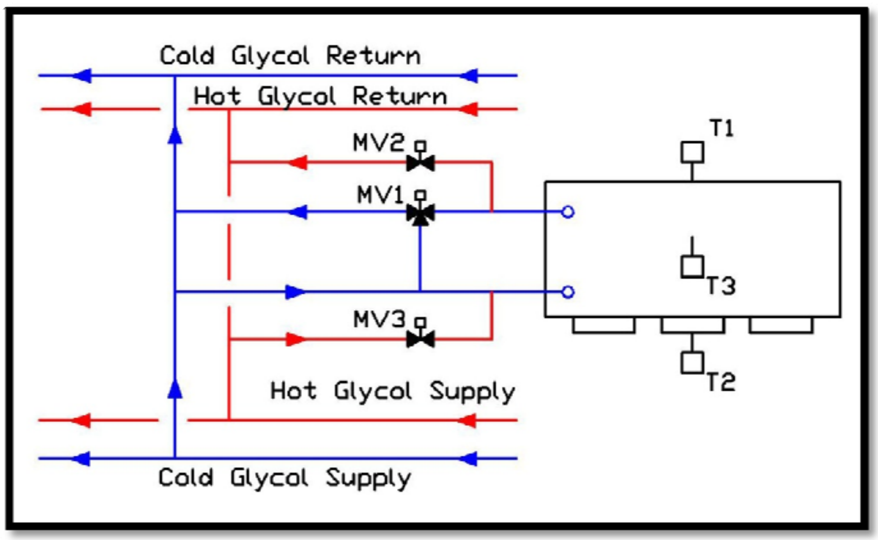


Figure 9: Schematic of a Typical Recirculation Cooler

Snowdome Snowmaking Water Tank Cooling

The snowmaking water tank's function is to cool the water that will be used for snowmaking to a temperature near freezing in preparation for a phase change. The water temperature of the snowmaking water and the filling tank will operate under fully automatic controls to balance out the demand for cooling and the water supply.

During non snowmaking periods the water tank will be filled with the cold water supply via valve SV1. The supply water is cooled by a plate-type heat exchanger located in the bottom of the tank. The heat exchange is fed with glycol from the main return glycol system. The cooling system is comprised of an injection design with the glycol flow being controlled by a three-way valve V3, and the glycol circulation is controlled by pump P4. The flow through V3 is controlled by the tank temperature sensor T1. The modulating of valve V3 will ensure that the water temperature in the snowmaking tank is to be maintained at the design temperature of 36°F. A second temperature sensor T2 will ensure that the glycol temperature never falls too low. To ensure proper snowmaking, ice is required on the plate heat exchanger. To provide consistent ice formation the tank is fitted with a compressed air blower which is connected to a sparge pipe under the plates which discharges air bubbles from the base of the tank. Figure 10 below provides a schematic for the operation of the snowmaking water tank.

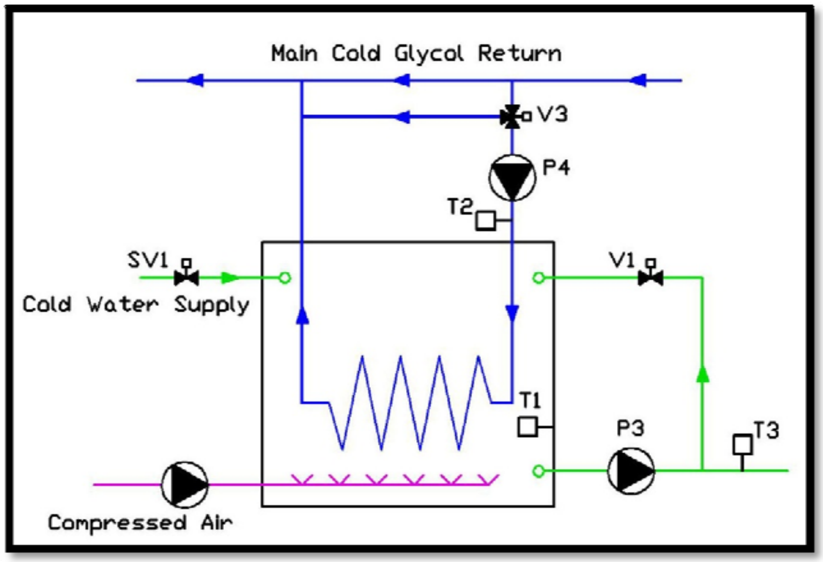


Figure 10: Schematic of the Snowmaking Water Tank

Snowdome Snowmelting Pit

A snowmelting pit is located at the bottom of the ski slope to melt all unwanted snow. Every night before the snowmaking process begins plows will scrape the top two inches of old snow into the snow melting pits. After the snow is removed a fresh two inches of snow will be made to sit on top of the existing fourteen inches of old snow underneath.

The snowmelting pit uses the hot glycol recovery system to provide the heat to melt the waste snow. The meltpit is designed to retain an amount of water at all times, and the temperature of the water is monitored by temperature sensor T1. When snow is added to the pit, the temperature of the water will fall and this will be detected by T1, and the snowmelting process will be initiated. During this time the two-way hot glycol control valve MV3 will open to allow hot glycol to circulate though the heat exchange, and the drain valve MV2 will close, and the main valve MV1 will remain open. The spray pump P5 will start to circulate the water through the heat exchanger and discharge the warm water onto the snow via the spray nozzles. The level sensor will prevent operation of the spray pump in the event of a low level of water and will also control the water level within the pit. When the snow has melted, the water temperature sensed by T1 will rise, and the system will automatically shut down. The drain valve MV2 will open, and the main valve MV1 will close. The water will then be pumped to the drain until the preset level is reached. Also, at this time the hot glycol valve MV3 will close shutting off the flow to the heat exchanger. Figure 11 below provides a schematic for the operation of the snowmelting pit.

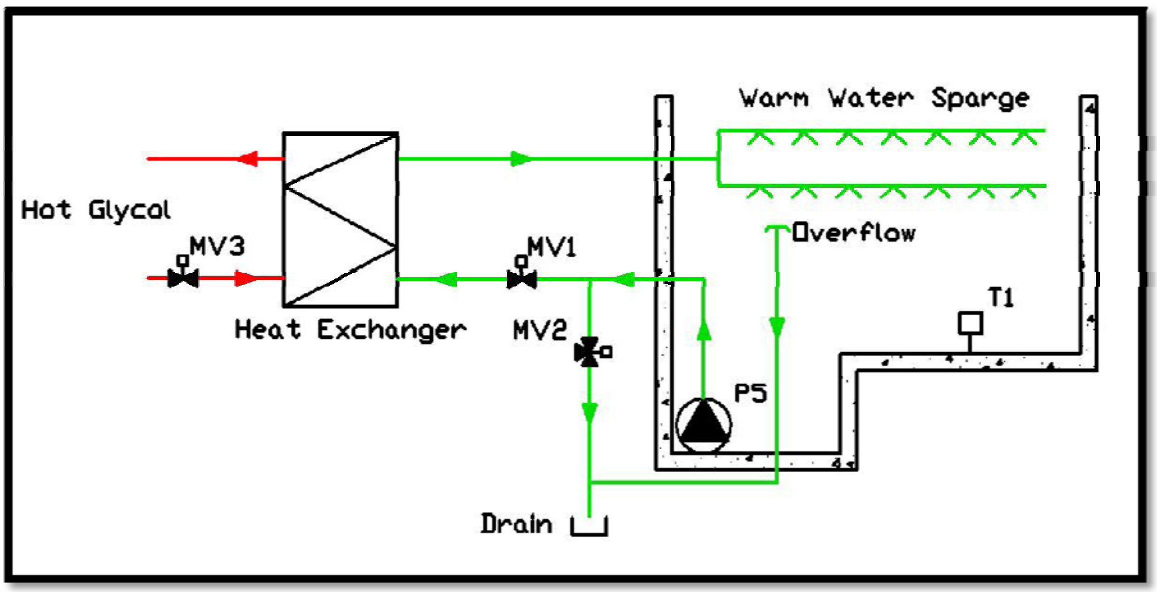


Figure 11: Schematic of the Snowmelting Pit

Snowdome Snowguns

Ceiling mounted snowguns will be used at night time to create fresh snow. The snowguns will start from a main time clock control loop which will start the operation after the top two inches of old snow has been cleared. Once the snow making process has begun the recirculation coolers will step up to full load to lower the indoor temperature to 27°F. Once the indoor temperature setpoint has been reached the air compressor and water pumps will start. Once the compressed air is flowing valve V1 will open. After a preset time, the water valve V2 will open. At this point the snowgun will be fully operational. Once the snowmaking process is over the system will begin to shut down. During shutdown valves V1 and V2 will close, and the air compressor and water pumps will shut down. Figure 12 below provides a schematic for the operation of a typical snowgun.

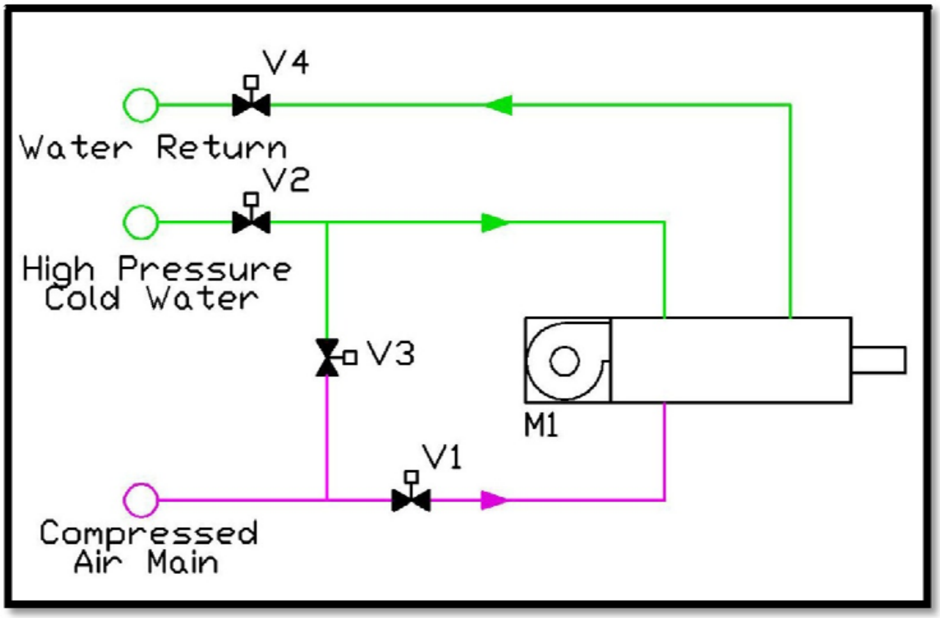


Figure 12: Schematic of a Typical Snowgun

ASHRAE Standards Compliance

ASHRAE Standard 62.1 Ventilation Requirements

The American Society of Heating, Refrigerating and Air-Conditioning Engineers Standard 62.1 (ASHRAE 2007) provides a source to ensure that minimum ventilation requirements are met within a building. Proper outdoor air ventilation to spaces in the building is essential in maintaining a proper level of indoor air quality. Every day the Xanadu Meadowlands Sports Complex will entertain thousands of occupants for long periods of time. For this reason excellent indoor air quality is critical in ensuring the well being of every guest to this state of the art facility. To evaluate the effectiveness of the ventilation systems in the Xanadu Sports Complex Building A, calculations have been conducted using the ASHRAE Standard 62.1 guidelines to determine whether or not the current system meets the standards requirements.

The retail section of the buildings receives ventilations from four rooftop air handling units (RTUs) while the Snowdome indoor ski resort is served by a single air handling unit (AHU) housed in a mechanical room adjacent to the ski resort. For this analysis, the required ventilation rates for various spaces are governed based on the peak occupancy, the use of the space, and the floor area of the space. (ASHRAE 2007)

The majority of the retail space is comprised of a single large atrium that is open from the first to third floor. Two of the RTUs will provide ventilation directly to the first and second floor walkways of the atrium while back of house rooms are to draw fresh air supplied to the atrium through corridors. Two larger RTUs supply fresh air to the third floor; however, these two units have been oversized to allow air to drop from the top of the atrium and supply more fresh air to the first and second floor. The ground floor of the retail section houses a loading dock and back of house rooms that are supplied fresh air through louvers in the exterior walls.

The ASHRAE 62.1 compliance analysis of Building A revealed some potential ventilation problems. The largest problem is that ductwork only supplies fresh air to the central atrium. There is no ductwork to the other spaces which are required to have ventilation. In place of ductwork, the design is meant to have the over ventilated atrium air work its way through various passageways and corridors to the rooms in need of ventilation. Besides the air having to travel long distances through corridors, it also must try to find its way through door cracks since there are no louvers to allow the corridor air in. This presents a problem since only a minority of the rooms are equipped with exhaust fans to create a negative pressure to draw air from the corridors. Another area of concern is the placement of the return grilles. The only return grilles are placed at the top of the atrium, the same place where the majority of all the air for the building is supposed to be supplied from. This presents a large threat of short circuiting which would cause all the spaces to receive little to no ventilation. The AHU compliance summary table is listed below demonstrating how the poor air distribution in AHU-1 and AHU-2 are creating low ventilation efficiencies which increases the demand of fresh outdoor air.

Table 1: Air Handling Unit Compliance Summary

Air Handling Unit	Serves	Ventilation Efficiency	Required O.A. (cfm)	Supplied O.A. (cfm)	Meets Standard?
RTU-1	1st & 2nd Floor East Common Areas	0.6	9,410	1,358	**No**
RTU-2	1st & 2nd Floor West Common Areas	0.6	11,564	1,637	**No**
RTU-3	3rd Floor	1.0	1,515	3,039	**Yes**
RTU-4	3rd Floor	1.0	1,563	3,038	**Yes**
AHU-Snowdome	Indoor Ski Resort	1.0	48,000	15,000	**No**

Problems also arose with the natural ventilation louvers that are installed on the ground floor. In all cases either the louver-free area was too small or the louver was too close to a confinement source.

It is to be noted that many of the discrepancies in the compliance are due to differences from ASHRAE Standard 62.1 2007 and the Building Officials and Code Administrators 1996 code which is the governing code for this project.

The results from the ventilation calculations as prescribed by ASHRAE 62.1 Ventilation Rate Procedure show some potential problems in the mechanical system when it comes to proper ventilation. The roof top units that serve the retail section of the building dump the majority of all the air from the units directly into the large atrium space and nowhere else. This design reduces the amount of ductwork needed and essentially uses the corridors as the duct to carry ventilation air to spaces. This can present a problem since in some cases spaces are relying on air to travel from the atrium though hundreds of feet of corridors to spaces that need ventilation. On top of the long distances the air must travel to corridors. The majority of rooms that are supposed to receive ventilation through the corridors are not negatively pressurized; therefore, it is practical that many of these spaces will never see ventilation. Since the only ductwork that exists serves the atrium and ignores branches of the building, the system efficiency used to calculate the total required ventilation is very low. This is causing much higher ventilation rates to all spaces served by RTU-1 and RTU-2.

It can be noted that assumptions were made on occupancy levels from the ASHRAE default occupancy density which may change the amount of ventilation needed in spaces; however, for this particular problem no direct ventilation from ducted diffuses are provided to spaces other than the atrium and mall walkways. It is fully possible that the over ventilated atrium air does reach the rooms that need ventilation through the corridors, but this type of design does not satisfy the principle of ASHRAE 62.1.

The Snowdome's air handling unit seems to be very undersized for the amount of ventilation that will be needed for such a large space. Using the Ventilation Rate Procedure, the current amount of outdoor air needs to be increased 3.2 times. Discrepancies may have been caused from the assumption of the occupancy category or also from the variations from ASHRAE 62.1 2007 and the code used to design this project which is Building Officials and Code Administrators (BOCA) 1996.

The natural ventilation analysis of the ground floor also shows some areas that can potentially be under ventilated. Three of the spaces are to be ventilated using natural ventilation that would be delivered through louvers on the exterior walls; however, the free area of the louvers is very small in comparison to the minimum requirements presented by ASHRAE 62.1. Besides not meeting the size requirements, the louvered natural ventilation also fails the Air Intake Minimum Separation Distance which can be found in Table 5 of ASHRAE 62.1 (ASHRAE 2007). This section requires that any opening that is to be used for natural ventilations be at a minimum of 25 feet from truck loading docks, which in this case is closer than the requirement. The rest of the spaces on the ground floor are completely closed off and do not have either exterior louvers or interior louvers to gain ventilation from other rooms. The complete ASHRAE 62.1 compliance calculations can be found in Appendix B of this report.

ASHRAE Standard 90.1

The American Society of Heating, Refrigerating and Air-Conditioning Engineers Standard 90.1 (ASHRAE 90.1) provide a source to ensure proper energy efficiency is met within a building. Standard 90.1 was utilized to verify compliance for the Xanadu Sports Complex Building A retail section. The Snowdome portion of the building is not a commercial space and is a very special case. For this reason 90.1 does not apply to this part of the building. Areas that were analyzed consisted of minimum thermal properties of the building envelope; minimum wattages on the interior and exterior lighting; minimum efficiencies of heating, ventilating, air conditioning, and hot water service equipment; and minimum efficiencies of motors. Since Xanadu resides in East Rutherford, New Jersey, a climate zone of 5A was used to determine the proper values to meet compliance with the standard. Calculations were carried out as prescribed by the ASHRAE Standard 90.1, and the

Department of Energy's Energy Code software, ComCheck, was also used to verify the findings. Table 2 below summarizes the findings of the ASHRAE Standard 90.1-2004 compliance check.

Table 2 ASHRAE Standard 90.1-2004 Compliance Summary

Building Envelope	Interior Lighting	Exterior Lighting	HVAC Equipment Efficiencies	HVAC Economizer	Duct Insulation	Pipe Insulation	Motor Efficiencies
30% Better Than Requirements	37% Better Than Requirements	Does Not Comply	Complies	Complies	Not Applicable	Not Applicable	Does Not Comply

As shown in Table 2, the existing building only has two areas of concern when it comes to the compliance of ASHRAE Standard 90.1. The exterior of the building is washed by multiple lighting fixtures that surround the base of the building. The large amount of exterior lighting wattage does not comply with the prescribed standard. Due to the fact that the exterior lighting is largely an architectural feature, a solution to the non-compliance will not be discussed in this report. Similarly, since the motors present in the HVAC equipment will be replaced with new equipment in the redesign, the non-compliance is no longer an issue and will not be discussed further in this report.

While Standard 90.1 did not present any large problems to be considered in the redesign, Standard 62.1 did reveal significant problems with the ventilation system. The non-compliance of Standard 62.1 is enough of a concern that a small portion of the mechanical system redesign work will focus on properly ventilation the building as prescribed by Standard 62.1

Retail Ventilation System Redesign

The mechanical system redesign will consist of two parts. The first part of the system redesign will incorporate changes in the retail section's ventilation system. As discussed in the previous section of this report, the current ventilation system does not come close to meeting the requirements set forth in ASHRAE Standard 62.1-2007. For this reason the ventilation system redesign is being considered an essential change to ensure proper building conditions; therefore, the additional cost associated with the additional duct work will not be included in the overall mechanical system redesign costs discussed in the next section of this report.

Ventilation System Redesign Objectives

The foremost objective of the ventilation system redesign is to ensure proper ventilation to the occupants breathing level. The current system configuration is over ventilating the third floor of the atrium which has the smallest floor area of all the floors, while the second and first floor are severely under ventilated. These floors are under ventilated at times by ten times less than prescribed in ASHRAE Standard 62.1. The design is intended to allow the over ventilated air to flow from the third floor to the lower levels; however, the problem of short circuiting is a serious concern due to the returns for four air handling units being placed just a few feet from the supply air on the third floor. To handle this situation all new supply ductwork was laid out to directly ventilate all spaces that require ventilation as prescribed by Standard 62.1. Similarly, the large return air plenums found on the ceiling of the third floor will be replaced with return air ductwork that will ensure proper air travel and to eliminate any short circuiting. While more duct work will have a large impact on the cost of the ventilation system, it will untimely increase the efficiency of the system and ensure proper ventilation to all spaces.

The second objective eliminates the naturally ventilated spaces on the ground floor. The proximity of the parking garage and loading dock to these spaces caused a concern and in fact did not comply with the natural ventilation standards. The redesign will use an existing duct riser from RTU-2 to supply the previously naturally ventilated spaces with a forced air system.

Ventilation System Redesign Results

To redesign the ventilation system the results of the building load calculations obtained from TRACE 700 were used. The maximum supply air to a space was designed based on either the thermal load demand or the required outdoor air found from Technical Report One. Both were used to ensure that the correct amount of air was being supplied. The ventilation calculations can be found in Appendix B of this report, and the load calculations will be discussed in greater detail in the next section of this report. The dimensions of the supply ductwork were selected based on a value of 0.06 inches of static pressure per hundred feet of supply air ductwork. The dimensions of the return ductwork were selected based on a value of 0.08 inches of static pressure per hundred feet of return air ductwork. Plenum space was also taken into consideration when sizing the ductwork. In all cases the existing plenum space did not need to be altered to accommodate the new ductwork.

Before the layout of the new ductwork was chosen, a computational fluid dynamic model was created to track the particle distribution on the existing and the proposed ventilation system. Both models were created using the same geometry file as well as the same meshing conditions to ensure accurate comparisons. The major change between the two models are the boundary conditions. The existing boundary conditions were taken from the existing drawings. These conditions include diffuser locations on each floor, the velocity of air supplied from the diffuser, the temperature of supply air, and the location of the high return plenums. The proposed redesign also models the same conditions as the existing but includes the new diffuser locations, supply air velocity, and the localized return air grilles. Figure 13 below shows a side by side dye trace comparison of the two models during winter heating conditions.

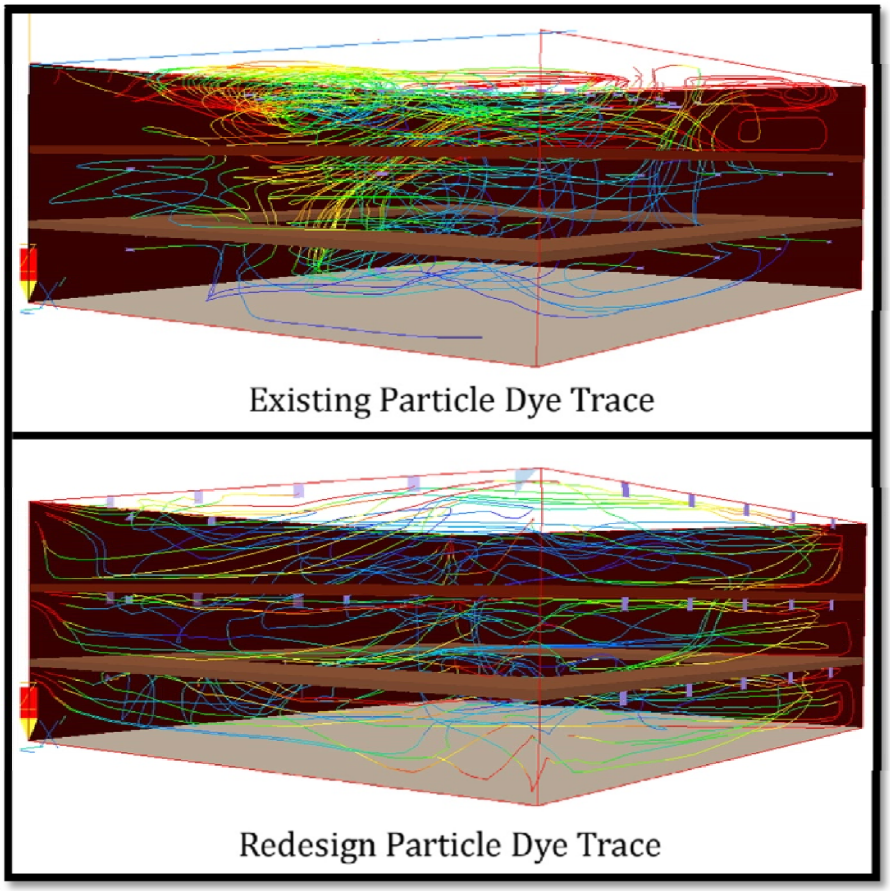


Figure 13: Computational Fluid Dynamics Particle Trace Model

The above CFD model images show the winter heating conditions present in the retail sections atrium. A summer cooling model was also run; however, due to the buoyancy effect of air, the cool supply air dropped to the lower floors and did not present much of a short circuiting problem. However, the winter case shown has a significant short circuiting problem. The warm supply air tends to linger at the top of the atrium and is quickly pulled back through to the return air system. This is evident by the large amount of dye traced particles on the third level of the existing conditions. These particles never make it to the lower level which is represented by the lack of traced particles on the first floor. The opposite can be seen for the redesign. The redesign has a much better overall distribution of particles. This allows the system to deliver the proper amount of ventilation to the spaces and increases the overall system efficiency. Based on ASHRAE Standard 62.1 and the results from the CFD study the ventilation system layout was used.

To incorporate the forced air system to the ground floor an existing ductwork riser serving RTU-2 was extended to the ground floor. Through this riser the supply air and return air ductwork can be routed to the ground floor, eliminating the concern of vehicle exhaust contaminants entering the building via the existing natural ventilation louvers. To ensure proper duct placement the use of three dimensional modeling was implemented. A sample image of the model used to redesign the ventilation system can be seen in Figure 14 below.

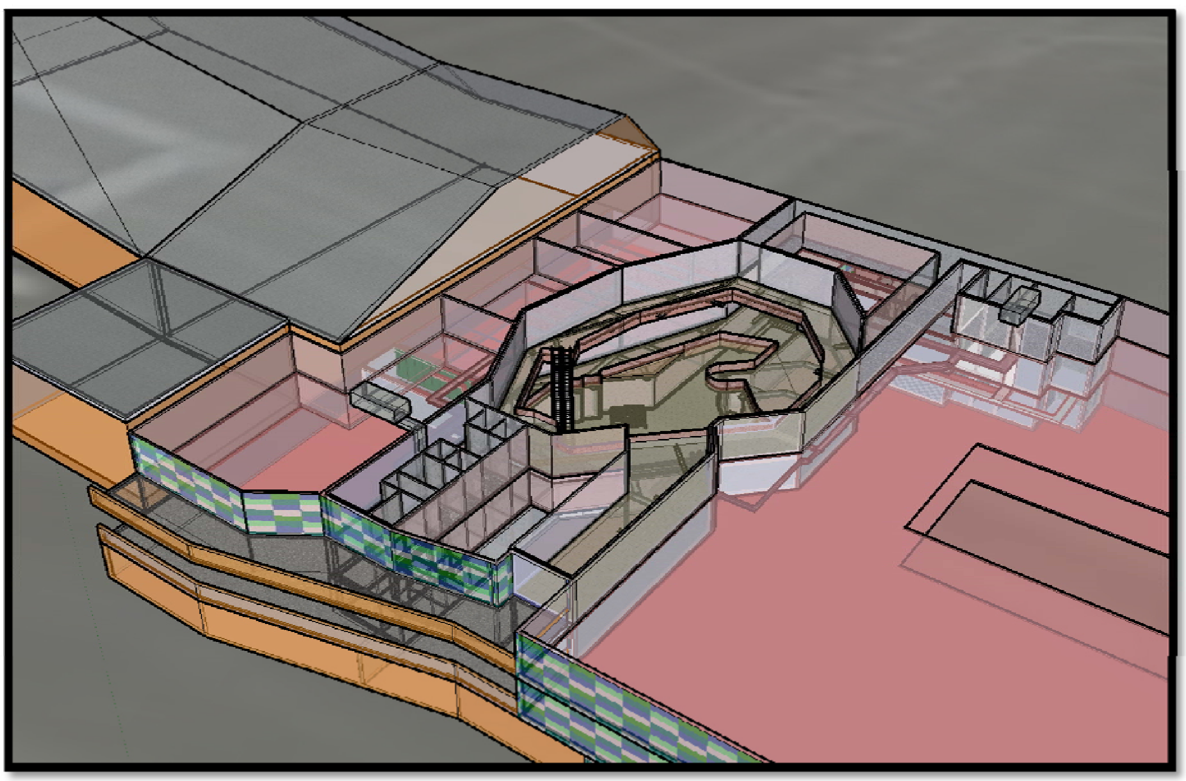


Figure 14: Ventilation System Layout Model Image

Ventilation System Redesign Summary

The redesigned ventilation system provides a better air distribution than the existing conditions as shown through ASHRAE 62.1 calculations and the use of computational fluid dynamics. While the overall effectiveness of the system is greater, the redesign introduces nearly 17,100 pounds of new sheet metal for ductwork. The new ductwork nearly doubles the price of the retail ventilation system; however, the increase in price can be seen as minimal to ensure proper ventilation. Spaces that are not properly ventilated can cause many types of indoor air quality problems which can be problematic and expensive to fix after the initial construction is finished. For these reasons the redesign of the retail ventilation system to meet compliance with ASHRAE Standard 62.1 is a practical if not necessary step in the mechanical system redesign.

Ventilation System Comparison Summary			
Item	**Existing System**	**Redesign System**	**Difference**
Total Length Supply Duct (ft)	2,423	3,450	**1,027**
Total Length Return Duct (ft)	0	2,294	**2,294**
Total Weight of Ductwork (lbs)	23,612	40,661	**17,049**
Total Cost	$1,013,193	$2,077,902	**$1,064,709**

Mechanical System Redesign

The second, larger, section of the mechanical redesign will use current technologies that have been proven to work, however, are still considered to be on the cutting edge in heating, ventilation, and air condition field. The redesign will analyze an existing building that uses a large amount of energy from the electrical grid throughout all hours of the day and convert it to a new building that still requires a large amount of energy; however, the building will now obtain the needed energy while: lowering the environmental impact, receiving the energy at a lower cost to the owner, and changing a negative situation in the community into a positive one that educates everyone. In short, the mechanical redesign will take a building that is currently a liability and turn it into an asset.

Redesign Objectives

Since the development of the Xanadu Sports Complex began the project has seen multiple lawsuits filed that delayed the construction. One of these lawsuits was filed by four environmental advocacy groups on October 13, 2004 in the New Jersey Appellate Court. The lawsuit requested the halt of construction of the complex due to the fact that state officials and the developers had not fully assessed the environmental affects that such a complex will have on the area. The delays produced from this lawsuit and the others have raised the estimated cost of the Xanadu Sports Complex from $1.3 billion to the current amount of $2 billion. This lawsuit sparked the debate of whether or not an indoor ski resort is worth the environmental impact that such a space will produce. Considering that the existing building obtains all its energy through an electrical grid that receives 70% of its power through coal plants, the environmental impact produced will be a large one. Therefore, the overall objective of the mechanical system redesign is to reduce that environmental impact produced while still providing an economically feasible system.

Redesign Summary

To achieve these goals a combine heat and power (CHP) system will be implemented in the Xanadu Sports Complex. The CHP system will use a source of fuel to power a combustion process on the site of the building. This combustion process will take place in the building's prime mover. A prime mover for use in a CHP system can come in the form of an engine, turbine, or microturbine. The combustion process in the prime mover will be used to create the electricity needed to power the sports complex. The combustion process produces a large amount of excess heat that can be used through the use of heat exchanger to produce medium pressure steam. The combination of the electrical production and steam produced creates a fairly high efficient process that utilizes a cleaner burning fuel than coal.

The medium pressure steamed produced can be used for multiple uses throughout the building; however, for this report the steam will be used to run a steam fired heating and cooling absorption chiller. The absorption chiller can use the available steam to heat or cool the building. When a CHP system is designed, the prime mover can be designed to either meet the electrical demand or the thermal demand based on the steam output and the absorption chiller efficiency. In this report the prime mover will be designed to meet the electrical load and the resulting steam capacity will either meet all of the thermal demand or partially meet the thermal demand. Depending on the steam output a lag chiller and a lag boiler may need to be implemented to meet thermal demand loads during times of off-peak electrical demand. During times of off peak electrical demand when the building does not require as much electricity, the steam production will also decrease as the prime mover throttles down to meet the current electrical demand. At these times a centrifugal chiller or a gas fired boiler will be used in conjunction with the heating or cooling cycle of the absorption chiller to meet the current thermal load. Due to the large amount of energy needed to power the building, it is also possible that the electrical load will far outweigh the thermal demand. In this case there is no need for the lag chiller and boiler, and the excess steam produced will be used to heat the domestic water in the building.

One of the biggest impacts on the environmental impact is the type of fuel used to power the building. In many cases natural gas is used for CHP systems; however, a growing number of systems are using reclaimed landfill gas to power the prime mover's combustion process. Landfill gas can be collected by drilling large well systems deep into the piles of garbage at a local landfill. The well system collects the mixture of methane gas which is then sent through a treatment cycle to clean the gas of all impurities. The cleaned gas is then piped to the site to be used. Any excess gas collected can be flared off or sold to other local buildings in need of a fuel source.

Building Load Analysis

In order to successfully design any mechanical system the building's load profiles must be accurately predicted. This is especially true for combined heat and power system due to the fact that the thermal capacity of the system is a function of the electrical capacity. If the prime mover were to be sized to meet the building's thermal loads, the thermal load profile would be calculated throughout the year, and the prime mover would be selected accordingly. Since the Xanadu Sports Complex mechanical system redesign's prime mover is designed to meet the building's electric demand, it is essential that the electrical profiles are accurately calculated for all days of the year. Using a combination of mechanical equipment technical data, building operation schedules, TRANE's TRACE 700 Energy Simulation Software, and the Oak Ridge National Laboratory's BCHP Screening Tool software the building's electrical profile for a typical year was calculated. Figure 15 below illustrates the average monthly electrical demand for both the existing conditions and the mechanical system redesign.

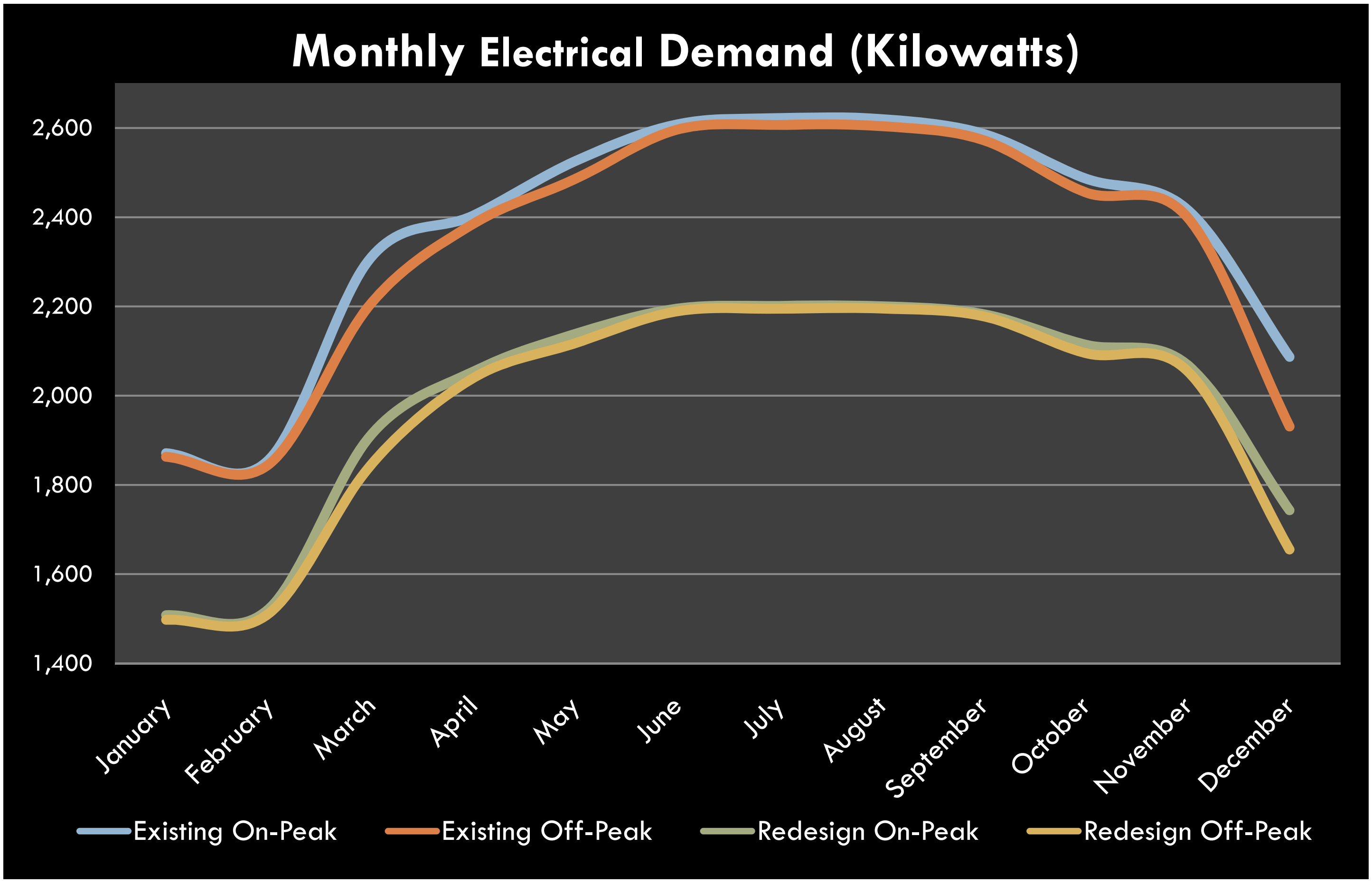


Figure 15: Existing and Redesign Monthly Electrical Demand

When the type schedule for Building A is considered it can be seen from the graph that the electrical demand is very accurate. As discussed in the Building Background Section of this report, due to the schedules of both the indoor ski resort and the retail section the electrical on-peak and off-peak demands stay very consistent throughout the year. This is due to the fact that the majority of the electrical demand required is drawn from the mechanical equipment in the Snowdome section of the building. To be able to maintain skiing conditions throughout the day the equipment must run nearly all hours of the day. However, as the snow making process begins at night and the ski resort temperature is driven to 28°F the electrical demand for that section of building increases. At the same time the snow making process is beginning, the retail section's mechanical system is beginning its nighttime setback cycle. The fact that when one section of the building is demanding more energy the other section requires less energy provides the fairly constant demand profile. This constant daily demand profile will greatly improve the overall efficiency of the system since the constant demand will more than likely eliminate the need for an electrical lag chiller and gas fired lag boiler.

As mentioned, Figure 15 illustrates both the existing and redesigned systems. Both systems follow the trend of less electrical demand in the winter months due to the fact that less cooling is needed to maintain skiing conditions. The obvious difference in the systems comes from the magnitude of the overall electrical demand. This difference is due to the fact that the four direct expansion rooftop units that serve the retail section have now been replaced with the steam fired absorption chiller/heater that will provide the thermal capacity to the new rooftop units serving the retail section. While the retail section equipment has changed, the Snowdome equipment will remain the same. The main reason for this decision is that to produce the temperatures needed for the indoor skiing conditions, an electrically driven chiller is the only option.

Beyond monthly electric demand profiles, daily profiles are also required to assure that based on the amount of electricity generated that the thermal demand can also be reached. Figure 16 and Figure 17 below illustrate a February day electrical demand and a July day electrical demand profile respectively. February and July were picked to be illustrated in this report due to the fact that the lowest demand and the highest demand come from days in these months. Both days follow somewhat similar trends. From 9:00 P.M. until approximately 5:00 A.M. the snow making process is running in the Snowdome. It can be seen that as the process progresses throughout the night and nears the end of the cycle less energy is needed. Shortly after, the load demand from the retail section quickly brings the demand to a higher level. Throughout the day the electrical demand fluctuates as electricity is needed. Towards the end of the day the occupancy begins to decrease, thus the electrical demand begins to decrease. However, throughout the day the overall demand only fluctuates by 25 kilowatts.

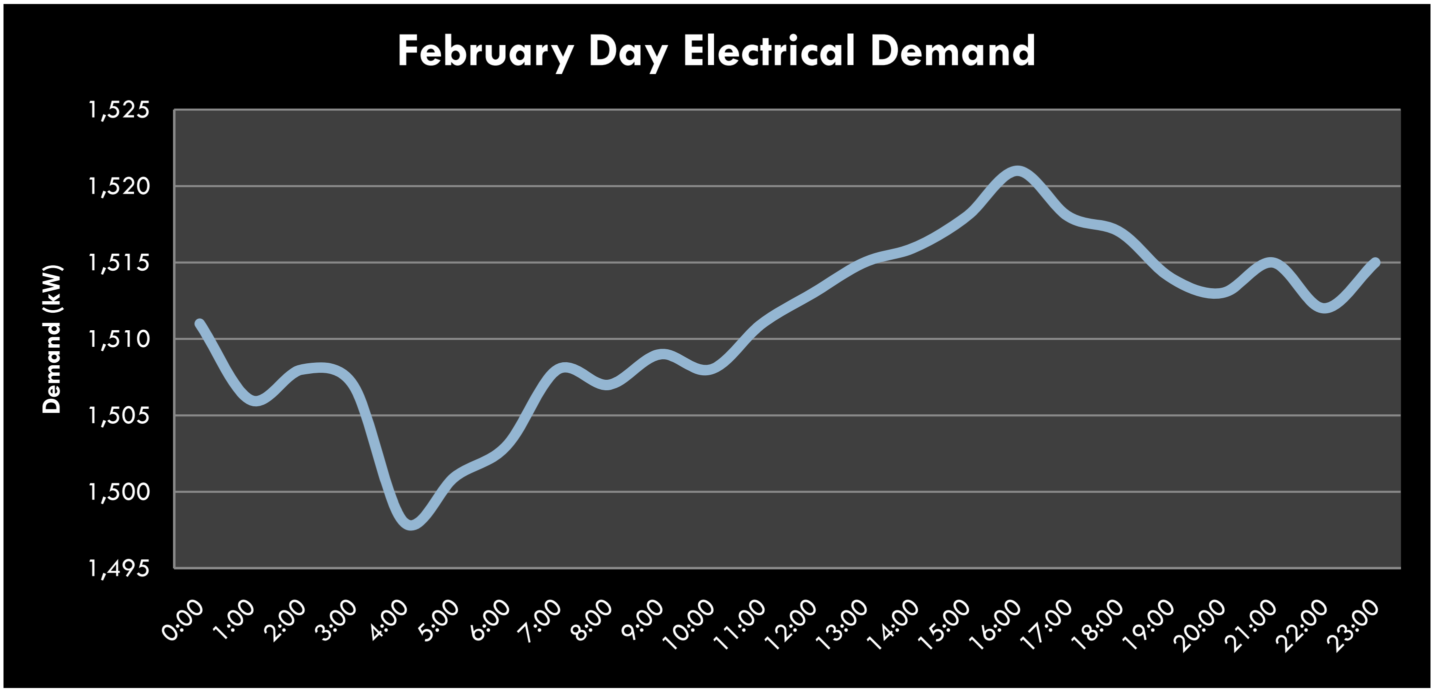


Figure 16: Typical Redesign February Day Electrical Demand

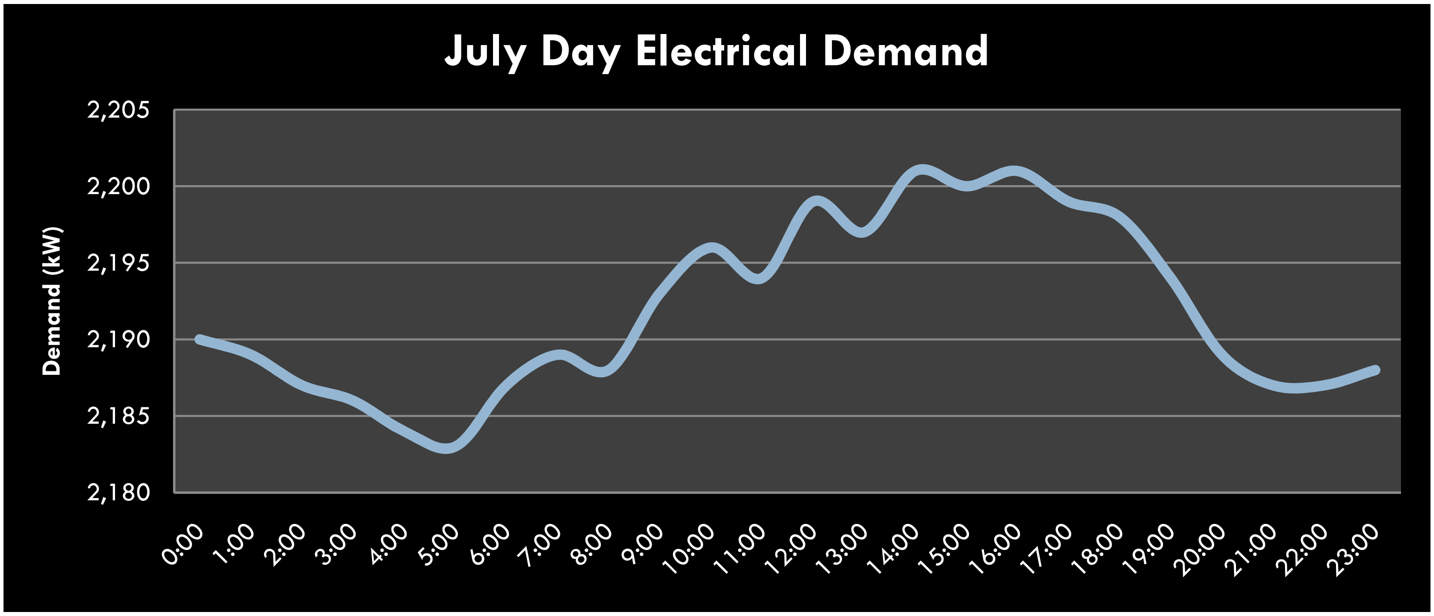


Figure 17: Typical Redesign July Day Electrical Demand

In addition to demand it is also to calculate the overall building electrical consumption. Figure 18 illustrates the consumption of both the existing and redesigned system.

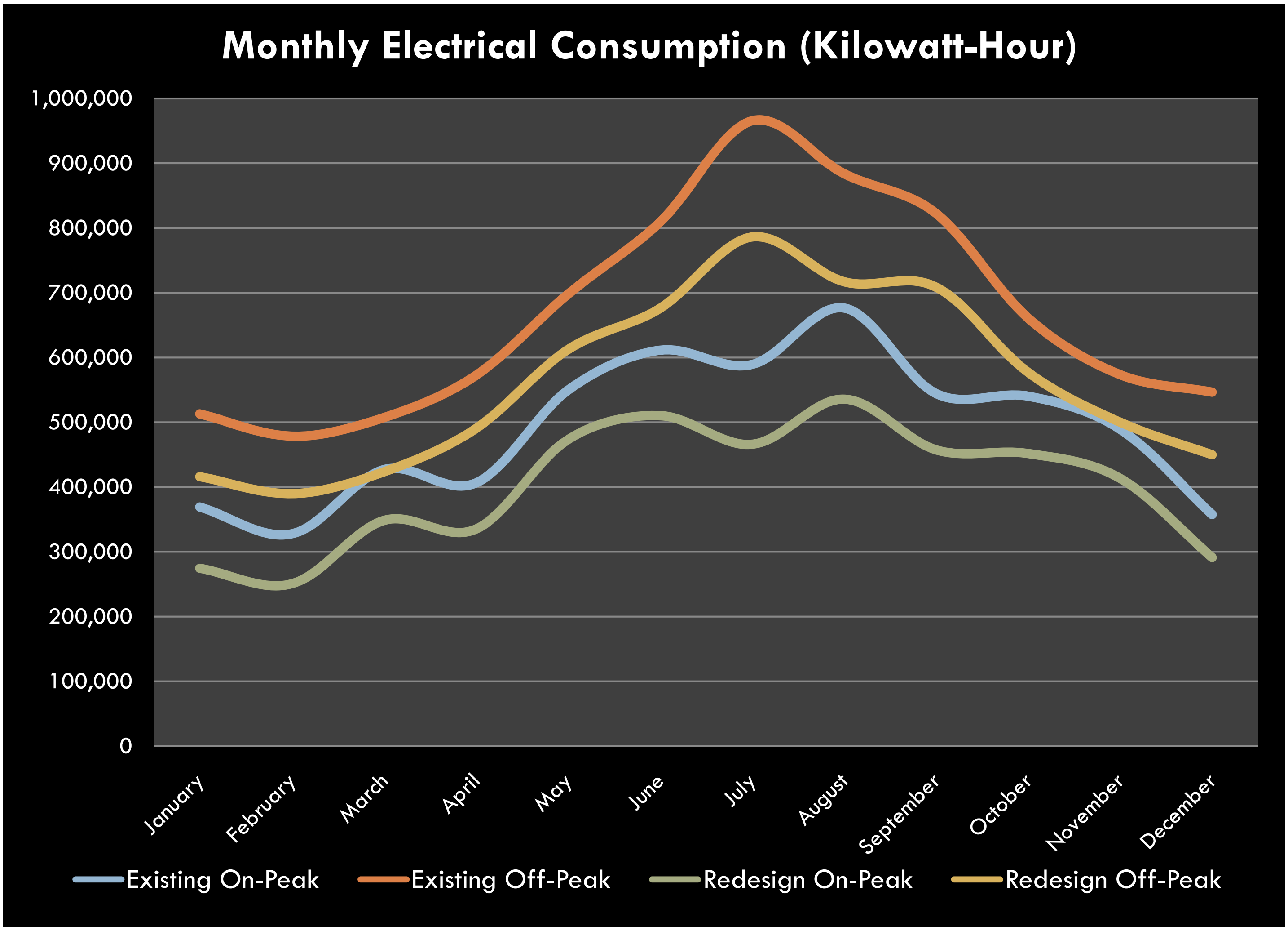


Figure 18: Existing and Redesign Monthly Electrical Consumption

Based on all the data calculated regarding building loads, the overall steam production can be calculated. With the steam production capacity calculated it can be determined if the steam alone can meet the thermal demand for the building year round. Figure 19 below illustrates the overall steam production. The steam produced by the prime mover meets the thermal demand throughout the whole year. This confirms that a single absorption chiller/heater will be able to meet the thermal loads for the entire building. The excess steam created presents another opportunity that will be utilized by heating the domestic hot water for the entire complex. This will lower the sizing of the domestic hot water heater for the complex. Since the domestic hot water encompasses the entire complex and just not Building A, the resizing of the domestic hot water boiler is beyond the scope of this redesign. It should also be noted that in order to calculate the steam production the redesigned system's equipment technical data was used. At this point in the report the equipment technical data has not been discussed and will be discussed in detail in the next sections.

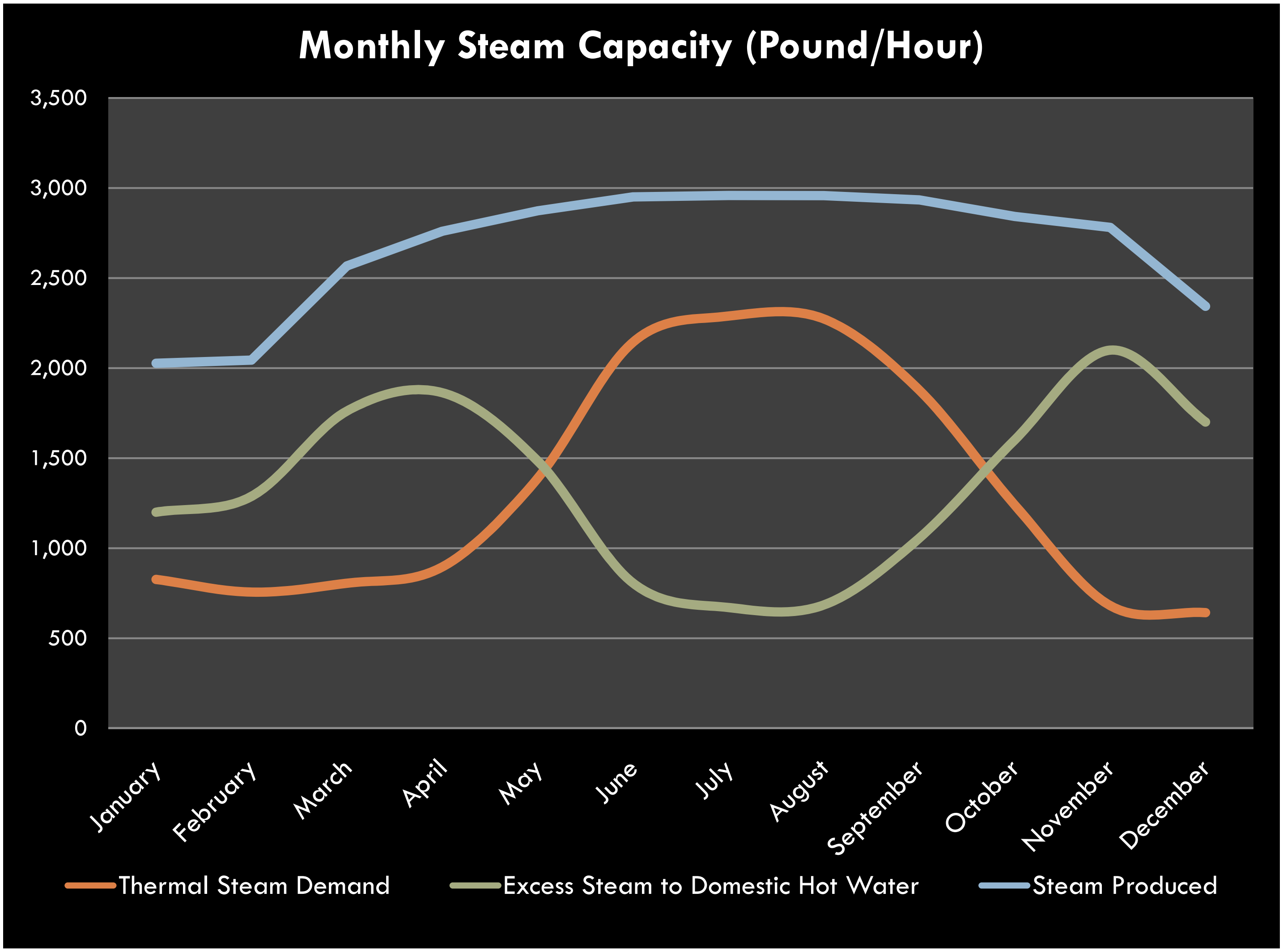


Figure 19: Redesign Prime Mover Steam Production

Mechanical System Redesign Component Analysis

This section of the report will describe the process from beginning to end of the mechanical system redesign in order to power, heat, and cool the Xanadu Sports Complex. While this section will address the theory behind the redesign's process, more technical calculations used to size the various components can be found in Appendix D of this report.

Fuel Source

The heart of a combined heat and power system is the source of electricity production, the prime mover. In order for the prime mover to create electricity on site, fuel is needed to maintain a combustion process. One of the most commonly used source of fuel for a CHP system is natural gas, however, recently there has been a steady increase in projects that utilize landfill gas to power their building. Currently there are approximately 424 operational landfill gas projects in 42 states that supply 10 billion kilowatt hours of electricity annually, and this number has been steadily rising each year.

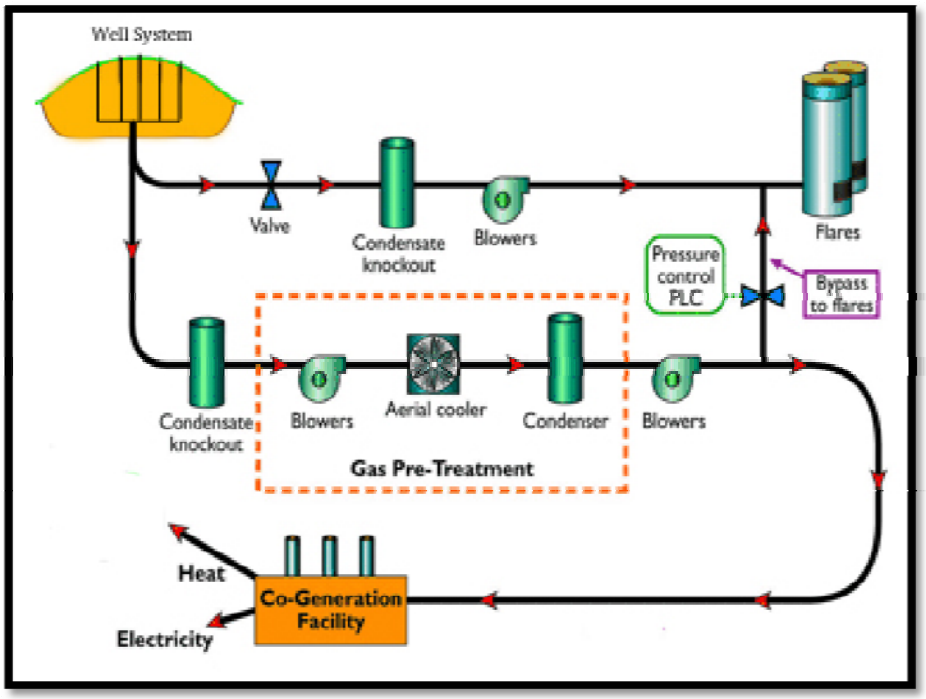


Figure 20: Landfill Gas Collection Schematic

Landfills are the largest human-made source of methane in the United States, accounting for nearly 24% of all methane created. The methane created by landfills is a by-product of the decomposition of solid waste that is collected at the site. The landfill gas (LFG) is composed of approximately 50% methane, 49% carbon dioxide, and 1% of non-methane organic compounds. Under normal conditions the LFG is generated by the decomposition process and is released to the atmosphere contributing to smog, global warming, and health concerns. However, it is possible to collect the LFG, treat the gas on site, and then pipe the treated gas to a building site to drive a CHP system. The collection of LFG is utilized by drilling into the landfill and then placing large vertical wells deep into the waste. The LFG flows into the wells and is either piped to the treatment center or to flares to burn off any excess gas. In lieu of flaring the excess gas it can be sold to other nearby facilities in need of a clean-burning fuel. During the treatment process moisture, particulates, and a large portion of contaminants are removed. The process begins by passing the gas through a filter and then a condenser that reduces the dewpoint of the gas to approximately 37 °F. After the dewpoint is reached, the gas is passed through one more filter and then reheated. The treated methane gas is now ready for use in the CHP system. Figure 20 provides a schematic of the landfill gas collection system.

GROWS Inc. landfill will be the landfill used for the Xanadu Sports Complex. The landfill is located approximately 3.5 miles from the building site. Through the use of the aerial imaging software Google Earth it was found that the GROWS landfill is roughly 4,053,804 square feet in active landfill area. Through multiple sources of research it has been determined that the average gas production for landfills is 0.344 standard cubic feet (scf) per square foot (sf) of landfill daily. This data yields a value of 58,104 scf/hr or 1,645 normal cubic meters (Nm^3) per hour produced from this particular landfill.

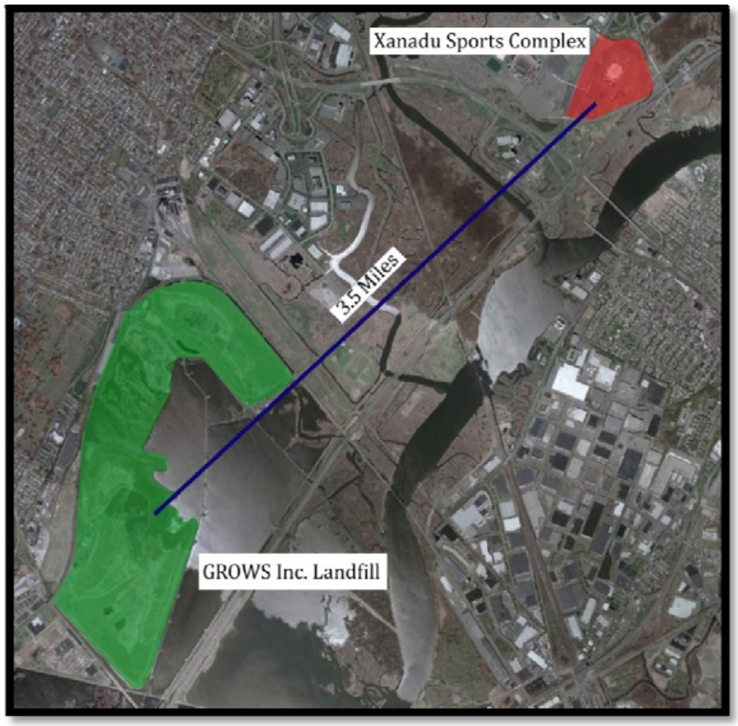


Figure 21: Landfill Gas Service Aerial Image

Finally, the quality of gas supplied to the building needs to be examined. The typical lower heating value for natural gas is 9.5 kWh/Nm^3. While the treatment of the landfill gas creates a high quality fuel, the lower heating value of methane is roughly half that of natural gas. The resulting lower heating value of 5.0 kWh/Nm^3 will need to be taken into consideration when selecting the prime mover.

Prime Mover

When selecting a prime mover, multiple options can be considered. The three most popular solutions are through the use of a turbine, a microturbine, or an engine. Each system has advantages and different ranges of the amount of electricity production capacity. As discussed in the building load analysis section of this report, the demand for the redesigned mechanical system ranges from 1,480 kilowatts in February to 2,200 kilowatts in July. This range of electrical capacity eliminates the possibility of a microturbine system due to the fact that a single microturbine can produce anywhere from 20 kilowatts to 500 kilowatts. This range is considerably lower than that needed for the Xanadu Sports complex; therefore, either a turbine system or an engine system are the logical choices. Besides the capacity the source of fuel must also be taken into consideration. In this case a treated methane gas with a lower heating value (LHV) of 5.0 kWh/Nm^3 will be the available fuel. Upon extensive research it was determined that General Electric (GE) had the most experience in the use of treated natural gas to fire their engines. GE has more than 25 years of experience in the combustion of landfill gas and currently, more than 1,100 landfill gas systems with a total electrical output of 1,050 megawatts use GE engines, specifically Jenbacher line of gas engines. Multiple case studies on the use of landfill gas for cogeneration have used GE Jenbacher engines, and they have proven to be very reliable throughout many years of service. For these reasons a GE Jenbacher engine was chosen to be the prime mover for the Xanadu Sports Complex.

Due to GE's specialty in the use of biogas produced from landfills, a special model of Jenbacher engines is available for the use of landfill gas with an approximate LHV of 5 kWh/Nm^3. In order to properly size the engine a decision must be made for the design to meet the building's thermal loads based on the engine's steam production or to meet the electrical load. Based on the results from the building load analysis section, it has been determined that the electrical load will always be much higher than the thermal loads; therefore, the system is designed to meet the electrical loads. Based on the electrical demand, a GE Jenbacer Engine model JMS 620 GS-BL was selected. Based on the technical calculations in Appendix D, this model engine can provide a maximum of 2,433 kilowatts. This will allow the engine to meet the electrical demand all year round with a 233 kilowatt leeway.

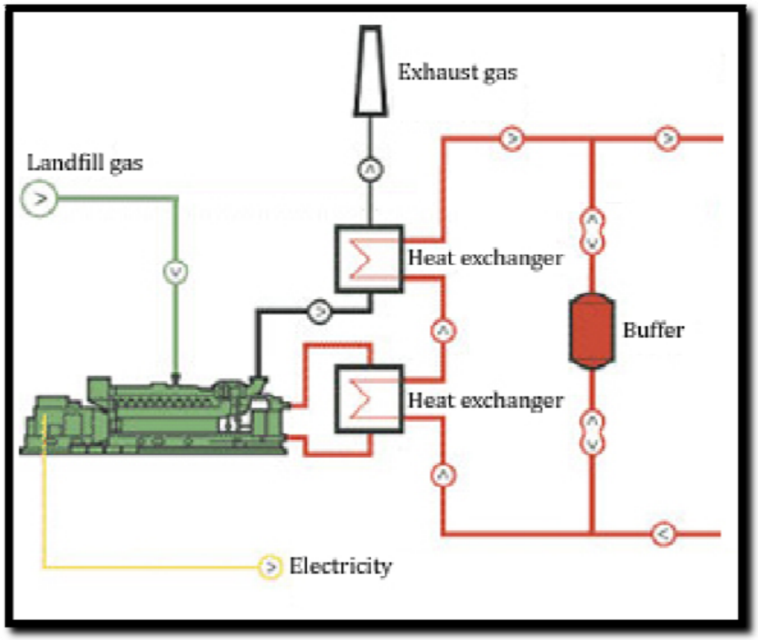


Figure 22: Engine Heat Exchanger Schematic

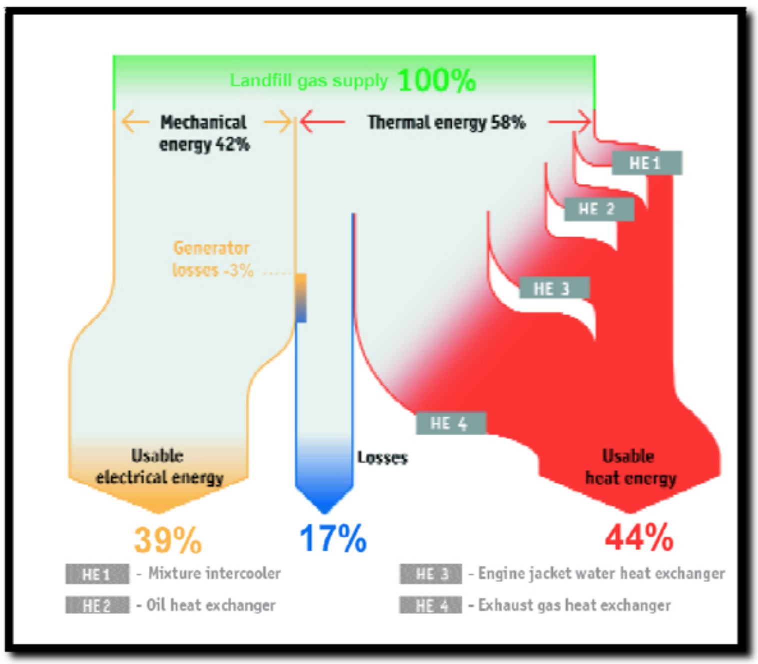


Figure 23: Engine Efficiency Breakdown

Through the continuous supply of landfill gas, the Jenbacher engine will run 24 hours a day, 365 days a year. The engine will throttle up or down to meet the current electrical demand. Through the combustion process a significant amount of energy cannot be converted to mechanical energy which would be used to produce electricity. This extra energy comes in the form of thermal energy which can be used with heat exchangers to produce medium pressure steam. Overall, a heat exchanger for the exhaust gas and a hot water loop heat exchanger are use to create steam. Figure 22 illustrates this process in a schematic.

The efficiency for the engine process is illustrated in Figure 23. When the fuel enters the engine, 42% of the energy is converted to mechanical energy and the remaining 58% is attempted to be recovered for steam production. However, the generator used to convert mechanical energy to electrical energy produces losses of 3%, and through the heat exchangers another 17% of thermal energy is lost. This produces an electrical efficiency of 39% and a thermal efficiency of 44% for a total efficiency around 83%.

Absorption Chiller/Heater

An absorption chiller/heater will replace the four existing direct expansion rooftop units in order to maintain thermal comfort inside the retail section of the building. This will replace the use of electricity for heating and cooling with the use of steam. The steam produced from the Jenbacher engine will be used to fire the absorption chiller. An absorption chiller replaces the mechanical compressing of a refrigerant found in the direct expansion units. The absorption chiller can achieve this process by using a thermochemical compressor. Essentially, two different fluids are used. One fluid is used as an absorber and another is used as a refrigerant. Typically, water is used as the refrigerant while lithium bromide, a nontoxic salt, is used as the absorber.

An absorption chiller is comprised of four main components: the generator, the condenser, the evaporator, and the absorber. The process begins in the generator where the steam produced from the engine is introduced. The steam flows into the generator's heat exchanger where the chiller will pump the water and lithium bromide solution over the heat exchanger coils. The solution begins to boil allowing the lithium bromide and water to separate. The water now separated from the lithium bromide turns to vapor and is carried over to the condenser. In the condenser the water vapor is condensed on the surface of a heat exchanger. The condenser's heat exchanger removes the vapor's latent heat by rejecting the energy to a cooling tower. The liquid water collects in the condenser and is sent to the evaporator. In the evaporator the liquid water flows over the surface of an evaporator coil. The water begins to boil and removes heat from the chilled water loop. This chilled water will then run to the four new rooftop units with chilled water coils. At the same time the lithium bromide collected in the generator is precooled through the use of a heat exchanger before it is used in the absorber. Once it reaches the absorber the water vapor from the evaporator process is absorbed by the lithium bromide flowing across the surface of the absorber coil. The heat of condensation and dilution is rejected to the cooling tower through the cooling water loop. The resulting water and lithium bromide solution is collected and pumped back to the generator to start the process once again. In order to provide heating the absorption chiller's change-over valve must be opened. This valve bypasses the absorber process. The generated hot water vapor is used to exchange heat between the evaporator coil and the hot water loop which services the hot water coils in the rooftop units. Figure 24 on the next page illustrates the process described in this paragraph.

In order to select the proper size of absorption chiller both the cooling and heating peak loads for the retail section need to be considered. Based on the TRACE 700 load calculations the peak cooling load is 267 tons and the peak heating load is 1,241 MBtu/hr. Based on the peak loads, it was determined that in order to meet the full capacity with a single chiller a double-effect absorption chiller was needed. The largest difference between a single-effect and a double-effect absorption chiller is that the double-effect captures some

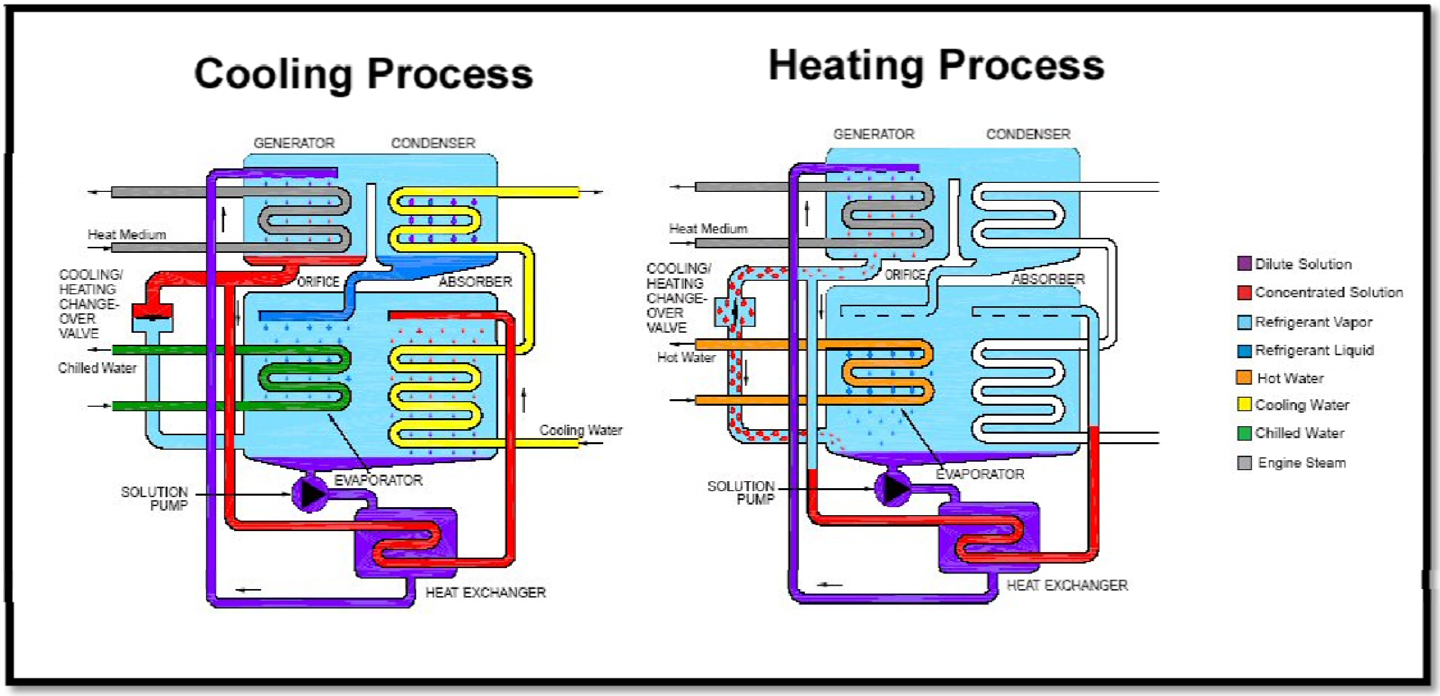


Figure 24: Absorption Chiller/Heater Process

internal heat and uses it in the generator. This extra process reduces the steam requirements and boosts system efficiency. To meet the thermal loads a Carrier Double-Effect Absorption Chiller Model 16NK was selected. This model's cooling capacity is listed at 294 tons providing adequate cooling to the retail section year round. The maximum amount of steam consumption is 2,601 lbs/hr providing more than enough heating capacity for the few months it is needed. Based on the calculations in the building loads section and in Appendix D of this report, there will be anywhere from 630 lbs/hr to 2,100 lbs/hr of excess steam produced. Based on the final selection of the absorption chiller/heater the proper form of heat rejection must be selected. For this redesign heat ejection will be accomplished through the use of a cooling tower. Using the values of the cooling water flow rate and chiller cooling capacity a SPX Model JT49290 Cooling tower was selected through the use of use of the SPX web-based tower sizing and selection program.

The amount of excess steam produced is a considerable amount and can be used elsewhere in the complex to increase the overall efficiency of the project. The most practical application for this steam is for the use of heating the domestic water in the complex. While Building A itself does not have a high demand for domestic hot water, other sections of the complex do have a high demand. The excess steam can be piped to other parts of the complex to heat the domestic hot water and save more energy and utilities. While the savings from this extra process in the overall system can produce a large amount of savings due to the sheer size of the whole complex, the domestic hot water demand is beyond the scope of this report. It is recognized that extra savings and efficiency are possible but will not be analyzed and are considered an extra perk of this system.

Rooftop Air Handling Units

For the four new rooftop units TRANE customizable rooftop units were selected. Based on the calculations and TRACE 700 energy model discussed in the ventilation system redesign section of this report, the four new rooftop units were sized. The total amount of air flow through the rooftop unit was found using the TRACE building model. The amount of supply air was calculated by selecting the higher required air flow based on either the ASHRAE 62.1 ventilation standard or the required air flow to maintain thermal comfort. To determine the required heating and cooling coil capacities the TRACE 700 peak loads were used based on the spaces each rooftop unit is supplying. With the data calculated in the ventilation redesign, the building load calculations, and the TRANE rooftop unit literature the units were designed. Table 3 below summarizes the four rooftop units selected.

Table 3: Rooftop Unit Summary

Rooftop Unit	Casing Size	Supply Fan		Exhaust Fan		Heating Coil	Cooling Coil
		BHP	RPM	BHP	RPM	Mbtu/hr	Mbtu/hr
A1	2	25	1043	10	750	317	924
A2	4	30	1150	15	1000	563	1,296
A3	2	11	800	6	700	109	504
A4	2	11	800	6	700	86	480

All the mechanical system components discussed in this section work together to provide an efficient system to power, heat, and cool the Xanadu Sports Complex year round. Figure 25 on the next page illustrates in a schematic how all the mechanical system components come together.

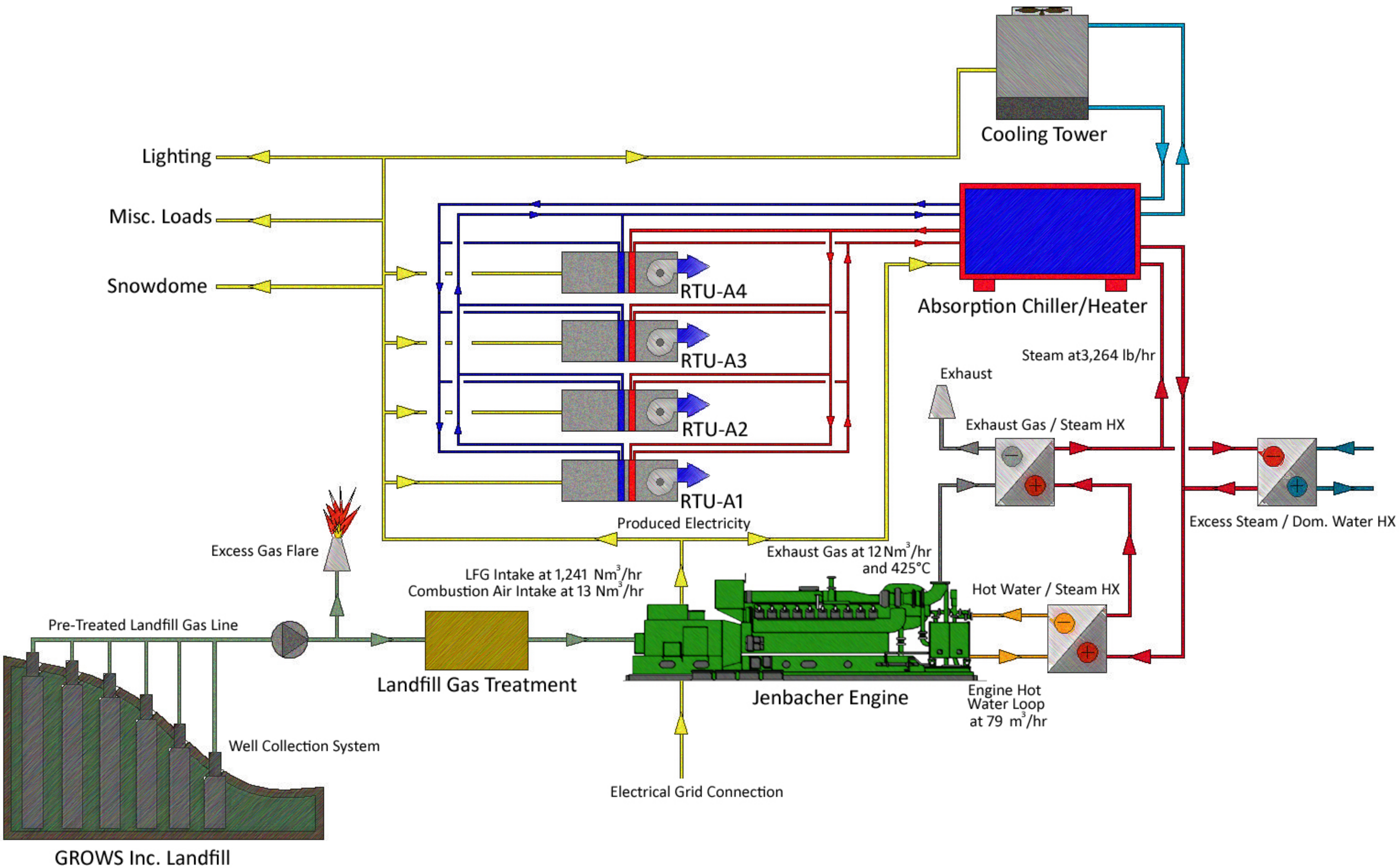


Figure 25: Redesign Mechanical Schematic

Mechanical System Redesign Conclusions

The objective behind the redesign of the mechanical system was to take a negative situation and create a positive one, turning a liability into an asset. In order to meet this goal two key factors had to be met, substantially reducing the environmental impact the building produces while maintaining an economically feasible system. If, and only if, these two criteria are met can the system redesign be considered a success.

Economic Analysis

In order to maintain a retail building and indoor ski resort year round a large amount of energy is required. Due to this large amount of energy a large amount of money must be spent to run the building each year. Due to the location of the Xanadu Sports Complex the local utility provider of electricity and natural gas is PSEG Power. Table 4 below summarizes the electrical rates for PSEG. As an alternative, if the building were to use natural gas instead of landfill gas, the PSEG CS-CFG gas rate would be used. This gas rate is used for buildings that are going to use the gas to produce their own electricity. This rate also comes with a small fee to still remain connected to the electrical grid. The charge is applied to ensure the electrical capacity will be available to the building in the case of a engine failure. The natural gas rate averages around 99 cents per therm throughout the year and the monthly fee for the grid connections is approximately $4,200.

Table 4: PSEG Electricity Rates

Charge Type	Months	Rate
Electric Demand On Peak	October-May	$3.894 /kW
	June-September	$7.227 /kW
Electric Demand Off Peak	October-May	$2.923 /kW
	June-September	$5.420 /kW
Electric Consumption On Peak	October-May	$0.088 /kWh
	June-September	$0.097 /kWh
Electric Consumption Off Peak	October-May	$0.070 /kWh
	June-September	$0.071 /kWh

There is a large difference between typical utility rates and the rate structure of current landfill gas systems. Typical utility rates have a structure dictated by the utility company and are subject to increase. Current utility rate trends and predicted trends will be used in the overall economical evaluation. Figures 26 and 27 illustrate the trend of utility rates for the past years. This is not the case with landfill gas systems. The rate for landfill gas delivery is worked out between the landfill and the building owner in the form of a multiple year contract. This locks the price of landfill gas to a set value for years. Not only is the price set for years, the price per therm of LFG is much less than that of natural gas. Through research it was found that the average price of LFG per therm is around 30 cents,

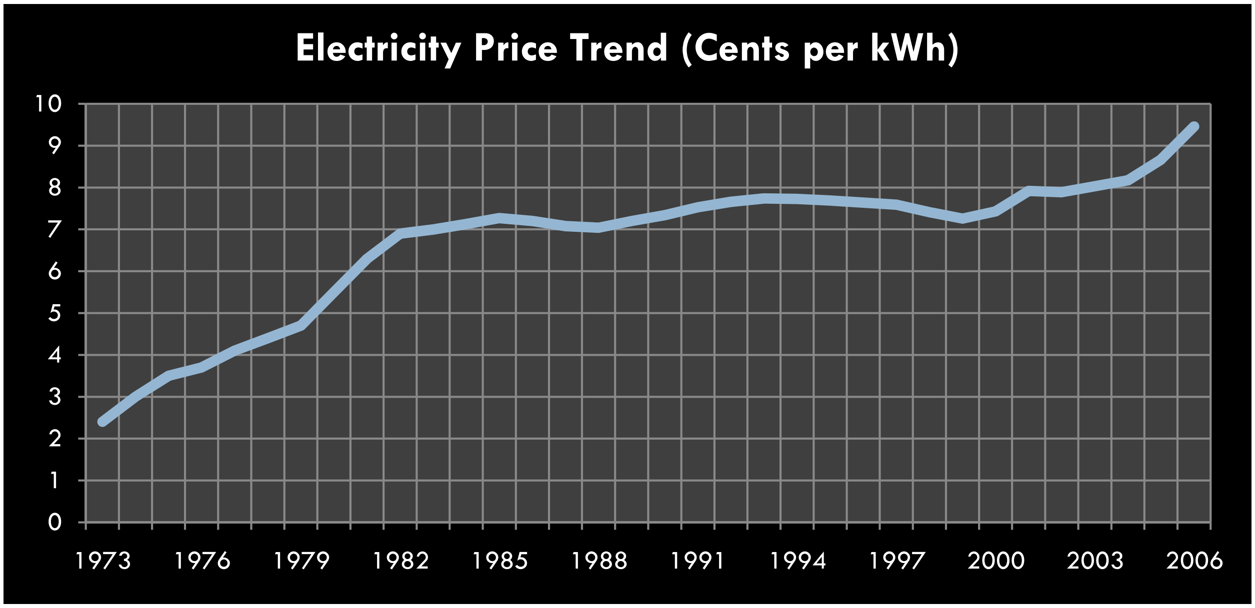


Figure 26: Electricity Price Trends

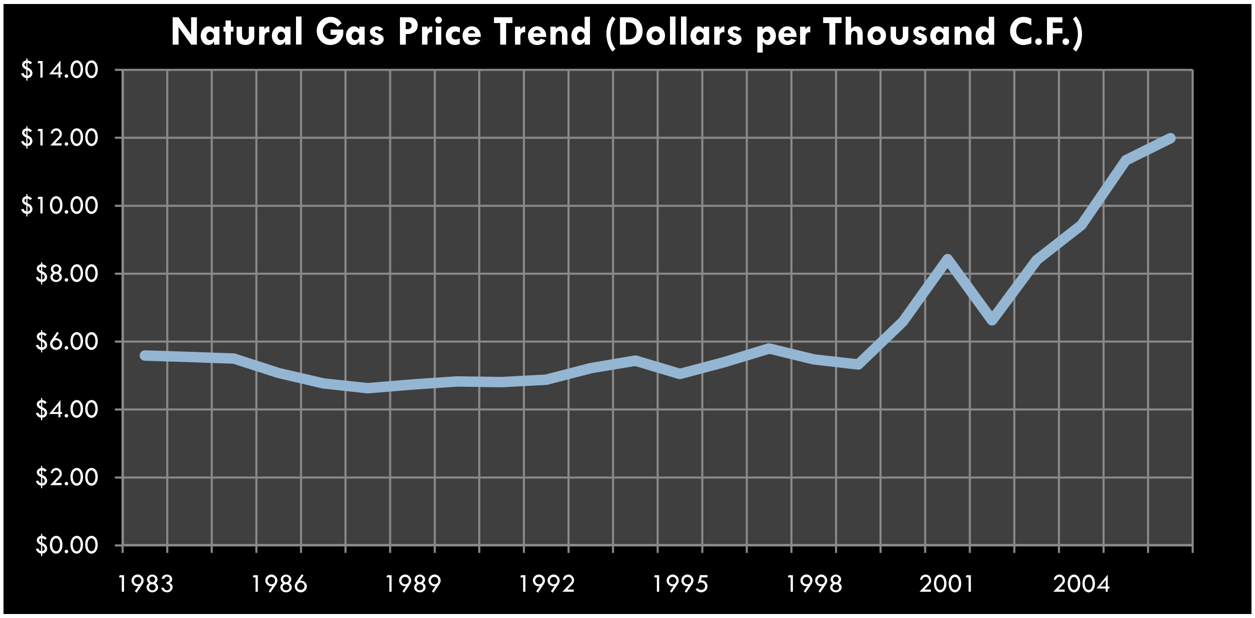


Figure 27: Natural Gas Price Trends

more than a third less than that of natural gas. As long as there is an abundance of landfill waste, the cost of LFG will be much lower than the cost of other typical utilities. In addition to the lower costs, there are multiple tax credits available to promote the use of renewable fuel. The biggest credit is the Environmental Protection Act of 2005 Section 45 Credit. This credit requires the use of renewable energy and that the building is in operation by December, 2008. The use of LFG is considered a renewable energy, and the Xanadu Sports Complex is scheduled to open in November of 2008, therefore this is a feasible tax credit. This credit provides 1 cent for each per kilowatt-hour used. This credit will be evaluated in the overall cost analysis.

Based on the different utility rates, the TRACE 700 energy model, and the results from the BCHP Screening Tool, the overall utility costs for the three alternatives can be determined. Figures 28 through 31 illustrates the findings.

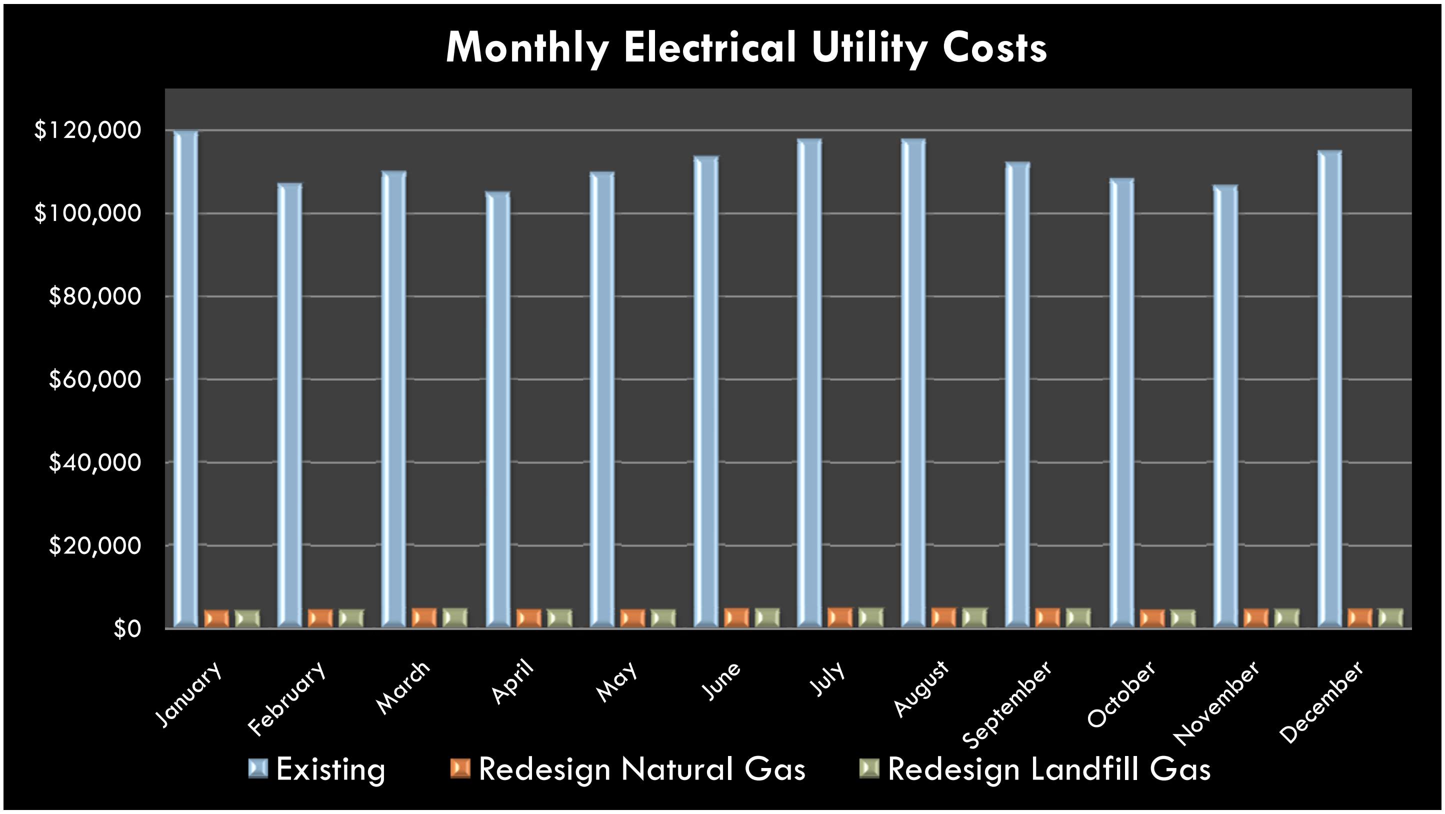


Figure 28: Monthly Electrical Utility Costs

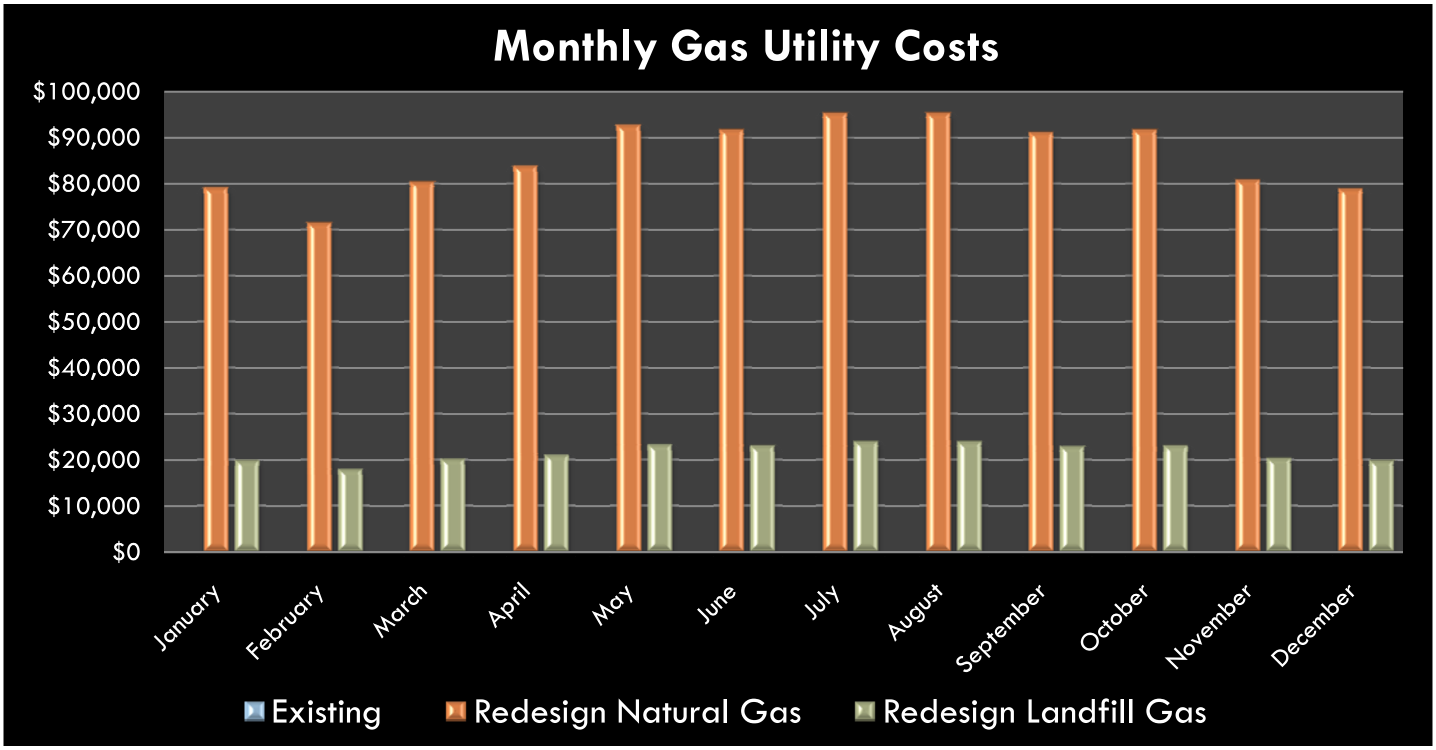


Figure 29: Monthly Gas Utility Costs

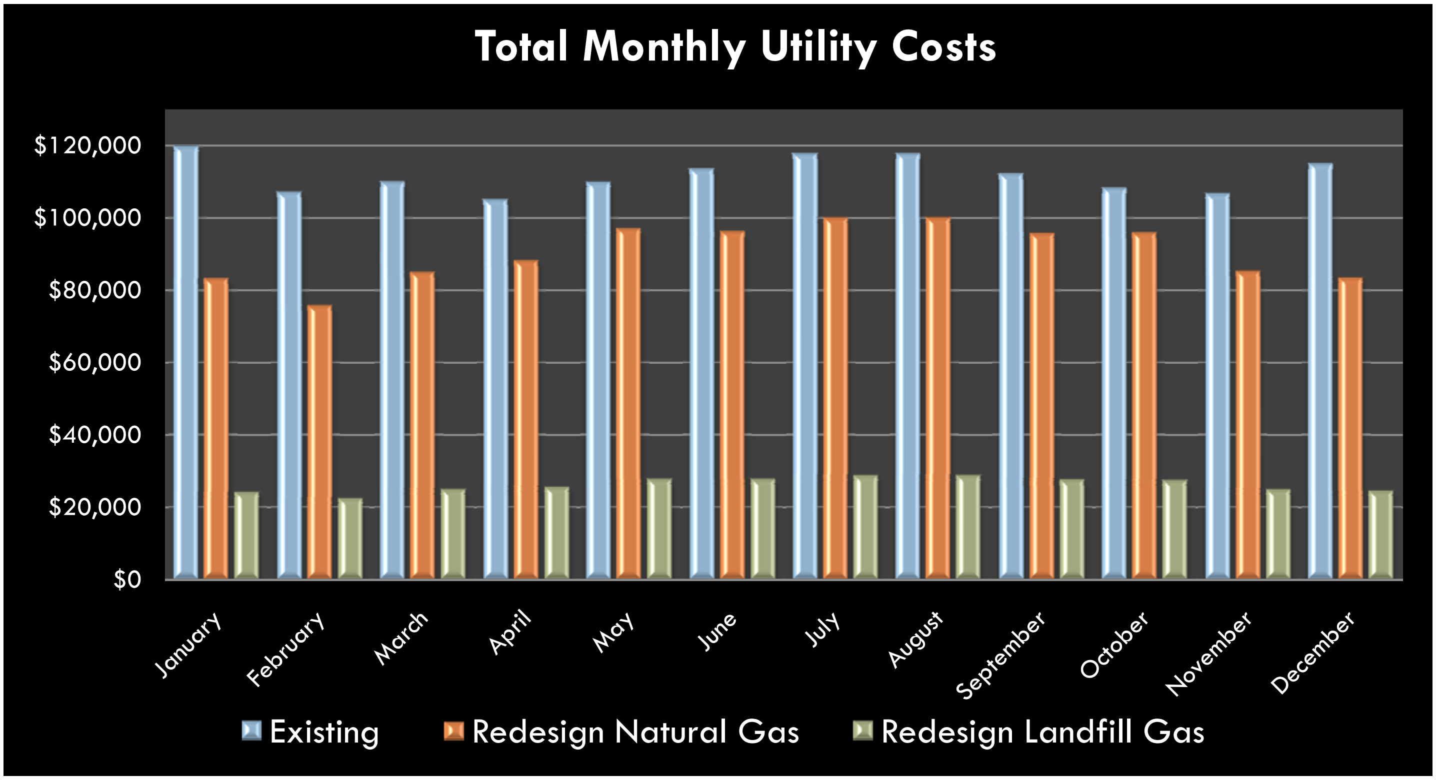


Figure 30: Total Monthly Utility Costs

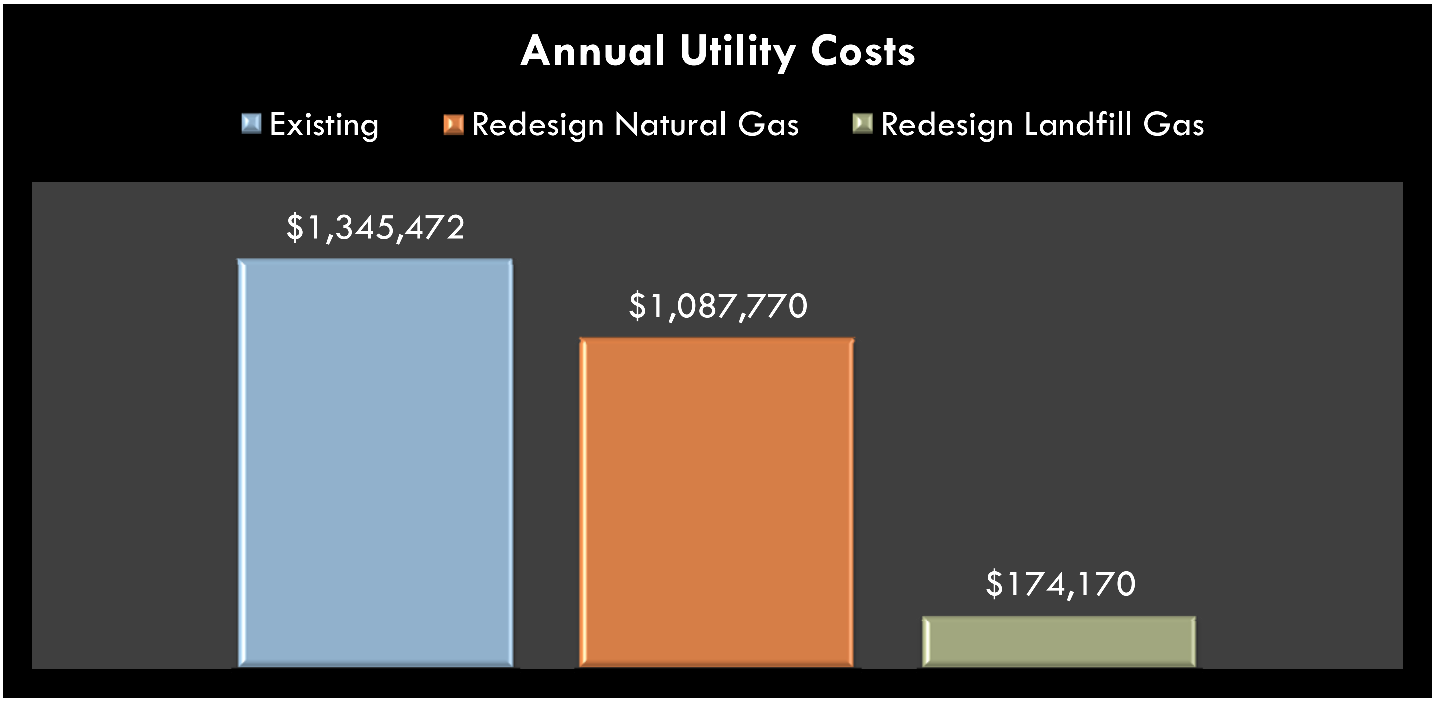


Figure 31: Total Annual Utility Costs

The above figures indicate that the most expensive annual operation rate is produced from the existing building conditions costing approximately $1.4 million a year. The second most expensive operation cost comes from the use of natural gas with the redesigned system costing approximately $1.2 million a year. It should be noted that the natural gas cogeneration system does not produce a significant savings. This is due to the electricity and natural gas utility rates. While energy from natural gas is cheaper than the grid electricity during on-peak conditions, it is more expensive to use natural gas during off-peak conditions. For this reason, if natural gas is to be used it would be much more beneficial to install an electrically driven lag boiler and lag chiller to operate during off-peak conditions. Finally, the lowest operating cost comes from the redesigned CHP system using the landfill gas, costing only $405,249 a year to operate. The redesigned system produces operational savings nearly 3.5 times less than the existing system.

Beyond the annual costs, the initial capital costs of the systems needs to be evaluated. While the annual savings are significant, a higher initial cost is to be expected. Table 5 on the next page summarizes the total costs of each system. The evaluation indicated that the redesigned landfill gas and CHP system will increase the initial system cost by 1.5 times. This increased initial cost and the annual savings works out to produce a payback period of just under 7 years. While 7 years is higher than originally desired, the 13 year span after the payback period will produce savings of $15,042,055.

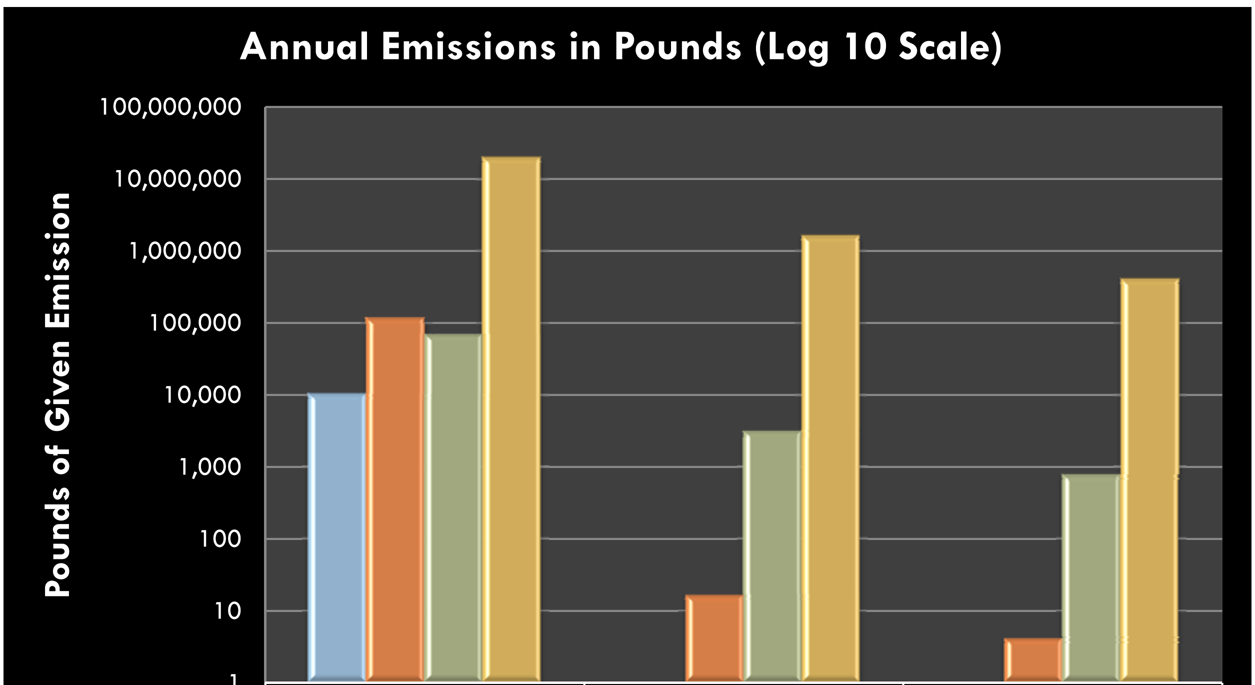
Table 5: Mechanical System Redesign Economic Evaluation

	Existing	Redesign Natural Gas	Redesign Landfill Gas
Capital Costs			
Unchanged Costs	$3,809,428	$3,809,428	$3,809,428
Snowdome	$9,493,073	$9,493,073	$9,493,073
Rooftop Units	$426,155	$462,393	$462,393
Retail UPS System	$9,000	$0	$0
Snowdome Emergency Generator	$19,000	$0	$0
GE Jenbacher Engine	$0	$1,703,100	$1,703,100
Absorption Chiller	$0	$471,600	$471,600
Cooling Tower	$0	$37,900	$37,900
Landfill Well System	$0	$0	$4,866,000
LFG Transportation	$0	$0	$104,412
LFG Excavation	$0	$0	$242,088
Totals	**$13,756,656**	**$15,977,494**	**$21,189,994**
Yearly Costs			
Grid Electricity	$1,345,472	$54,641	$54,641
Natural Gas	$0	$1,032,963	$0
Landfill Gas	$0	$0	$258,725
EPA 2005 Section 45 Credit	$0	$0	-$139,196
Maintenance	$83,517	$138,648	$231,079
Totals	**$1,428,990**	**$1,226,252**	**$405,249**
Economic Evaluation			
Payback Period	-	**8.4 Years**	**6.6 Years**
Total Utilities After 20 Years	$30,580,382	$25,260,787	$8,104,989
Total Savings After 20 Years	-	**$3,098,757**	**$15,042,055**

Environmental Analysis

While the economic analysis produced favorable results, the true goal of the system redesign was to turn a system that was a large liability and produce an asset not only to the owner but also to the local community. The existing system runs entirely on the PSEG electricity grid. This electrical grid produces nearly 70% of its electricity through coal-burning plants. The use of coal-burning plants is considered a highly dirty energy source due to the composition of coal. The exact chemical composition of coal is based largely on many variables. However, all coal shares the same attribute of being mainly comprised of carbon atoms and few hydrogen atoms. During the combustion process the small amount of hydrogen is used to create energy while the remaining products, largely carbon, are released into the atmosphere, thus creating large amounts of pollutants. The other 30% of the grid produces its electricity through the use of nuclear power plants. While coal is largely dirty, nuclear power is an extremely clean power and creates zero impact on the environment.

There are substantial environmental benefits through the use of natural gas and landfill gas. The chemical composition of natural gas is comprised of a single carbon atom and four hydrogen atoms. This fact makes the use of natural gas much cleaner due to the fact that for every carbon released into the atmosphere four hydrogen atoms have been utilized. The largest benefit is produced though the use of landfill gas. Under normal circumstances a landfill will produce large amounts of methane that will be directly introduced to the environment. However, when the landfill gas is collected for the use of a CHP system, the methane is used to offset the use of nonrenewable resources, such as coal, that will produce more pollutants. The total environmental impact is quantified in Figure 32 below.



	Existing	Natural Gas	Landfill Gas
Particulates	10,326	0	0
SO2	119,959	17	4
Nox	69,533	3,136	784
CO2	20,182,243	1,656,998	414,217

Figure 32: Annual Emission in Pounds

Figure 32 shows the large difference in emission between the three alternatives. The use of landfill gas for the use of a CHP system reduces the total carbon dioxide emissions by 19,768,026 pounds, nearly 50 times less. This value can be used to estimate the annual environmental impact into comparative terms. The use of the redesigned system can be estimated to be equivalent to planting 26,000 acres of forest or preventing the use of 221,000 barrels of oil or removing emissions equivalent to 18,200 vehicles annually.

Therefore, the use of landfill gas and a combined heat and power system truly is turning a liability into an asset by greatly reducing local air pollution while creating jobs, revenue, and cost savings.

Impact on the Structural System

The changes created by the mechanical system redesign discussed in the previous sections will affect other disciplines throughout the building. The two largest areas affected come from the structural reinforcement and the electrical system power requirements. This section of the report will discuss the structural changes needed in order to support the new mechanical equipment, while the next section will discuss the electrical changes.

Structural System Analysis

The existing mechanical system is comprised of four direct-expansion rooftop units that are located on the retail sections roof. The other mechanical equipment belongs to the Snowdome and is located inside of a mechanical room adjacent to the Snowdome. For the redesign the Snowdome mechanical equipment remains unchanged and will remain located in the same mechanical room. The changes in the mechanical system redesign that will affect the structural system result from the addition of new equipment. The existing four rooftop units are being replaced with four new units that are provided their cooling and heating capacity from the absorption chiller/heater. While the rooftop units will be simply replaced, the remaining equipment will be entirely new and represent loads that were not in the previous design. Table 6 below lists the existing equipment and new equipment weights.

Table 6: Mechanical Equipment Weight

Equipment	Existing (lb)	Redesign (lb)	Difference (lb)
RTU-A1	16,000	18,000	2,000
RTU-A2	16,000	17,800	1,800
RTU-A3	17,000	17,500	500
RTU-A4	17,000	17,300	300
Jenbacher Engine	0	41,350	41,350
Chiller/Heater	0	24,700	24,700
Cooling Tower	0	7,500	7,500
TOTALS	**66,000**	**144,150**	**78,150**

As shown in Table 6 the mechanical system redesigns introduce just over 78,000 pounds of loads that will need to be supported on the retail section's roof. In the case of the replaced rooftop units there is very little difference between the existing weight and the new weight. For this reason the ventilation system redesign was designed in order to keep the four rooftop units in the same location in an attempt to reduce the impact on the structural system.

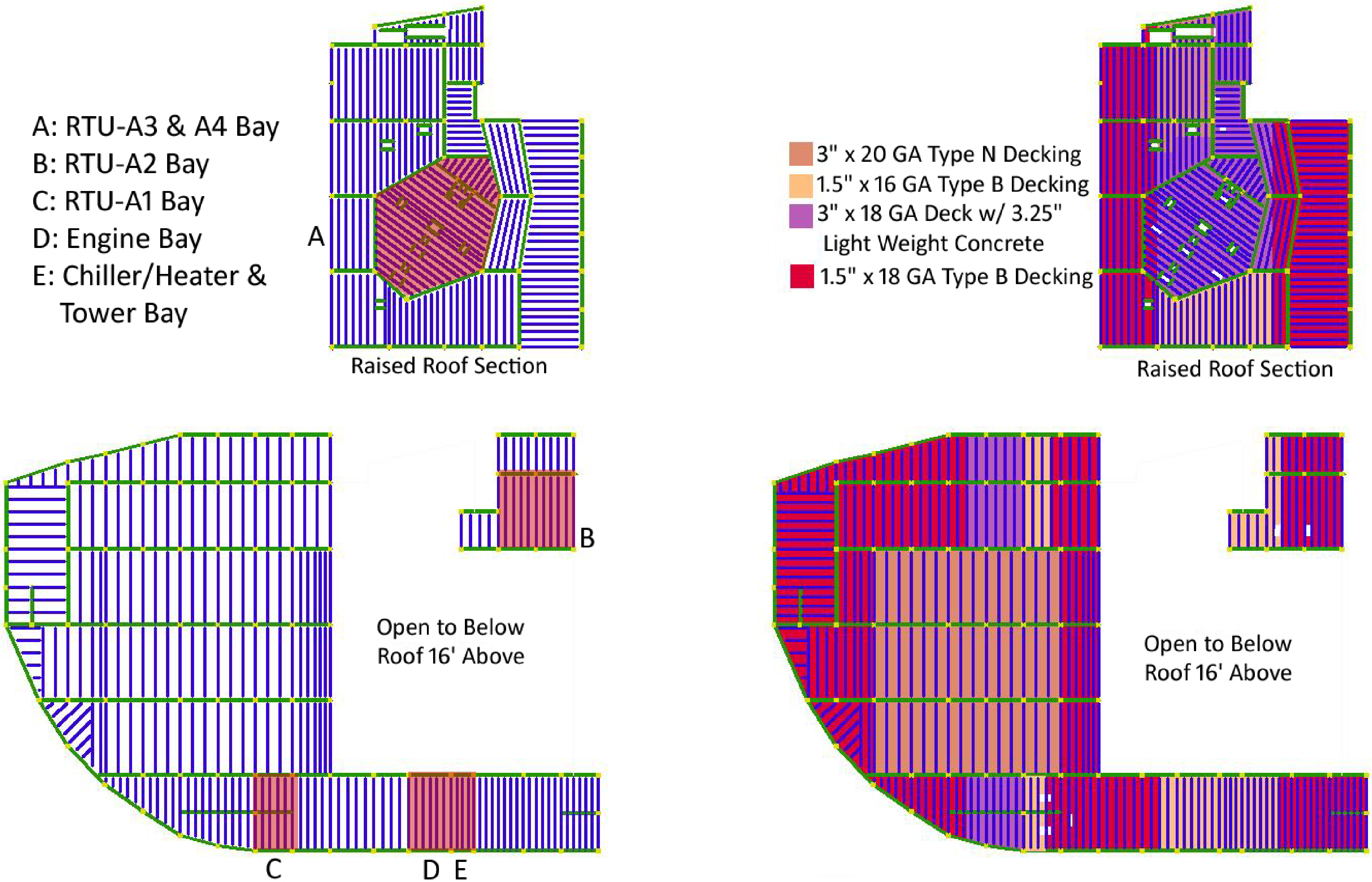


Figure 33: Structural System Layout

Figure 33 on the previous page shows the layout of the structural system on the retail's section roof. In the figure the green lines represent girders while the blue lines represent joists and the yellow boxes represent columns. The majority of the roof is at an elevation of 71 feet, however, the section of roof over the atrium is raised to an elevation of 91 feet. The left side of the figure shows the location of bays affected by the mechanical system redesign in red. Bay A, on the raised section of the roof, will support rooftop unit A3 and A4, Bay B will support rooftop unit A2, Bay C will support rooftop unit A1, Bay D will support the Jenbacher Engine, and Bay E will support both the absorption chiller/heater and cooling tower. The right side of the figure shows the varying types of decking on the roof. The majority of the roof is covered with just a roofing membrane, however, some spots have been covered with 3" of lightweight concrete.

In order to evaluate the mechanical system redesign impact on the structural system RAM Structural System software was used. In order to simplify the structural calculations only the affected bays were created in the RAM model. Based on the structural drawings used for construction all proper dimensions and existing loads were used. Based on the existing structural calculations, a live load of 25 pounds per square foot (psf) to compensate for snow was used, and a dead load of 30 psf was used on the areas of roofing that are free of lightweight concrete. The dead load for the areas of concrete have a dead load comprised of 48 psf for the concrete slab and a superimposed load of 22 psf to create a total dead load of 70 psf. The equipment loads were placed in the proper location in the bay, and point loads were modeled to simulate the equipment loads. The representation of the structural calculations and the RAM member sizing output can be found in Appendix E of this report. Figure 34 below shows a sample of a structural bay model in the RAM Structural System software.

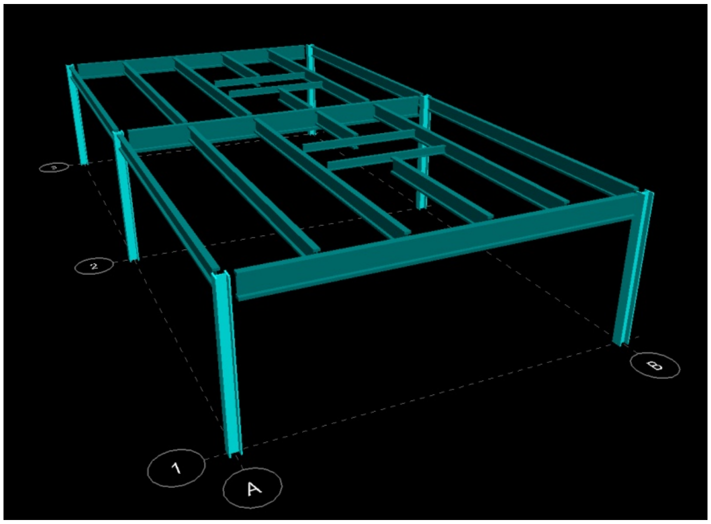


Figure 34: Example of Structural Bay Model

With the existing dead loads, live loads, and new equipment loads the new structural members were sized. In general all the members were sized to eliminate any cambers. However, if the existing structural member was designed with a camber, the redesigned member was designed with the same length of camber. This was done in an attempt to keep the redesigned system as close as possible to the existing. The largest change between the existing system and redesigned system comes with the replacement of size 36LH12 joists in the structural bay where the engine will reside. Due to the increase in gravity loads and vibrations the engine will introduce into the system the joists were replaced with wide flanged members. This bay's deck was also changed from just a roofing membrane to a heavier construction using 3.5" of concrete. In addition to the composite system, the engine will reside on a housekeeping pad and will be placed on an inertia base as specified by General Electric.

With the new members sized a cost comparison between the existing and redesigned systems can be determined. For the structural members of W36 or lower and for the 36LH12 joists R.S. Means was used to estimate the total cost per linear foot. However, R.S. Means does not provide pricing information for wide flange members over the size of W36. A price of $3,500 per ton or $1.75 per pound of steel was used to price the remaining members. The results are shown in Table 7 on the next page. The results show that the existing structural bays will cost approximately $508,556 and the redesigned bays will cost $638,177. The total increase of cost to reinforce the structural system then comes to approximately $130,000. While the mechanical system redesign provides much lower annual costs and lower annual emissions, the initial cost is approximately $7,433,000 more than the existing mechanical system as discussed in the previous section of this report. With the addition of the structural reinforcement the total initial cost comes to $7,563,000 more than the existing system. This additional cost plus the cost of the additional electrical work will be factored into the overall feasibility of the system redesign.

Table 7: Structural System Take Off and Cost Comparison

Existing				Redesign			
Member	Length (ft)	Cost ($/foot)	Total Cost	Member	Length (ft)	Cost ($/foot)	Total Cost
W8X10	42	23	$966	W8X10	42	23	$966
W10X12	83	25.5	$2,117	W12X14	198	25	$4,950
W12X14	198	25	$4,950	W12X16	34	27.8	$945
W12X16	34	27.8	$945	W12X19	21	31.9	$670
W12X19	21	31.9	$670	W14X22	105	40.5	$4,253
W14X22	153	40.5	$6,197	W16X26	248	40.5	$10,044
W16X26	365	40.5	$14,783	W16X31	161	48	$7,728
W16X31	60	48	$2,880	W18X35	55	54.5	$2,998
W18X35	52	54.5	$2,834	W21X44	94	66	$6,204
W18X40	37	61	$2,257	W24X55	60	80	$4,800
W21X44	59	66	$3,894	W24X62	90	89.5	$8,055
W24X55	176	80	$14,080	W24X76	52	108	$5,616
W24X68	90	97.5	$8,775	W27X84	172	119	$20,468
W24X76	608	108	$65,664	W30X90	67	139	$9,313
W24X103	60	145	$8,700	W30X108	120	151	$18,120
W27x84	156	119	$18,564	W33X118	873	164	$143,172
W30X99	244	139	$33,916	W33X130	120	164	$19,680
W36X130	60	185	$11,100	W36X135	226	187	$42,262
W36X130	60	187	$11,220	W40X149	162	260.75	$42,242
W36X130	60	233	$13,980	W40X167	90	292.25	$26,303
W40X149	97	260.8	$25,293	W40X183	152	320.25	$48,678
W40X167	60	292.3	$17,535	W40X211	64	369.25	$23,632
W40X183	197	320.3	$63,089	W40X215	159	376.25	$59,824
W40X215	162	376.3	$60,953	W40X297	64	519.75	$33,264
W40X324	128	567.0	$72,576	W44X262	205	458.5	$93,993
W44X230	60	402.5	$24,150				
36LH12 SP2	540	30.5	$16,470				
TOTAL:			**$508,556**	**TOTAL:**			**$638,177**

Power Requirements for Mechanical System Redesign

As mentioned previously in the report, the changes to the mechanical system bring large changes to the electrical system. The most obvious change comes through the on-site generation on electricity. Other changes arise due to the use of less electrically driven equipment. Also, since the engine was sized to meet the electrical demand it is extremely important to the success of the system to accurately estimate the building's electrical loads. The building's electrical loads were calculated earlier in the report and can be found in the Building Load Analysis section.

There are three pieces of electrical equipment that are directly impacted by the changes in the mechanical system; they are Switchboards 8 and 26 and Panelboard EHVPAWG. In the existing design Switchboard 8 distributes electricity to Rooftop Unit A1, A3, and A4 in order to provide heating and cooling. Panelboard EHVPAWG supplies the same Rooftop units with the electricity needed for the supply fans. Panelboard EHVPAWG is fed through Swithboard 8 as well. Switchboard 26 distributes electricity to RTU-A2 to provide heating and cooling; however, due to an error in the drawings provided the supply fan in RTU-A2 does not have a power connection. This fan, which has been overlooked, will require an additional 21.3 kilovolt-amps(kVA) of electrical demand which will be addressed in the redesign. Figure 35 illustrates a riser diagram of the existing electrical design.
It should also be noted that both Switchboard 8 and 26 distribute power to sections of the Xanadu complex other than Building A. For this reason the listed demand loads will be higher than those discussed previously in this report.

In order to design the new electrical system the ampacities and voltages of all new equipment were taken from the equipment technical data. The sizing of new equipment, wiring, grounds, and conduits was based on equations and tables in the National Electrical Code (NEC) Handbook. When sizing wires in the redesign, copper or aluminum was used in the same situations as the existing system. As prescribed by the NEC Handbook, proper factors for continuous loads, number of current carrying conductors in a conduit, and ambient temperature were used where applicable. The results of the redesign are illustrated in Figure 36, which illustrates the redesign riser diagram. In order to power the new equipment a new panelboard has been installed, this panelboard will be fed by Switchboard 8. Overall the new equipment reduces the overall electrical demand by 354 kVA. It should be noted that a reduction between 300 kVA and 400 kVA depending on the time of year was found through the use of TRACE and the BCHP Screening Tool. This verifies that the electrical demand profiles used to design the engine were accurate. The overall equipment, conductor, and conduit take-off with prices can be found in Tables 8 and 9 for both the existing and redesigned systems.

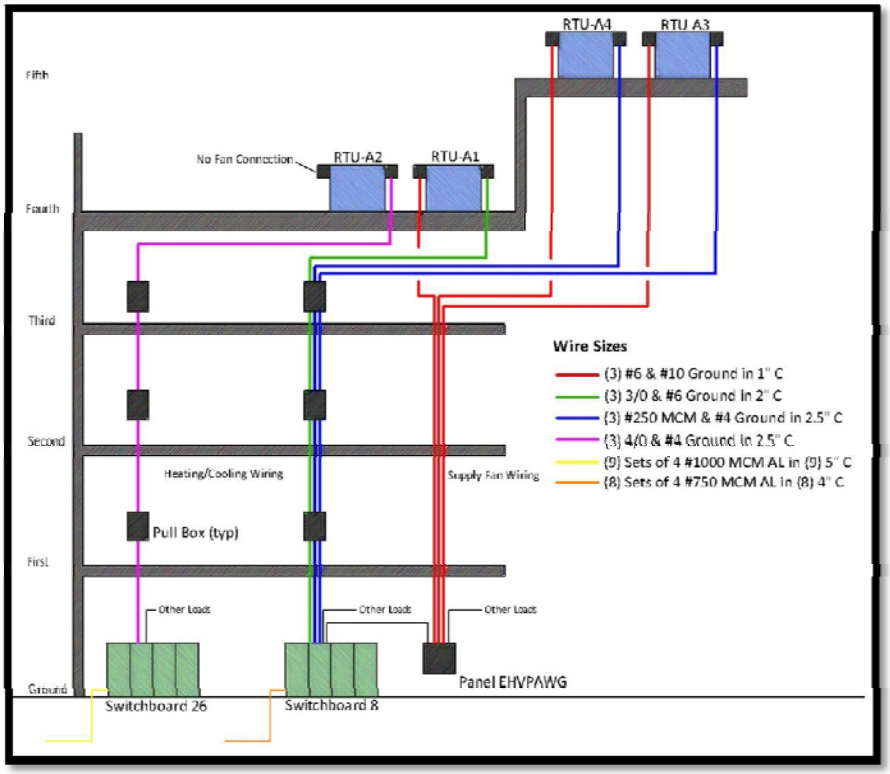


Figure 35: Existing Electrical System

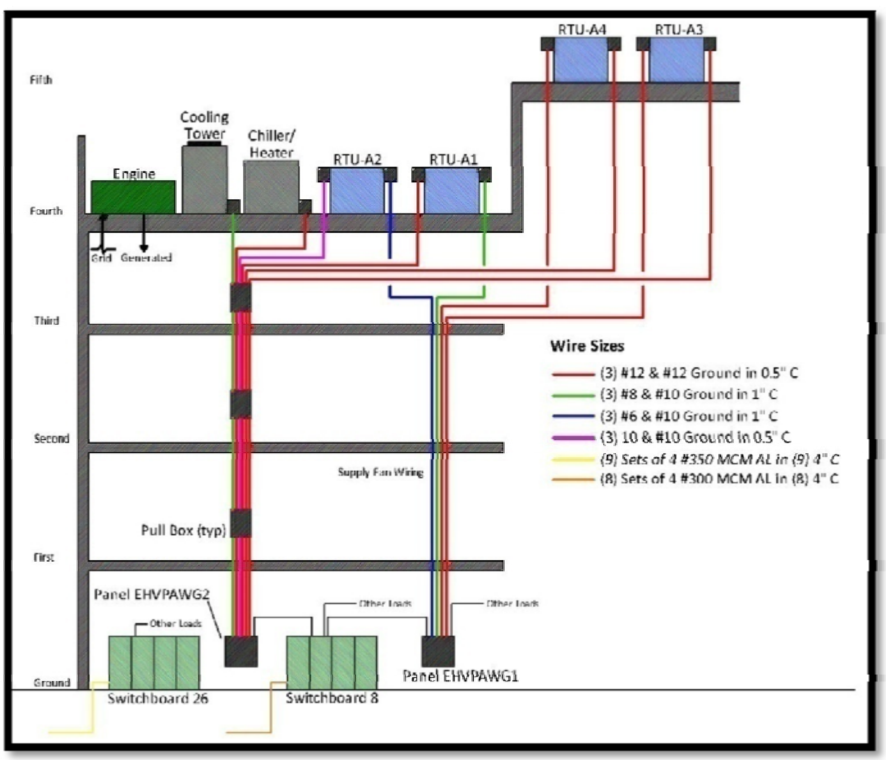


Figure 36: Redesign Electrical System

Table 8: Existing Electrical Cost to Change

Equipment Served	Wire Size	Length (ft)	Price/ 100 ft Conductor	Conduit	Total Cost
RTU-A1 Supply Fan	(3) #6 & #10 G in 1"C	167	$152	12.4	$782
RTU-A1 DX	(3) #3/0 & #6 G in 2"C	179	$620	20.5	$3,366
RTU-A2 Supply Fan	(3) #6 & #10 G in 1"C	127	$152	12.4	$595
RTU-A2 DX	(3) #4/0 & #4 G in 2.5"C	71	$755	31.5	$1,631
RTU-A3 Supply Fan	(3) #6 & #10 G in 1"C	291	$152	12.4	$1,363
RTU-A3 DX	(3) #250 MCM & #4 G in 2.5"C	303	$895	31.5	$8,231
RTU-A4 Supply Fan	(3) #6 & #10 G in 1"C	248	$152	12.4	$1,162
RTU-A4 DX	(3) #250 MCM & #4 G in 2.5"C	260	$895	31.5	$7,063
Switchboard 26	(9) Sets of 4 #1000 MCM AL in (9) 5" C	126	$958	61.2	$43,532
Switchboard 8	(8) Sets of 4 #750 MCM AL in (9) 4" C	121	$815	54.5	$31,623
Emergency Gen	(3) #3/0 & #1/0 G in 5" C	405	$620	61.2	$7,781
Emergency Gen	(3) #3/0 & #1/0 G in 5" C	202	$620	61.2	$3,881
Emergency Gen	(3) #3/0 & #1/0 G in 5" C	430	$620	61.2	$8,261
					$119,270

Equipment	Size (Amps)	Total Cost
Switchboard S8	3000	$8,875
Switchboard S26	4000	$12,200

TOTAL COST:	**$140,345**

From Tables 8 and 9 it can be determined that a total savings of $79,591 is obtained through the electrical system changes. This is due to the reduction of electrically driven equipment. A direct benefit of the reduction of electrically driven equipment is the reduction of copper and aluminum in conductors and the reduction of the switchboard sizes. The savings produced from the electrical system redesign will be factored into the overall feasibility determination of the redesigned system in the Final Conclusions and Recommendation section of this report.

Table 9: Redesign Electrical Cost Changed

Equipment Served	Current (Amps)	Wire Size	Length (ft)	Price/ 100 ft Conductor	Price/ 100 ft Conduit	Total Cost
RTU-A1 Supply Fan	35	(3) #8 & #10 G in 1"C	167	113	12.4	$587
RTU-A1 Exhaust Fan	14	(3) #12 & #12 G in 0.5"C	172	67	8.6	$361
RTU-A2 Supply Fan	45	(3) #6 & #10 G in 1"C	127	152	12.4	$595
RTU-A2 Exhaust Fan	22	(3) #12 & #12 G in 0.5"C	132	67	8.6	$277
RTU-A3 Supply Fan	15	(3) #12 & #12 G in 0.5"C	291	67	8.6	$610
RTU-A3 Exhaust Fan	8	(3) #12 & #12 G in 0.5"C	296	67	8.6	$620
RTU-A4 Supply Fan	15	(3) #12 & #12 G in 0.5"C	248	67	8.6	$520
RTU-A4 Exhaust Fan	8	(3) #12 & #12 G in 0.5"C	253	67	8.6	$530
Switchboard 26	1819	(9) Sets of 4 #350 MCM AL in (9) 4" C	126	465	54.5	$21,161
Switchboard 8	1772.5	(8) Sets of 4 #300 MCM AL in (9) 4" C	121	445	54.5	$17,296
Chiller/Heater	11	(3) #12 & #12 G in 0.5"C	111	67	8.6	$233
Cooling Tower	40	(3) #8 & #10 G in 1"C	118	113	12.4	$415
						$43,204

Equipment	Size (Amps)	Total Cost
Switchboard S8	2500	$7,500
Switchboard S26	2500	$7,500
Panelboard EHVPAWG2	85.5	$2,550

TOTAL COST: $60,754

Final Conclusions and Recommendations

The criteria of the mechanical system redesign explored the possibilities of taking a liability and creating an asset for all parties involved as well as the local community. The existing Xanadu Sports Complex design has been subjected to multiple lawsuits, concerns on the environmental impact voiced by the local community, long delays, financial uncertainties, and a large increase in the budget, thus presenting a large liability.

The redesign focused on alleviating some of the issues presented in court, specifically the lawsuit filed by four environmental advocacy groups. The best way to reduce the environmental impact was through the use of landfill gas to generate electricity on-site. The atypical electrical on-peak and off-peak electrical demands produced through the combination of the retail space and indoor ski resort provided ideal conditions for 24 hour on-site continuous production. While the initial cost of the mechanical system, structural redesign, and electrical redesign was an additional $7.5 million, the annual savings achieved through the use of landfill gas provides a payback period just under 7 years. Not only will the owner save more than $15 million over a 20 year span, but also they could possibly have avoided the environmental advocacy groups' lawsuit and avoided some of the $700 million increase in construction time due to work stoppages.

While this redesign is an economical win for the owner both initially and annually, there are other assets created due to the redesign. The negative publicity created by the very public lawsuit could have been avoided, and people's opinions about the project would have been positive rather than negative. The existing design had people in the area questioning the reasoning of an indoor ski resort with the currently soaring energy prices. However, the redesign creates a positive story by using a naturally occurring untapped resource, landfill gas, and creates a positive public relationship. Instead of questioning the project, potential guests of the complex might hear the story and feel intrigued. This feeling of intrigue will bring more guests to the complex once again benefiting the owner.

Aside from the owner the community also is positively affected through the redesign. The use of landfill gas reduces the local pollution created by the landfill and offsets the pollution that would be created by a coal burning power plant. The installation of the landfill gas collection system creates more local jobs, overall stimulating the local economy. The success of this initial project could spawn similar projects in the future while drastically decreasing the pollution and creating jobs for years to come.

These benefits truly present a unique opportunity to turn a large liability into an asset for all. For these reasons the overall redesign is a large success and is highly beneficial to the owner and the community and creates a blueprint for similar systems to come.

References

An Overview of Landfill Gas Energy in the United States. U.S. Environmental Protection Agency Landfill Methane Outreach Program (LMOP). May 2007. <http://www.epa.gov/landfill/docs/overview.pdf>.

ASHRAE. 2005, 2005 ASHRAE Handbook – Fundamentals. American Society of Heating Refrigeration and Air Conditioning Engineers, Inc., Atlanta, GA. 2001.

ASHRAE. 2004, ANSI/ASHRAE, Standard 90.1 – 2004, Energy Standard for Buildings Except Low-Rise Residential Buildings. American Society of Heating Refrigeration and Air Conditioning Engineers, Inc., Atlanta, GA. 2004.

ASHRAE. 2007, ANSI/ASHRAE, Standard 62.1 – 2007, Ventilation for Acceptable Indoor Air Quality. American Society of Heating Refrigeration and Air Conditioning Engineers, Inc., Atlanta, GA. 2007.

Battles, Stephanie J. and Burns, Eugene M. "Trends in Building-Related Energy and Carbon Emissions: Actual and Alternate Scenarios." The Department of Energy's Energy Information Administration. 21 Aug. 2000. 29 Oct. 2007. <http://www.eia.doe.gov/emeu/ efficiency/aceee2000.html>.

Bechtold, Robert. "Harbec Plastics Takes Control of Energy Costs." Rochester Green Building Network. 9 Nov. 05. 7 Nov. 2007. <http://www.ceinfo.org/rgbn/details.php?CaseStudyID=1>.

"Electric Power Annual 1999, Volume II." The Department of Energy's Energy Information Administration. October 2000. 30 Oct. 2007. <http://www.eia.doe.gov/eneaf/electricity/ epav2/epav2.pdf>.

"How They Work." Yazaki Energy Systems, Inc.. 28 Feb. 2008. <http://www.yazakienergy.com/waterfired.htm>.

"Niagara Waste Systems – Landfill Gas to Energy." Environment Canada. 05 July. 2006. 25 Feb. 2008. <http://www.ec.gc.ca/wmd-dgd/default.asp?lang=En&n=6092B72B-1>.

Riley, David, PhD. AE 597D Sustainable Building Lecture Number 14: Case Study Alveretti. The Pennsylvania State University. University Park, PA. 6 Nov. 2007.

R.S. Means, Mechanical Cost Data, 28th Annual Edition. R.S. Means, Kingston, MA. 2005.

Smothers, Ronald. *New Jersey: Trenton: Suit Over Sports Complex.* New York Times. October 14, 2004.

“Technology Characterization: Microturbines.” The Environmental Protection Agency. Mar. 2002. 6 Nov. 2007. <http://www.epa.gov/CHP/documents/microturbines.pdf>.

“The World Factbook.” Central Intelligence Agency. 18 Oct. 2007. 29 Oct. 2007. <https://www.cia.gov/library/publications/the-world-factbook/print/us.html>.

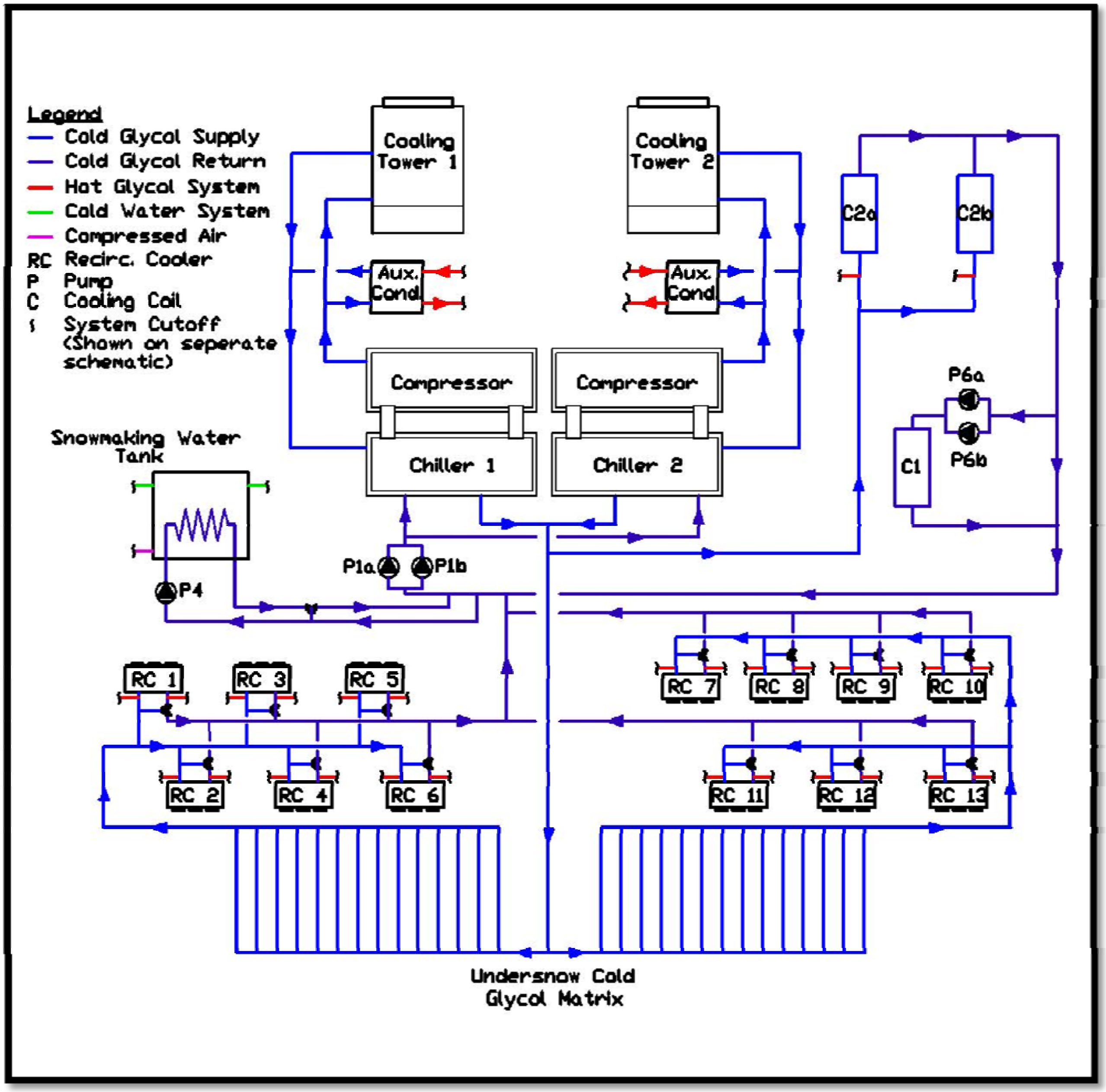
Turner Construction Company. 2007, Mechanical Construction Documents. Turner Construction Company, East Rutherford, NJ. 2007.

Turner Construction Company. 2007, Architectural Construction Documents. Turner Construction Company, East Rutherford, NJ. 2007.

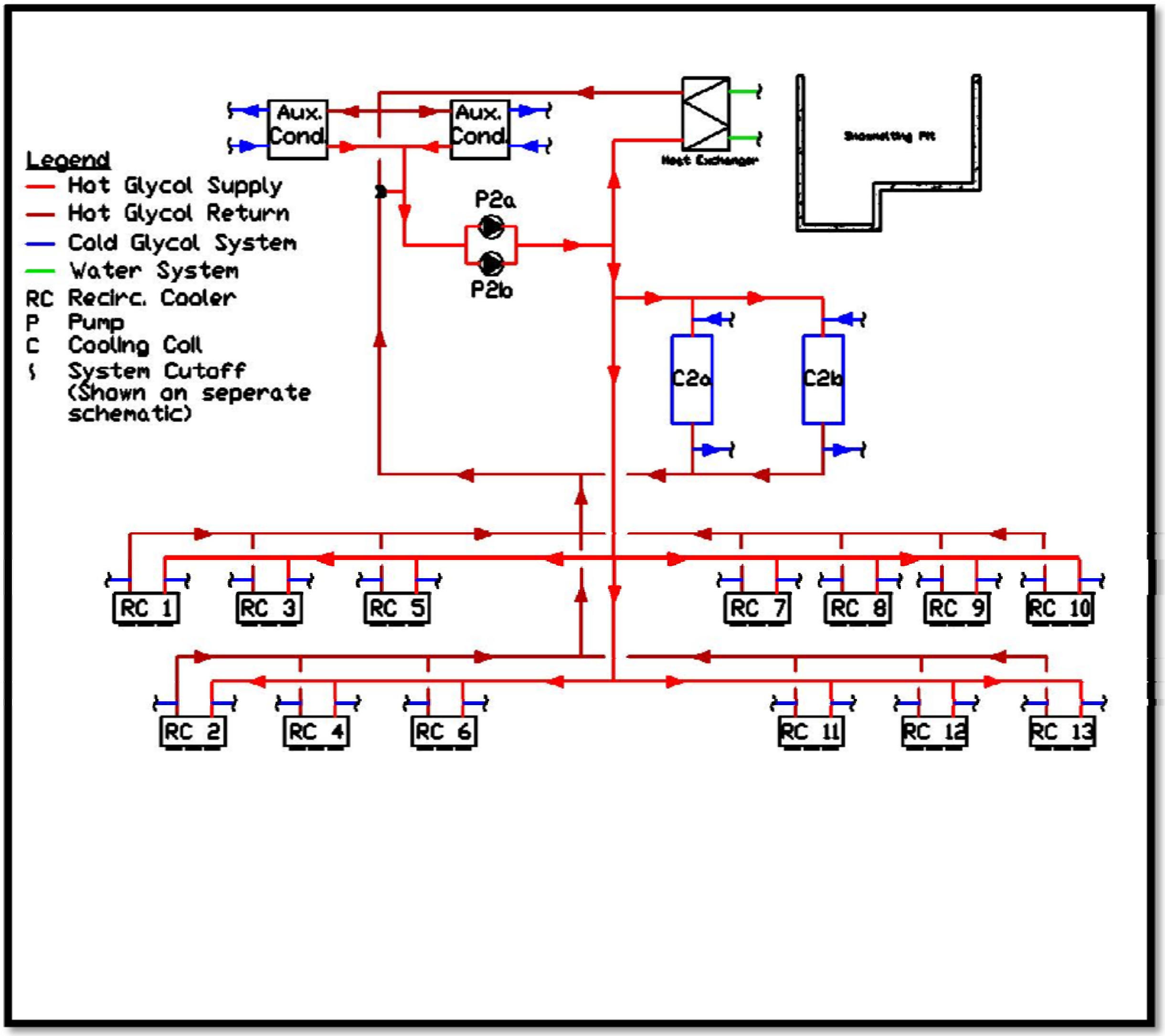
Turner Construction Company. 2007, Electrical Construction Documents. Turner Construction Company, East Rutherford, NJ. 2007.

Appendix A: Existing Systems Schematics

Cold Glycol System



Hot Glycol System



Appendix B: Existing ASHRAE Standard 62.1 Calculations

Naturally Ventilated Space Compliance

Room	Space	ASHRAE 62.1 Area (SF)	ASHRAE 62.1 Natural Ventilation Direct	ASHRAE 62.1 Natural Ventilation In-Direct	ASHRAE 62.1 Required Opening (SF)	Design Case Opening (SF)	Meets Standard?	Notes:
A 005	Atrium Entrance	2,101	-	-	84	0	**No**	1
A 006	Electrical Equip.	470	X		19	1	**No**	2
A 007	Telecom Room	178	-	-	7	0	**No**	
A 008	Electrical Equip.	244	X		10	1	**No**	2
A 009	Electrical Equip.	692	X		28	3	**No**	3
A 010	Telecom Room	327	-	-	13	0	**No**	
A 011	Water Room	294	-	-	12	0	**No**	
A 012	Electrical Equip.	383	-	-	15	9	**No**	3

1. Open to the atrium spaces on the above floors
2. Louver is open to the adjacent loading dock
3. Louver is open to the adjacent parking garage

Assigned Occupancy Categories

Room Type	ASHRAE 62.1 2007 Occupancy Category	People O.A. (cfm / Person)	Area O.A. (cfm / SF)	Occupancy Density (People / 1000 SF)
Stores	Retail Sales	7.5	0.12	15
Walkways	Mall Common Areas	7.5	0.06	40
Utility	Electrical Equipment	0	0.06	0
Exit Passageways	Corridors	0	0.06	0
Janitor Closets	Storage	0	0.12	0
Ski Resort	Gym (Play Area)	0	0.3	30
Sky Diving Sim.	Gym (Play Area)	0	0.3	30
Restaurant	Restaurant	7.5	0.18	70
Night Clubs	Dance Floors	20	0.06	100

Spaces Served by Roof Top Unit 1

		ASHRAE 62.1			Design Case		
Room	Space	Area (SF)	Occupancy Level (People)	Required O.A. (cfm)	Supplied O.A. (cfm)	Meets Standard?	Notes:
A 105	Central Atrium	9,820	393	5892	651	No	
A 106	Electrical Equip.	453	0	45	0	No	1, 2, 3
A 107	Exit Passageway	863	0	86	0	No	1
A 108	Telecom Room	284	0	28	0	No	1
A 205	Central Atrium	5,136	205	3082	753	No	
A 206	Electrical Equip.	466	0	47	0	No	1, 2, 3
A 207	Exit Passageway	1,125	0	113	0	No	1
A 208	Telecom Room	282	0	28	0	No	1

1. There is no direct ventilation to this space
2. Exhaust fan is installed to create negative pressure and draw air from outside the room
3. The space the exhaust air is drawing air from is under-ventilated o not directly ventilated

Spaces Served by Roof Top Unit 2

		ASHRAE 62.1			Design Case		
Room	Space	Area (SF)	Occupancy Level (People)	Required O.A. (cfm)	Supplied O.A. (cfm)	Meets Standard?	Notes:
A 101	Corridor	287	11	172	0	No	1
A 105	Central Atrium	8,695	348	5217	744	No	
A 109	Electrical Equip.	487	0	49	0	No	1, 2, 3
A 110	Electrical Equip.	292	0	29	0	No	1
A 111	Corridor	1,389	0	139	0	No	1
A 112	Storage	75	0	15	0	No	1, 2, 3
A 116	Storage	438	0	88	0	No	1
A 201	Corridor	298	12	179	0	No	
A 205	Central Atrium	9,128	365	5477	753	No	
A 209	Electrical Equip.	422	0	42	0	No	1, 2, 3
A 210	Electrical	236	0	24	0	No	1

	Equip.						
A 211	Corridor	1,187	0	119	0	No	1
A 212	Storage Room	75	0	15	0	No	1, 2, 3

1. There is no direct ventilation to this space
2. Exhaust fan is installed to create negative pressure and draw air from outside the room
3. The space the exhaust air is drawing air from is under-ventilated o not directly ventilated

Spaces Served by Roof Top Unit 3

		ASHRAE 62.1			Design Case		
Room	Space	Area (SF)	Occupancy Level (People)	Required O.A. (cfm)	Supplied O.A. (cfm)	Meets Standard?	Notes:
A 302	Corridor	3,398	0	204	0	No	1
A 305	Central Atrium	3,535	141	1,273	3,039	Yes	
A 309	Electrical Equip.	412	0	25	0	No	1, 2, 3
A 310	Electrical Equip.	237	0	14	0	No	1

1. There is no direct ventilation to this space
2. Exhaust fan is installed to create negative pressure and draw air from outside the room
3. The space the exhaust air is drawing air from is under-ventilated o not directly ventilated

Spaces Served by Roof Top Unit 4

		ASHRAE 62.1			Design Case		
Room	Space	Area (SF)	Occupancy Level (People)	Required O.A. (cfm)	Supplied O.A. (cfm)	Meets Standard?	Notes:
A 305	Central Atrium	6,542	262	2,355	3,038	Yes	
A 306	Electrical Equip.	338	0	20	0	No	1, 2, 3
A 307	Exit Passageway	1,210	0	73	0	No	1
A 308	Electrical Equip.	284	0	17	0	No	1

1. There is no direct ventilation to this space
2. Exhaust fan is installed to create negative pressure and draw air from outside the room
3. The space the exhaust air is drawing air from is under-ventilated o not directly ventilated

Snowdome AHU

		ASHRAE 62.1			Design Case		
Room	Space	Area (SF)	Occupancy Level (People)	Required O.A. (cfm)	Supplied O.A. (cfm)	Meets Standard?	Notes:

Snowdome	Snowdome	160,000	999	48,000	15,000	**No**	1, 2

1. Peak load will occur during special events housed within the Snowdome
2. Occupany level is known for special events, no assumptions where made

Exhaust Rate Compliance

		ASHRAE 62.1					Design Case	
Room	**Space**	**Area (SF)**	**Exhaust Rate (cfm/SF)**	**Exhaust Rate (cfm/unit)**	**Units**	**Required Exhaust (cfm)**	**Exhaust (cfm)**	**Meets Standard?**
A 112	Janitors Closet	75	1	-		75	100	**Yes**
A 113	Womens Room	488	-	70	11	770	800	**Yes**
A 114	Mens Room	483	-	70	8	560	950	**Yes**
A 212	Janitors Closet	75	1	-		75	100	**Yes**
A 213	Womens Room	475	-	70	11	770	800	**Yes**
A214	Mens Room	498	-	70	8	560	950	**Yes**

Appendix C: Ventilation System Redesign Take Off

RTU-1 Supply Air														
Supply Air Duct										Supply Duct Insulation			Overall Total
Dimension* (in x in)			L (ft)	2-S (in)	W/ L** (lb / ft)	Weight (lb)	Total w/ O&P Cost ($ / lb)	Sub-Total	Corrected Total	Area (SF)	Total w/ O&P Cost ($ / SF)	Total	
Second Floor													
35	x	30	19	65	16.3	309.7	13.3	$4,119	$18,536	206	3.54	$729	**$19,264**
30	x	20	5	50	10.7	53.5	14.2	$760	$3,419	42	3.54	$148	**$3,566**
30	x	9	31	39	8.4	260.4	13.3	$3,463	$15,585	202	3.54	$713	**$16,298**
30	x	5	10	35	7.5	75	14.2	$1,065	$4,793	58	3.54	$207	**$4,999**
20	x	8	14	28	6	84	14.2	$1,193	$5,368	65	3.54	$231	**$5,599**
20	x	7	20	27	5.8	116	14.2	$1,647	$7,412	90	3.54	$319	**$7,731**
6	x	4	10	10	2.2	22	14.2	$312	$1,406	17	3.54	$59	**$1,465**
6	x	4	11	10	2.2	24.2	14.2	$344	$1,546	18	3.54	$65	**$1,611**
6	x	4	12	10	2.2	26.4	14.2	$375	$1,687	20	3.54	$71	**$1,758**
30	x	16	36	46	9.9	356.4	13.3	$4,740	$21,331	276	3.54	$977	**$22,308**
20	x	6	26	26	5.6	145.6	14.2	$2,068	$9,304	113	3.54	$399	**$9,703**
30	x	12	6	42	9	54	14.2	$767	$3,451	42	3.54	$149	**$3,599**
30	x	10	31	40	8.6	266.6	13.3	$3,546	$15,956	207	3.54	$732	**$16,688**
30	x	8	33	38	8.2	270.6	13.3	$3,599	$16,195	209	3.54	$740	**$16,935**
30	x	6	39	36	7.8	304.2	13.3	$4,046	$18,206	234	3.54	$828	**$19,035**
20	x	6	39	26	5.6	218.4	13.3	$2,905	$13,071	169	3.54	$598	**$13,670**
First Floor													
25	x	25	17	50	10.7	181.9	14.2	$2,583	$11,623	142	3.54	$502	**$12,125**
30	x	9	31	39	8.4	260.4	13.3	$3,463	$15,585	202	3.54	$713	**$16,298**
30	x	5	10	35	7.5	75	14.2	$1,065	$4,793	58	3.54	$207	**$4,999**

20	x	8	14	28	6	84	14.2	$1,193	$5,368	65	3.54	$231	**$5,599**
20	x	7	20	27	5.8	116	14.2	$1,647	$7,412	90	3.54	$319	**$7,731**
6	x	4	10	10	2.2	22	14.2	$312	$1,406	17	3.54	$59	**$1,465**
6	x	4	11	10	2.2	24.2	14.2	$344	$1,546	18	3.54	$65	**$1,611**
6	x	4	12	10	2.2	26.4	14.2	$375	$1,687	20	3.54	$71	**$1,758**
30	x	20	38	50	10.7	406.6	13.3	$5,408	$24,335	317	3.54	$1,121	**$25,456**
30	x	16	23	46	9.9	227.7	13.3	$3,028	$13,628	176	3.54	$624	**$14,252**
30	x	8	21	38	8.2	172.2	14.2	$2,445	$11,004	133	3.54	$471	**$11,474**
30	x	6	41	36	7.8	319.8	13.3	$4,253	$19,140	246	3.54	$871	**$20,011**
20	x	6	31	26	5.6	173.6	14.2	$2,465	$11,093	134	3.54	$476	**$11,569**
30	x	9	33	39	8.4	277.2	13.3	$3,687	$16,590	215	3.54	$759	**$17,350**
30	x	7	33	37	8	264	13.3	$3,511	$15,800	204	3.54	$720	**$16,521**
20	x	6	24	26	5.6	134.4	14.2	$1,908	$8,588	104	3.54	$368	**$8,956**
Ground Floor													
30	x	12	17	42	9	153	14.2	$2,173	$9,777	119	3.54	$421	**$10,198**
30	x	6	25	36	7.8	195	14.2	$2,769	$12,461	150	3.54	$531	**$12,992**
30	x	6	6	36	7.8	46.8	14.2	$665	$2,991	36	3.54	$127	**$3,118**
10	x	8	3	18	3.9	11.7	14.2	$166	$748	9	3.54	$32	**$779**
10	x	8	11	18	3.9	42.9	14.2	$609	$2,741	33	3.54	$117	**$2,858**
10	x	8	11	18	3.9	42.9	14.2	$609	$2,741	33	3.54	$117	**$2,858**
20	x	14	21	34	7.3	153.3	14.2	$2,177	$9,796	119	3.54	$421	**$10,217**
20	x	14	27	34	7.3	197.1	14.2	$2,799	$12,595	153	3.54	$542	**$13,136**
20	x	7	21	27	5.8	121.8	14.2	$1,730	$7,783	95	3.54	$335	**$8,118**
20	x	7	26	27	5.8	150.8	14.2	$2,141	$9,636	117	3.54	$414	**$10,050**
						6,468			$398,131			$17,596	**$415,727**

* All supply air ductwork sized for 0.08 inches per 100 ft. of static pressure

** RS Means Reference Table 233100-40 includes allowance for scrap in the figures listed

***RS Means Stainless Steel used and assume 25% fittings

RTU-1 Return Air														
Return Air Duct										Return Duct Insulation			Overall Total
Dimension* (in x in)			Length (ft)	2-S (in)	W/L** (lb / ft)	Weight (lb)	Total w/ O&P Cost ($ / lb)	Sub-Total	Corrected Total	Area (SF)	Total w/ O&P Cost ($ / SF)	Total	
Second Floor													
20	x	6	46	26	5.6	257.6	7.05	$1,816	$8,172	199	3.54	$706	**$8,878**
20	x	12	44	32	6.9	303.6	7.05	$2,140	$9,632	235	3.54	$831	**$10,462**
20	x	12	38	32	6.9	262.2	7.05	$1,849	$8,318	203	3.54	$717	**$9,036**
30	x	14	18	44	9.5	171	7.3	$1,248	$5,617	132	3.54	$467	**$6,085**
30	x	14	8	44	9.5	76	7.3	$555	$2,497	59	3.54	$208	**$2,704**
20	x	10	50	30	6.5	325	7.05	$2,291	$10,311	250	3.54	$885	**$11,196**
30	x	16	23	46	9.9	227.7	7.05	$1,605	$7,224	176	3.54	$624	**$7,848**
9	x	5	15	14	3	45	7.3	$329	$1,478	35	3.54	$124	**$1,602**
20	x	8	9	28	6	54	7.3	$394	$1,774	42	3.54	$149	**$1,923**
20	x	9	16	29	6.2	99.2	7.3	$724	$3,259	77	3.54	$274	**$3,532**
30	x	8	9	38	8.2	73.8	7.3	$539	$2,424	57	3.54	$202	**$2,626**
30	x	9	76	39	8.4	638.4	7.05	$4,501	$20,253	494	3.54	$1,749	**$22,002**
30	x	40	17	70	17.5	297.5	7.05	$2,097	$9,438	198	3.54	$702	**$10,140**
First Floor													
9	x	5	15	14	3	45	7.3	$329	$1,478	35	3.54	$124	**$1,602**
20	x	8	9	28	6	54	7.3	$394	$1,774	42	3.54	$149	**$1,923**
20	x	9	16	29	6.2	99.2	7.3	$724	$3,259	77	3.54	$274	**$3,532**
20	x	8	9	28	6	54	7.3	$394	$1,774	42	3.54	$149	**$1,923**
30	x	9	16	39	8.4	134.4	7.3	$981	$4,415	104	3.54	$368	**$4,783**
30	x	25	17	55	11.8	200.6	7.05	$1,414	$6,364	156	3.54	$552	**$6,916**
30	x	8	32	38	8.2	262.4	7.05	$1,850	$8,325	203	3.54	$717	**$9,042**

30	x	8	60	38	8.2	492	7.05	$3,469	$15,609	380	3.54	$1,345	**$16,954**
30	x	12	35	42	9	315	7.05	$2,221	$9,993	245	3.54	$867	**$10,861**
30	x	8	32	38	8.2	262.4	7.05	$1,850	$8,325	203	3.54	$717	**$9,042**
30	x	18	28	48	10.3	288.4	7.05	$2,033	$9,149	224	3.54	$793	**$9,942**
30	x	18	27	48	10.3	278.1	7.05	$1,961	$8,823	216	3.54	$765	**$9,587**
30	x	8	10	38	8.2	82	7.3	$599	$2,694	63	3.54	$224	**$2,918**
30	x	20	10	50	10.7	107	7.3	$781	$3,515	83	3.54	$295	**$3,810**
Ground Floor													
15	x	6	15	21	4.5	67.5	7.3	$493	$2,217	53	3.54	$186	**$2,403**
15	x	6	15	21	4.5	67.5	7.3	$493	$2,217	53	3.54	$186	**$2,403**
20	x	8	8	28	6	48	7.3	$350	$1,577	37	3.54	$132	**$1,709**
20	x	12	17	32	6.9	117.3	7.3	$856	$3,853	91	3.54	$321	**$4,174**
20	x	9	30	29	6.2	186	7.3	$1,358	$6,110	145	3.54	$513	**$6,623**
30	x	10	22	40	8.6	189.2	7.3	$1,381	$6,215	147	3.54	$519	**$6,734**
30	x	10	25	40	8.6	215	7.05	$1,516	$6,821	167	3.54	$590	**$7,411**
20	x	20	17	40	8.6	146.2	7.3	$1,067	$4,803	113	3.54	$401	**$5,204**
						6,542			$209,707			$17,824	**$227,532**

* All return air ductwork sized for 0.06 inches per 100 ft. of static pressure

** RS Means Reference Table 233100-40 includes allowance for scrap in the figures listed

***RS Means Stainless Steel used and assume 25% fittings

RTU-2 Supply Air													
Supply Air Duct										Supply Duct Insulation			Overall
Dimension* (in x in)			L (ft)	2-S (in)	W/ L** (lb / ft)	Weight (lb)	Total w/ O&P Cost ($ / lb)	Sub-Total	Corrected Total	Area (SF)	Total w/ O&P Cost ($ / SF)	Total	Total
Second Floor													
40	x	30	19	70	17.5	332.5	13.3	$4,422	$19,900	222	3.54	$785	**$20,685**
20	x	12	4	32	6.9	27.6	14.2	$392	$1,764	21	3.54	$76	**$1,839**
20	x	12	30	32	6.9	207	13.3	$2,753	$12,389	160	3.54	$566	**$12,955**
20	x	12	15	32	6.9	103.5	14.2	$1,470	$6,614	80	3.54	$283	**$6,897**
20	x	7	8	27	5.8	46.4	14.2	$659	$2,965	36	3.54	$127	**$3,092**
15	x	5	8	20	4.3	34.4	14.2	$488	$2,198	27	3.54	$94	**$2,293**
20	x	8	14	28	6	84	14.2	$1,193	$5,368	65	3.54	$231	**$5,599**
20	x	7	8	27	5.8	46.4	14.2	$659	$2,965	36	3.54	$127	**$3,092**
15	x	5	8	20	4.3	34.4	14.2	$488	$2,198	27	3.54	$94	**$2,293**
6	x	5	30	11	2.4	72	14.2	$1,022	$4,601	55	3.54	$195	**$4,796**
30	x	16	40	46	9.9	396	13.3	$5,267	$23,701	307	3.54	$1,086	**$24,786**
30	x	16	76	46	9.9	752.4	13.3	$10,007	$45,031	583	3.54	$2,063	**$47,094**
30	x	16	14	46	9.9	138.6	14.2	$1,968	$8,857	107	3.54	$380	**$9,237**
30	x	8	54	38	8.2	442.8	13.3	$5,889	$26,502	342	3.54	$1,211	**$27,712**
30	x	6	33	36	7.8	257.4	13.3	$3,423	$15,405	198	3.54	$701	**$16,106**
30	x	6	10	36	7.8	78	14.2	$1,108	$4,984	60	3.54	$212	**$5,197**
20	x	6	28	26	5.6	156.8	14.2	$2,227	$10,020	121	3.54	$430	**$10,449**
10	x	5	28	15	3.2	89.6	14.2	$1,272	$5,725	70	3.54	$248	**$5,973**
20	x	16	41	36	7.8	319.8	13.3	$4,253	$19,140	246	3.54	$871	**$20,011**
20	x	16	9	36	7.8	70.2	14.2	$997	$4,486	54	3.54	$191	**$4,677**
20	x	12	41	32	6.9	282.9	13.3	$3,763	$16,932	219	3.54	$774	**$17,706**
20	x	6	19	26	5.6	106.4	14.2	$1,511	$6,799	82	3.54	$291	**$7,090**
20	x	9	28	29	6.2	173.6	14.2	$2,465	$11,093	135	3.54	$479	**$11,572**

20	x	6	43	26	5.6	240.8	13.3	$3,203	$14,412	186	3.54	$660	**$15,072**
First Floor													
30	x	25	17	55	11.8	200.6	13.3	$2,668	$12,006	156	3.54	$552	**$12,558**
30	x	12	12	42	9	108	14.2	$1,534	$6,901	84	3.54	$297	**$7,199**
30	x	12	17	42	9	153	14.2	$2,173	$9,777	119	3.54	$421	**$10,198**
20	x	7	12	27	5.8	69.6	14.2	$988	$4,447	54	3.54	$191	**$4,639**
15	x	6	17	21	4.5	76.5	14.2	$1,086	$4,888	60	3.54	$211	**$5,099**
20	x	14	5	34	7.3	36.5	14.2	$518	$2,332	28	3.54	$100	**$2,433**
20	x	12	6	32	6.9	41.4	14.2	$588	$2,645	32	3.54	$113	**$2,759**
10	x	8	11	18	3.9	42.9	14.2	$609	$2,741	33	3.54	$117	**$2,858**
20	x	7	15	27	5.8	87	14.2	$1,235	$5,559	68	3.54	$239	**$5,798**
10	x	8	11	18	3.9	42.9	14.2	$609	$2,741	33	3.54	$117	**$2,858**
10	x	6	12	16	3.4	40.8	14.2	$579	$2,607	32	3.54	$113	**$2,720**
8	x	4	50	12	2.6	130	14.2	$1,846	$8,307	100	3.54	$354	**$8,661**
30	x	18	65	48	10.3	669.5	13.3	$8,904	$40,070	520	3.54	$1,841	**$41,910**
30	x	7	18	37	8	144	14.2	$2,045	$9,202	111	3.54	$393	**$9,595**
10	x	5	15	15	3.2	48	14.2	$682	$3,067	38	3.54	$133	**$3,200**
30	x	7	29	37	8	232	13.3	$3,086	$13,885	179	3.54	$633	**$14,518**
15	x	6	15	21	4.5	67.5	14.2	$959	$4,313	53	3.54	$186	**$4,499**
30	x	5	18	35	7.5	135	14.2	$1,917	$8,627	105	3.54	$372	**$8,998**
15	x	6	32	21	4.5	144	14.2	$2,045	$9,202	112	3.54	$396	**$9,598**
30	x	16	103	46	9.9	1019.7	13.3	$13,562	$61,029	790	3.54	$2,795	**$63,824**
30	x	16	10	46	9.9	99	14.2	$1,406	$6,326	77	3.54	$271	**$6,598**
20	x	6	32	26	5.6	179.2	14.2	$2,545	$11,451	139	3.54	$491	**$11,942**
30	x	12	30	42	9	270	13.3	$3,591	$16,160	210	3.54	$743	**$16,903**
30	x	9	20	39	8.4	168	14.2	$2,386	$10,735	130	3.54	$460	**$11,195**
30	x	7	20	37	8	160	14.2	$2,272	$10,224	123	3.54	$437	**$10,661**
20	x	6	31	26	5.6	173.6	14.2	$2,465	$11,093	134	3.54	$476	**$11,569**
						9,032			$554,383			$24,628	**$579,011**

* All supply air ductwork sized for 0.08 inches per 100 ft. of static pressure
** RS Means Reference Table 233100-40 includes allowance for scrap in the figures listed
***RS Means Stainless Steel used and assume 25% fittings

RTU-2 Return Air														
Return Air Duct										Return Duct Insulation			Overall Total
Dimension* (in x in)			L (ft)	2-S (in)	W/ L** (lb / ft)	Weight (lb)	Total w/ O&P Cost ($ / lb)	Sub-Total	Corrected Total	Area (SF)	Total w/ O&P Cost ($ / SF)	Total	
Second Floor													
20	x	6	43	26	5.6	240.8	7.05	$1,698	$7,639	186	3.54	$660	**$8,299**
20	x	10	16	30	6.5	104	7.3	$759	$3,416	80	3.54	$283	**$3,700**
20	x	14	100	34	7.3	730	7.05	$5,147	$23,159	567	3.54	$2,006	**$25,165**
20	x	10	11	30	6.5	71.5	7.3	$522	$2,349	55	3.54	$195	**$2,543**
20	x	18	42	38	8.2	344.4	7.05	$2,428	$10,926	266	3.54	$942	**$11,868**
20	x	8	63	28	6	378	7.05	$2,665	$11,992	294	3.54	$1,041	**$13,033**
30	x	16	7	46	9.9	69.3	7.3	$506	$2,277	54	3.54	$190	**$2,466**
30	x	16	37	46	9.9	366.3	7.05	$2,582	$11,621	284	3.54	$1,004	**$12,625**
10	x	6	24	16	3.4	81.6	7.3	$596	$2,681	64	3.54	$227	**$2,907**
20	x	14	27	34	7.3	197.1	7.3	$1,439	$6,475	153	3.54	$542	**$7,016**
First Floor													
20	x	12	20	32	6.9	138	7.3	$1,007	$4,533	107	3.54	$378	**$4,911**
20	x	12	27	32	6.9	186.3	7.3	$1,360	$6,120	144	3.54	$510	**$6,630**
20	x	18	58	38	8.2	475.6	7.05	$3,353	$15,088	367	3.54	$1,300	**$16,389**
20	x	12	16	32	6.9	110.4	7.3	$806	$3,627	85	3.54	$302	**$3,929**
30	x	16	48	46	9.9	475.2	7.05	$3,350	$15,076	368	3.54	$1,303	**$16,378**
20	x	12	40	32	6.9	276	7.05	$1,946	$8,756	213	3.54	$755	**$9,511**
30	x	20	35	50	10.7	374.5	7.05	$2,640	$11,881	292	3.54	$1,033	**$12,914**

30	x	20	53	50	10.7	567.1	7.05	$3,998	$17,991	442	3.54	$1,564	**$19,555**
10	x	6	10	16	3.4	34	7.3	$248	$1,117	27	3.54	$94	**$1,211**
10	x	6	3	16	3.4	10.2	7.3	$74	$335	8	3.54	$28	**$363**
20	x	8	30	28	6	180	7.3	$1,314	$5,913	140	3.54	$496	**$6,409**
20	x	12	12	32	6.9	82.8	7.3	$604	$2,720	64	3.54	$227	**$2,947**
30	x	12	26	42	9	234	7.05	$1,650	$7,424	182	3.54	$644	**$8,068**
30	x	30	10	60	12.9	129	7.3	$942	$4,238	100	3.54	$354	**$4,592**
						5,856			$187,353			$16,075	**$203,428**

* All retun air ductwork sized for 0.06 inches per 100 ft. of static pressure

** RS Means Reference Table 233100-40 includes allowance for scrap in the figures listed

***RS Means Stainless Steel used and assume 25% fittings

RTU-3 Supply Air														
Supply Air Duct											Supply Duct Insulation			Overall Total
Dimension* (in x in)			L (ft)	2-S (in)	W/ L** (lb / ft)	Weight (lb)	Total w/ O&P Cost ($ / lb)	Sub-Total	Corrected Total	Area (SF)	Total w/ O&P Cost ($ / SF)	Total	
Second Floor														
30	x	25	10	55	11.8	118	14.2	$1,676	$7,540	92	3.54	$325	**$7,865**
30	x	16	5	46	9.9	49.5	14.2	$703	$3,163	38	3.54	$136	**$3,299**
30	x	14	37	44	9.5	351.5	13.3	$4,675	$21,037	271	3.54	$961	**$21,998**
30	x	9	35	39	8.4	294	13.3	$3,910	$17,596	228	3.54	$805	**$18,401**
30	x	6	28	36	7.8	218.4	13.3	$2,905	$13,071	168	3.54	$595	**$13,666**
10	x	7	72	17	3.7	266.4	13.3	$3,543	$15,944	204	3.54	$722	**$16,666**
8	x	4	70	12	2.6	182	14.2	$2,584	$11,630	140	3.54	$496	**$12,125**
30	x	16	38	46	9.9	376.2	13.3	$5,003	$22,516	291	3.54	$1,031	**$23,547**
30	x	14	26	44	9.5	247	13.3	$3,285	$14,783	191	3.54	$675	**$15,458**
30	x	12	11	42	9	99	14.2	$1,406	$6,326	77	3.54	$273	**$6,599**
30	x	6	12	36	7.8	93.6	14.2	$1,329	$5,981	72	3.54	$255	**$6,236**
30	x	8	49	38	8.2	401.8	13.3	$5,344	$24,048	310	3.54	$1,099	**$25,146**
30	x	8	31	38	8.2	254.2	13.3	$3,381	$15,214	196	3.54	$695	**$15,909**
15	x	9	12	24	5.2	62.4	14.2	$886	$3,987	48	3.54	$170	**$4,157**
20	x	8	15	28	6	90	14.2	$1,278	$5,751	70	3.54	$248	**$5,999**
15	x	9	19	24	5.2	98.8	14.2	$1,403	$6,313	76	3.54	$269	**$6,582**
6	x	4	10	10	2.2	22	14.2	$312	$1,406	17	3.54	$59	**$1,465**
6	x	4	11	10	2.2	24.2	14.2	$344	$1,546	18	3.54	$65	**$1,611**
6	x	4	12	10	2.2	26.4	14.2	$375	$1,687	20	3.54	$71	**$1,758**
						3,275			$199,540			$8,947	**$208,487**

* All supply air ductwork sized for 0.08 inches per 100 ft. of static pressure

** RS Means Reference Table 233100-40 includes allowance for scrap in the figures listed
***RS Means Stainless Steel used and assume 25% fittings

RTU-3 Return Air														
Return Air Duct										Return Duct Insulation			Overall Total
Dimension* (in x in)			L (ft)	2-S (in)	W/ L** (lb / ft)	Weight (lb)	Total w/ O&P Cost ($ / lb)	Sub-Total	Corrected Total	Area (SF)	Total w/ O&P Cost ($ / SF)	Total	
Second Floor													
10	x	8	38	18	3.9	148.2	7.3	$1,082	$4,868	114	3.54	$404	**$5,272**
20	x	14	51	34	7.3	372.3	7.05	$2,625	$11,811	289	3.54	$1,023	**$12,834**
20	x	16	17	36	7.8	132.6	7.3	$968	$4,356	102	3.54	$361	**$4,717**
30	x	16	19	46	9.9	188.1	7.3	$1,373	$6,179	146	3.54	$516	**$6,695**
30	x	16	57	46	9.9	564.3	7.05	$3,978	$17,902	437	3.54	$1,547	**$19,449**
25	x	35	7	60	15	105	7.3	$767	$3,449	70	3.54	$248	**$3,697**
6	x	8	15	14	3	45	7.3	$329	$1,478	35	3.54	$124	**$1,602**
20	x	8	8	28	6	48	7.3	$350	$1,577	37	3.54	$132	**$1,709**
20	x	9	18	29	6.2	111.6	7.3	$815	$3,666	87	3.54	$308	**$3,974**
20	x	8	8	28	6	48	7.3	$350	$1,577	37	3.54	$132	**$1,709**
20	x	14	62	34	7.3	452.6	7.05	$3,191	$14,359	351	3.54	$1,244	**$15,602**
25	x	18	50	43	9.2	460	7.05	$3,243	$14,594	358	3.54	$1,269	**$15,862**
25	x	18	17	43	9.2	156.4	7.3	$1,142	$5,138	122	3.54	$431	**$5,569**
30	x	20	17	50	10.7	181.9	7.3	$1,328	$5,975	142	3.54	$502	**$6,477**
						3,014			$96,930			$8,239	**$105,169**

* All return air ductwork sized for 0.06 inches per 100 ft. of static pressure
** RS Means Reference Table 233100-40 includes allowance for scrap in the figures listed
***RS Means Stainless Steel used and assume 25% fittings

RTU-4 Supply Air													
Supply Air Duct										Supply Duct Insulation			Overall
Dimension* (in x in)			L (ft)	2-S (in)	W/ L** (lb / ft)	Weight (lb)	Total w/ O&P Cost ($ / lb)	Sub-Total	Corrected Total	Area (SF)	Total w/ O&P Cost ($ / SF)	Total	Total
Second Floor													
30	x	25	10	55	11.8	118	14.2	$1,676	$7,540	92	3.54	$325	**$7,865**
30	x	8	13	38	8.2	106.6	14.2	$1,514	$6,812	82	3.54	$291	**$7,103**
30	x	6	25	36	7.8	195	14.2	$2,769	$12,461	150	3.54	$531	**$12,992**
30	x	6	8	36	7.8	62.4	14.2	$886	$3,987	48	3.54	$170	**$4,157**
30	x	20	10	50	10.7	107	14.2	$1,519	$6,837	83	3.54	$295	**$7,132**
30	x	8	42	38	8.2	344.4	13.3	$4,581	$20,612	266	3.54	$942	**$21,554**
30	x	8	14	38	8.2	114.8	14.2	$1,630	$7,336	89	3.54	$314	**$7,650**
30	x	6	43	36	7.8	335.4	13.3	$4,461	$20,074	258	3.54	$913	**$20,987**
30	x	18	13	48	10.3	133.9	14.2	$1,901	$8,556	104	3.54	$368	**$8,924**
30	x	16	10	46	9.9	99	14.2	$1,406	$6,326	77	3.54	$271	**$6,598**
30	x	16	19	46	9.9	188.1	14.2	$2,671	$12,020	146	3.54	$516	**$12,535**
30	x	6	9	36	7.8	70.2	14.2	$997	$4,486	54	3.54	$191	**$4,677**
30	x	12	34	42	9	306	13.3	$4,070	$18,314	238	3.54	$843	**$19,157**
30	x	6	14	36	7.8	109.2	14.2	$1,551	$6,978	84	3.54	$297	**$7,275**
30	x	10	10	40	8.6	86	14.2	$1,221	$5,495	67	3.54	$236	**$5,731**
30	x	10	100	40	8.6	860	13.3	$11,438	$51,471	667	3.54	$2,360	**$53,831**
30	x	10	40	40	8.6	344	13.3	$4,575	$20,588	267	3.54	$944	**$21,532**
10	x	14	16	24	5.2	83.2	14.2	$1,181	$5,316	64	3.54	$227	**$5,543**
10	x	16	15	26	5.6	84	14.2	$1,193	$5,368	65	3.54	$230	**$5,598**
10	x	14	16	24	5.2	83.2	14.2	$1,181	$5,316	64	3.54	$227	**$5,543**
4	x	8	7	12	2.6	18.2	14.2	$258	$1,163	14	3.54	$50	**$1,213**
						3,849			$237,057			$10,540	**$247,597**

* All supply air ductwork sized for 0.08 inches per 100 ft. of static pressure
** RS Means Reference Table 233100-40 includes allowance for scrap in the figures listed
***RS Means Stainless Steel used and assume 25% fittings

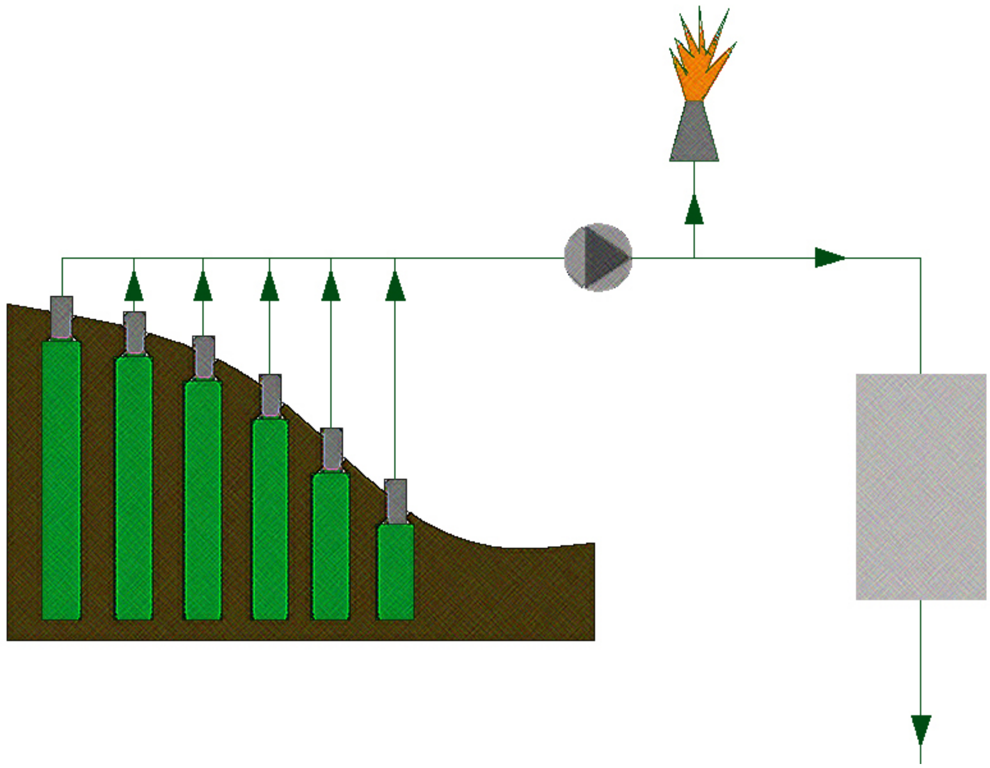
RTU-4 Return Air

Return Air Duct										Return Duct Insulation			Overall
Dimension* (in x in)			L (ft)	2-S (in)	W/ L** (lb / ft)	Weight (lb)	Total w/ O&P Cost ($ / lb)	Sub-Total	Corrected Total	Area (SF)	Total w/ O&P Cost ($ / SF)	Total	Total
Second Floor													
20	x	8	15	28	6	90	7.3	$657	$2,957	70	3.54	$248	**$3,204**
20	x	12	35	32	6.9	241.5	7.05	$1,703	$7,662	187	3.54	$661	**$8,322**
20	x	12	80	32	6.9	552	7.05	$3,892	$17,512	427	3.54	$1,510	**$19,023**
20	x	15	43	35	7.5	322.5	7.05	$2,274	$10,231	251	3.54	$888	**$11,119**
30	x	16	43	46	9.9	425.7	7.05	$3,001	$13,505	330	3.54	$1,167	**$14,672**
30	x	16	44	46	9.9	435.6	7.05	$3,071	$13,819	337	3.54	$1,194	**$15,014**
30	x	10	15	40	8.6	129	7.3	$942	$4,238	100	3.54	$354	**$4,592**
30	x	18	9	48	10.3	92.7	7.3	$677	$3,045	72	3.54	$255	**$3,300**
30	x	10	24	40	8.6	206.4	7.05	$1,455	$6,548	160	3.54	$566	**$7,114**
30	x	30	10	60	12.9	129	7.3	$942	$4,238	100	3.54	$354	**$4,592**
						2,624			$83,755			$7,197	**$90,952**

* All retun air ductwork sized for 0.06 inches per 100 ft. of static pressure
** RS Means Reference Table 233100-40 includes allowance for scrap in the figures listed
***RS Means Stainless Steel used and assume 25% fittings

Appendix D: Sample Redesign Calculations

GROWS Inc. Landfill



Landfill Gas Flowrate = 1,645 Nm^3/h

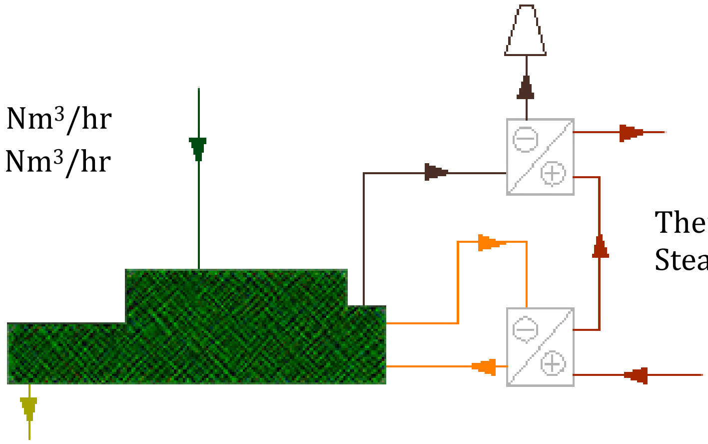
Approximate Size: 4,053,804 ft^2
Average Gas Production*= 0.344 scf/ ft^2/day

Landfill Gas = (4,053,804 ft^2) x (0.344 scf/ ft^2/day) / (24 hours) = 58,104 scf/hr
Landfill Gas Produced = (58,104 scf/hr) = **1,645 Nm^3/h**

*Sources: Waste Management http://www.americanlandfill.com/facility/gas_to_energy.asp
http://www.mrwmd.org/landfill-gas-power.htm

Engine: Jenbacher JMS 620 GS- NL

Gas Flowrate = 745 Nm^3/hr
Air Flowrate = 13.01 Nm^3/hr



Thermal Output = 3,022 kW
Steam Generation = 3572 lb/hr

Electrical Output = 3,043 kW

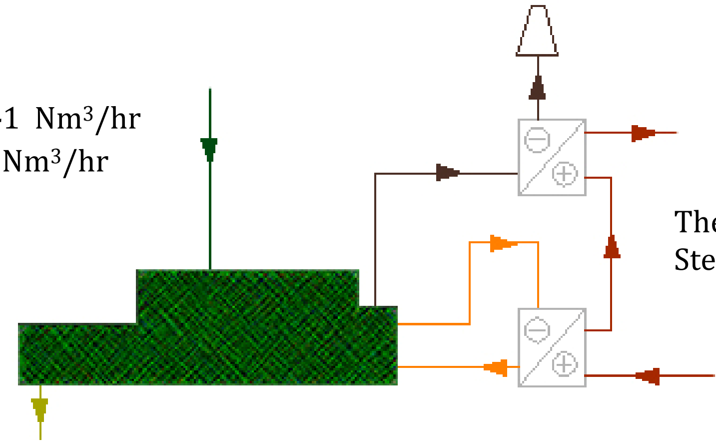
Natural Gas:

Natural Gas Volume Flowrate = 745 Nm^3/hr
Fuel Lower Heating Value = 9.5 kWh/Nm^3
Electrical Efficiency = 43.0%
Thermal Efficiency = 42.7%
Total Efficiency = 85.7%
Exhaust Gas to HX = 41.6%
Exhaust Gas Volume Flowrate = 13.66 Nm^3/hr
Full Load Exhaust Gas Temperature = 425°C
Steam Generated Pressure = 125 psig
Steam Total Heat = 1,193 (Btu/lb)
Combustion Air Volume Flowrate = 13.01 Nm^3/hr
Hot Water Volume Flowrate = 129.7 m^3/hr

Max Electrical Output = (745 Nm^3/hr) x (9.5 kWh/Nm^3) x (0.43) = **3,043 kW**
Max Thermal Output = (745 Nm^3/hr) x (9.5 kWh/Nm^3) x (0.427) = **3,022 kW**
Steam Generation = (3,002 kW) x (3,412 Btu/hr/kW) / (1193 Btu/lb) x (0.416)
= **3572 lb/hr**

Engine: Jenbacher JMS 620 GS- BL

Gas Flowrate = 1,241 Nm^3/hr
Air Flowrate = 10.85 Nm^3/hr



Thermal Output = 2,743 kW
Steam Generation = 3264 lb/hr

Electrical Output = 2,433 kW

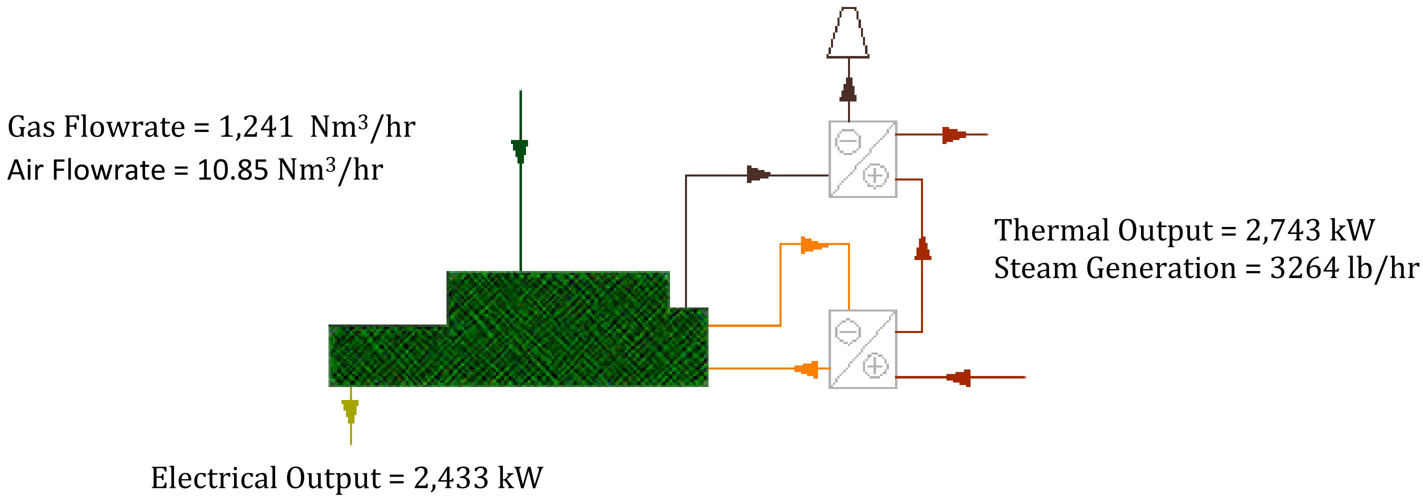
<u>Landfill Gas:</u>

Landfill Gas Volume Flowrate = 1,241 Nm^3/hr
Fuel Lower Heating Value = 5 kWh/Nm^3
Electrical Efficiency = 39.2%
Thermal Efficiency = 44.2%
Total Efficiency = 83.4%
Exhaust Gas to HX = 41.6%
Exhaust Gas Volume Flowrate = 11.78 Nm^3/hr
Maximum Demand Exhaust Gas Temperature = 467°C
Steam Generated Pressure = 125 psig
Steam Total Heat = 1,193 Btu/lb
Combustion Air Volume Flowrate = 10.85 Nm^3/hr
Hot Water Volume Flowrate = 78.5 m^3/hr

Summer

Max Electrical Output = (1,241 Nm^3/h) x (5 kWh/Nm^3) x (0.392) = **2,433 kW**
Max Thermal Output = (1,241 Nm^3/h) x (5 kWh/Nm^3) x (0.442) = **2,743 kW**
Amount of Flared Gas = (1,645 Nm^3/h) – (1,241 Nm^3/h) = **404 Nm^3/hr**
Max Steam Generation = (2,743 kW) x (3,412 Btu/h/kW) / (1193 Btu/lb) x (0.416)
= **3264 lb/hr**
Min Fuel Input = (2,407 kW) / (5 kWh/Nm^3) / (0.392) = **1,228 Nm^3/hr**
Min Thermal Output = (1,228 Nm^3/h) x (5 kWh/Nm^3) x (0.442) = **2,714 kW**
Min Steam Generation = (2,714 kW) x (3,412 Btu/h/kW) / (1193 Btu/lb) x (0.416)
= **3,229 lb/hr**

Engine: Jenbacher JMS 620 GS- BL (cont.)



Winter

Max Fuel Input = (1,855 kW) / (5 kWh/Nm^3) / (0.392) = **946 Nm^3/hr**

Max Thermal Output = (946 Nm^3/h) x (5 kWh/Nm^3) x (0.442) = **2,092kW**

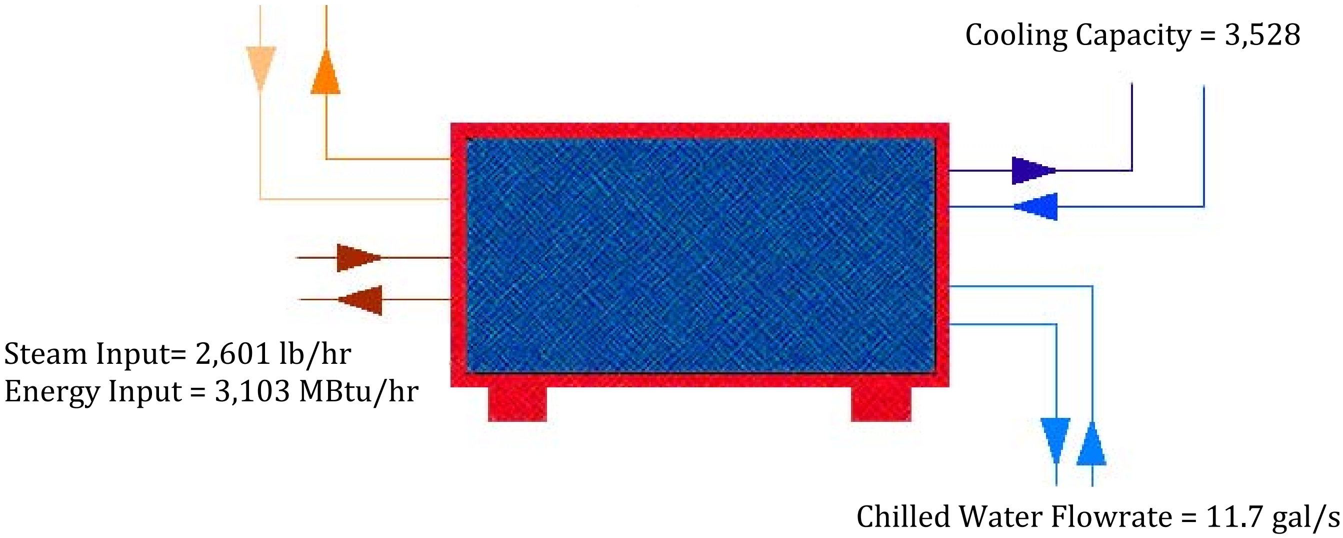
Max Steam Generation = (2,092 kW) x (3,412 Btu/h/kW) / (1193 Btu/lb) x (0.416)
= **2489 lb/hr**

Min Fuel Input = (1,832 kW) / (5 kWh/Nm^3) / (0.392) = **935 Nm^3/hr**

Min Thermal Output = (935 Nm^3/h) x (5 kWh/Nm^3) x (0.442) = **2,066 kW**

Min Steam Generation = (2,066 kW) x (3,412 Btu/h/kW) / (1193 Btu/lb) x (0.416)
= **2458 lb/hr**

Absorption Chiller/Heater: Carrier 16NK



Double-Effect and Steam Fired

Cooling Capacity = 1034 kW = 294 Tons = 3,528,000 Btu/hr

Chilled Water Volume Flowrate = 44.4 L/s = 11.7 gal/s

Cooled Water Temperature = 45°F

Cooled Water Volume Flowrate = 74.2 L/s = 1,176 gpm

Steam Consumption = 1180 kg/h = 2601 lb/hr

Energy Input = (2,601 lb/hr) x (1,193 Btu/lb) = **3,103 MBtu/hr**

Energy Output = **3,528 MBtu/hr**

COP = (3,528 MBtu/hr) / (3,103 MBtu/hr) = **1.14**

Cooling

Full Load Demand

Engine Steam Produced = **3,264 lb/hr**

Chiller Steam Consumption = **2,601 lb/hr**

Excess Steam = (3264 lb/hr) – (2601 lb/hr) = **663 lb/hr**

Partial Load Demand

Engine Steam Produced = **3,229 lb/hr**

Chiller Steam Consumption = **2601 lb/hr**

Peak Steam Consumption= **2,601 lb/hr**

Excess Steam = (3264 lb/hr) – (2601 lb/hr) = **628 lb/hr**

(Even at the minimum demand there is still enough steam to meet the maximum cooling load, therefore a standby centrifugal chiller is not needed.)

Heating

Minimum Load Demand

Engine Steam Produced = **2458 lb/hr**

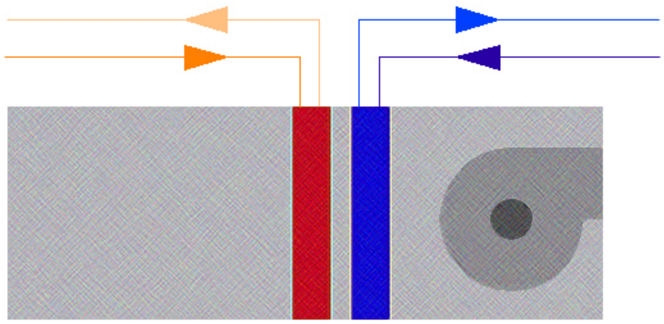
Steam Capacity = (2458 lb/hr) x (1,193 Btu/lb) = **2,932 MBtu/hr**

Peak Heating Demand = **1,239 MBtu/hr**

Excess Steam Capacity = (2,932 MBtu/hr) – (1,239 MBtu/hr) = **1693 MBtu/hr**

(Even at the minimum electrical demand there is still enough steam to meet the maximum heating load, therefore a standby gas-fired boiler is not needed.)

Rooftop Unit A1: TRANE Rooftop Unit



Peak Cooling = 77 tons
Peak Heating = 337 MBtu/hr
Peak Supply = 29,477 cfm
Peak Return = 24,761 cfm
Peak Outside Air = 16%
Total Static Pressure = 2.0 inches
Return Static Pressure = 0.8 inches

Step 1: Casing Size
Peak Heating = 337 MBtu/hr from Table GD-1 **Casing 2** is selected

Step 2: Supply and Exhaust Fan
Peak Supply = 29,477 cfm and External Static Pressure = 2.0 inches
a **supply fan at 25 bhp and 1043 rpm** is selected
Peak Return = 24,761 cfm and Return Static Pressure = 0.8 inches
an **exhaust fan at 10 bhp and 750 rpm** is selected

Step 3: Hot Water Heating System
Supply Fan Heat = (25 bhp x 2.8) = **70 Mbtu/hr**
Supply Fan Temperature Rise = 70,000 Btu / (1.085 x 29,477 cfm) = **2.19°F**
Mixed Air Temperature = 70°F + (0.16)(0°F - 70°F) = **58.8°F**
Total Winter Heating Load = 337 MBtu/hr - 20.3 Mbtu/hr = **316.7 Mbtu/hr**
Steam Needed = (316,700 Btu/hr) / (1,193 Btu/lb) = **265.5 lb/hr**
Steam Remaining = (2458 lb/hr) – (265.5 lb/hr) = **2192.5 lb/hr**

Step 4: Chilled Water Cooling System

Peak Cooling = 77 tons = **924,000 Btu/hr**

Water Leaving Temperature = [(924,000 Btu/hr) / (500) / (294 gpm)] + 45°F = **51°F**

ΔT_L = 90°F - 51°F = 39°F

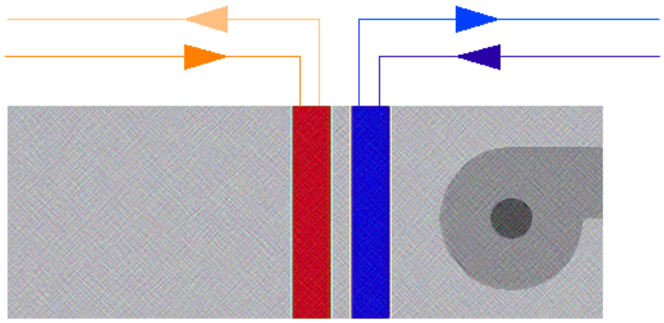
ΔT_S = 55°F - 45°F = 10°F

LMTD = **21.3°F** (From LMTD Table)

Capacity = 232,000 Btu/hr/row (Coil selection chart)

Rows = (924,000 Btu/hr) / (232,000 Btu/hr/row) = 3.98 rows = **4 Rows**

Rooftop Unit A2: TRANE Rooftop Unit



Peak Cooling = 108 tons
Peak Heating = 647 MBtu/hr
Peak Supply = 36,318 cfm
Peak Return = 27,239 cfm
Peak Outside Air = 25%
Total Static Pressure = 2.0 inches
Return Static Pressure = 0.8 inches

Step 1: Casing Size
Peak Heating = 647 MBtu/hr from Table GD-1 **Casing 4** is selected

Step 2: Supply and Exhaust Fan
Peak Supply = 36,318 cfm and External Static Pressure = 2.0 inches
a **supply fan at 30 bhp and 1150 rpm** is selected
Peak Return = 27,239 cfm and Return Static Pressure = 0.8 inches
an **exhaust fan at 15 bhp and 1000 rpm** is selected

Step 3: Hot Water Heating System
Supply Fan Heat = (30 bhp x 2.8) = **84 Mbtu/hr**
Supply Fan Temperature Rise = 84,000 Btu / (1.085 x 29,477 cfm) = **2.63°F**
Mixed Air Temperature = 70°F + (0.25)(0°F - 70°F) = **52.5°F**
Total Winter Heating Load = 647 MBtu/hr - 84 Mbtu/hr = **563 Mbtu/hr**
Steam Needed = (563,000 Btu/hr) / (1,193 Btu/lb) = **472 lb/hr**
Steam Remaining = (2192.5 lb/hr) – (472 lb/hr) = **1721 lb/hr**

Step 4: Chilled Water Cooling System

Peak Cooling = 108 tons = **1,296,000 Btu/hr**

Water Leaving Temperature = [(1,296,000 Btu/hr) / (500)/(294 gpm)] +45°F =**54°F**

ΔT_L = 90°F – 54°F = 36°F

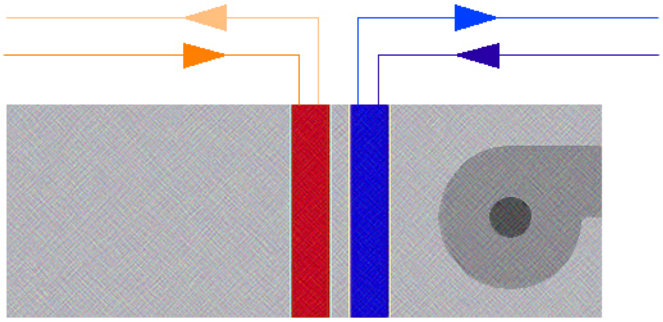
ΔT_S = 55°F - 45°F = 10°F

LMTD = **19.5°F** (From LMTD Table)

Capacity = 232,000 Btu/hr/row (Coil selection chart)

Rows = (1,296,000 Btu/hr) / (232,000 Btu/hr/row) = 5.58 rows = **6 Rows**

Rooftop Unit A3: TRANE Rooftop Unit



Peak Cooling = 42 tons
Peak Heating = 140 MBtu/h
Peak Supply = 17,615 cfm
Peak Return = 15,854 cfm
Peak Outside Air = 10%
Total Static Pressure = 1.5 inches
Return Static Pressure = 0.6 inches

Step 1: Casing Size
Peak Heating = 140 MBtu/hr from Table GD-1 **Casing 2** is selected

Step 2: Supply and Exhaust Fan
Peak Supply = 17,615 cfm and External Static Pressure = 1.5 inches
a **supply fan at 11 bhp and 800 rpm** is selected
Peak Return = 15,854 cfm and Return Static Pressure = 0.6 inches
an **exhaust fan at 6 bhp and 700 rpm** is selected

Step 3: Hot Water Heating System
Supply Fan Heat = (11 bhp x 2.8) = **31 Mbtu/hr**
Supply Fan Temperature Rise = 31,000 Btu / (1.085 x 17,615 cfm) = **1.62°F**
Mixed Air Temperature = 70°F + (0.10)(0°F - 70°F) = **63°F**
Total Winter Heating Load = 140 MBtu/hr - 31 Mbtu/hr = **109 Mbtu/hr**
Steam Needed = (109,000 Btu/hr) / (1,193 Btu/lb) = **91 lb/hr**
Steam Remaining = (1721 lb/hr) – (91 lb/hr) = **1630 lb/hr**

Step 4: Chilled Water Cooling System

Peak Cooling = 42 tons = **504,000 Btu/hr**

Water Leaving Temperature = [(504,000 Btu/hr) / (500) / (294 gpm)] + 45°F = **48°F**

ΔT_L = 90°F – 48°F = 42°F

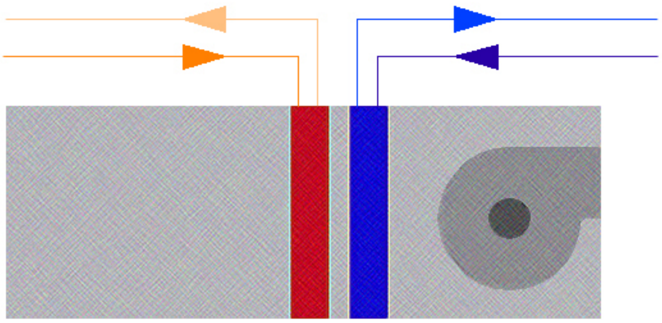
ΔT_S = 55°F - 45°F = 10°F

LMTD = **22.25°F** (From LMTD Table)

Capacity = 232,000 Btu/hr/row (Coil selection chart)

Rows = (504,000 Btu/hr) / (232,000 Btu/hr/row) = **2 Rows**

Rooftop Unit A4: TRANE Rooftop Unit



Peak Cooling = 40 tons
Peak Heating = 117 MBtu/h
Peak Supply = 16,553 cfm
Peak Return = 14,898 cfm
Peak Outside Air = 10%
Total Static Pressure = 1.5 inches
Return Static Pressure = 0.6 inches

Step 1: Casing Size
Peak Heating = 117 MBtu/hr from Table GD-1 **Casing 2** is selected

Step 2: Supply and Exhaust Fan
Peak Supply = 16,553 cfm and External Static Pressure = 1.5 inches
a **supply fan at 11 bhp and 800 rpm** is selected
Peak Return = 14,898 cfm and Return Static Pressure = 0.6 inches
an **exhaust fan at 6 bhp and 700 rpm** is selected

Step 3: Hot Water Heating System
Supply Fan Heat = (11 bhp x 2.8) = **31 Mbtu/hr**
Supply Fan Temperature Rise = 31,000 Btu / (1.085 x 16,553 cfm) = **1.73°F**
Mixed Air Temperature = 70°F + (0.10)(0°F - 70°F) = **63°F**
Total Winter Heating Load = 117 MBtu/hr - 31 Mbtu/hr = **86 Mbtu/hr**
Steam Needed = (86,000 Btu/hr) / (1,193 Btu/lb) = **72 lb/hr**
Steam Remaining = (1630 lb/hr) – (72 lb/hr) = **1558 lb/hr**

Step 4: Chilled Water Cooling System

Peak Cooling = 40 tons = **480,000 Btu/hr**

Water Leaving Temperature = [(480,000 Btu/hr) / (500) / (294 gpm)] + 45°F = **48°F**

ΔT_L = 90°F – 48°F = 42°F

ΔT_S = 55°F - 45°F = 10°F

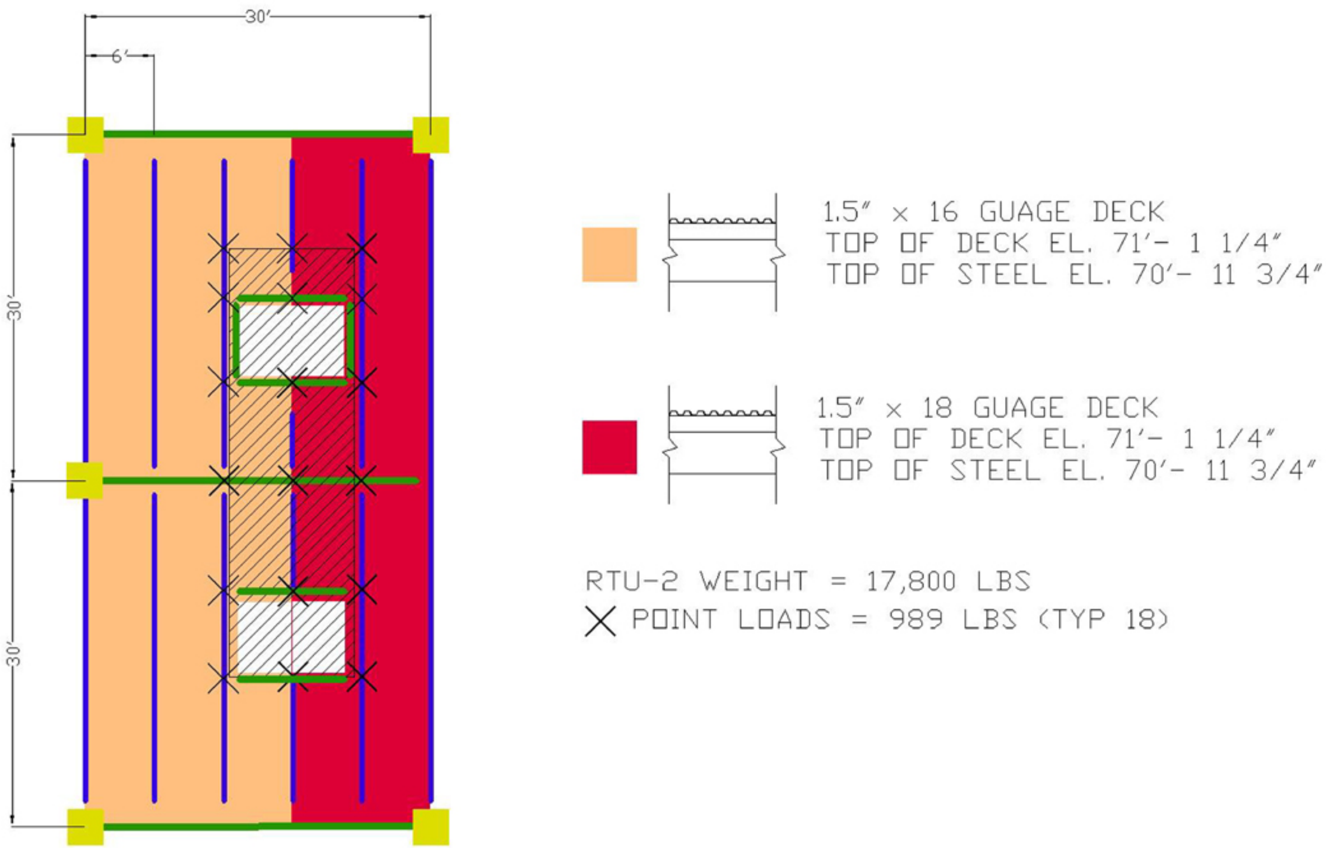
LMTD = **22.25°F** (From LMTD Table)

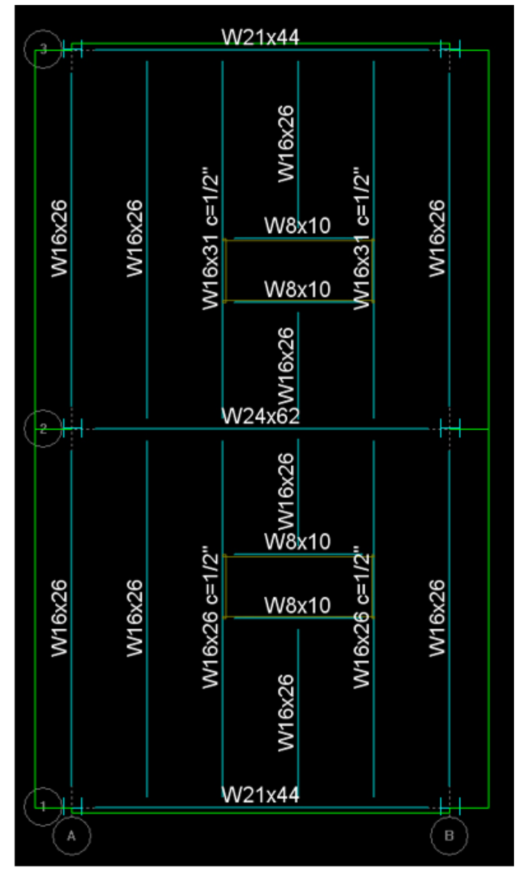
Capacity = 232,000 Btu/hr/row (Coil selection chart)

Rows = (480,000 Btu/hr) / (232,000 Btu/hr/row) = **2 Rows**

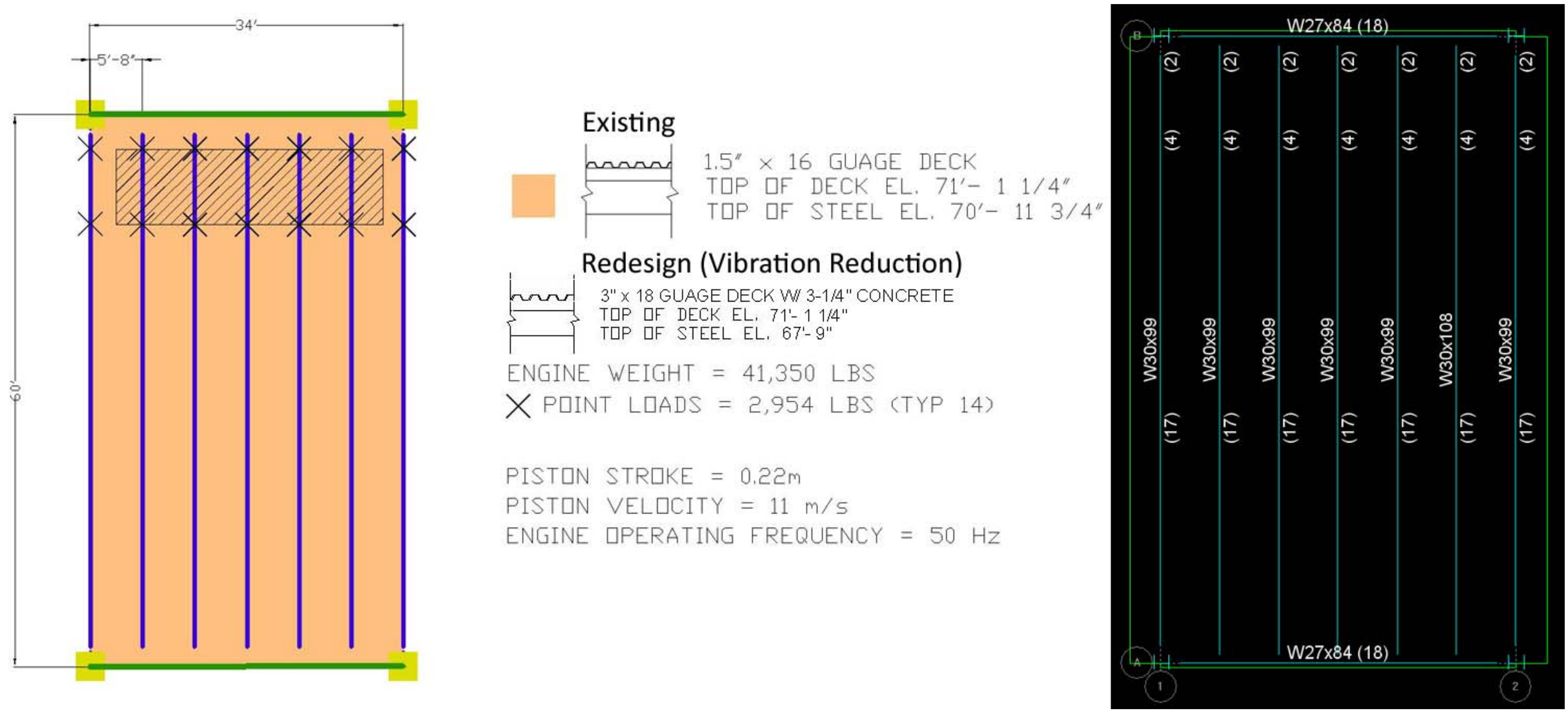
Appendix E: Structural Calculations

Rooftop Unit A1 Structural Bay

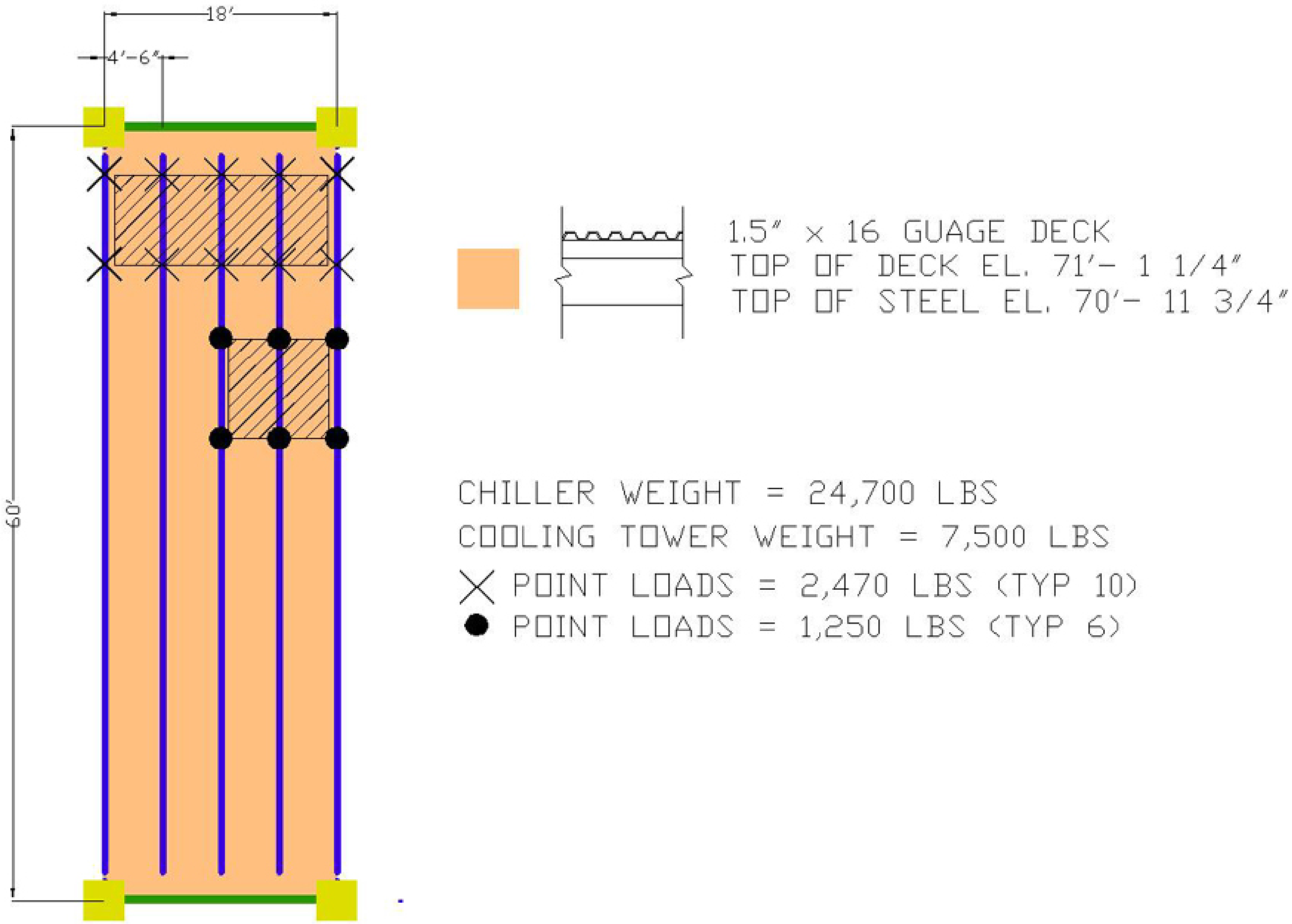


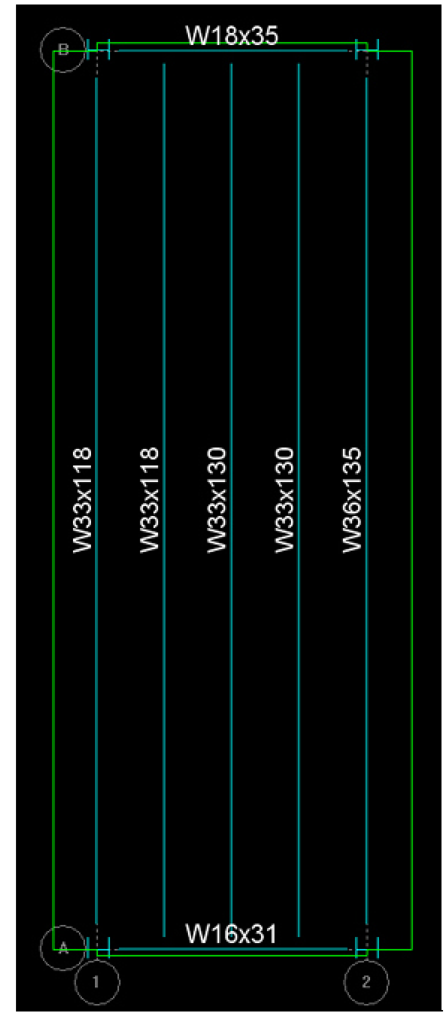


Jenbacher Engine Structural Bay

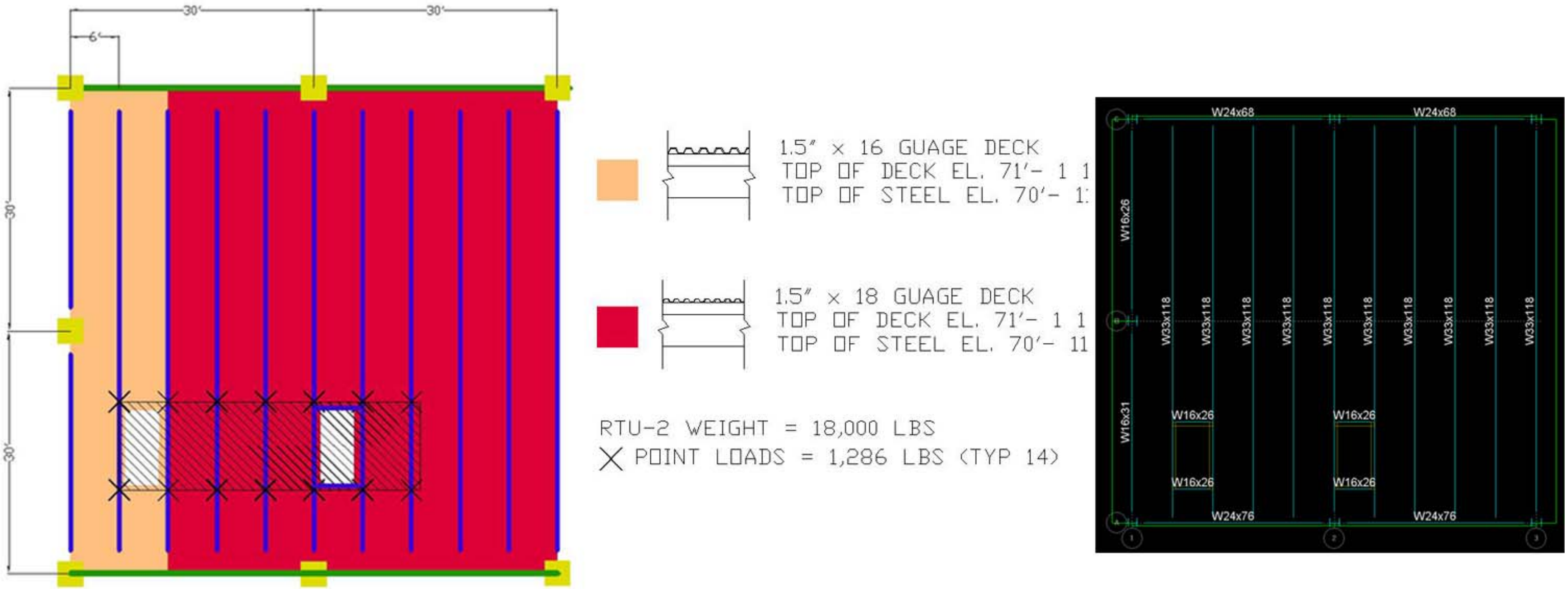


Absorption Chiller/Heater and Cooling Tower Structural Bay

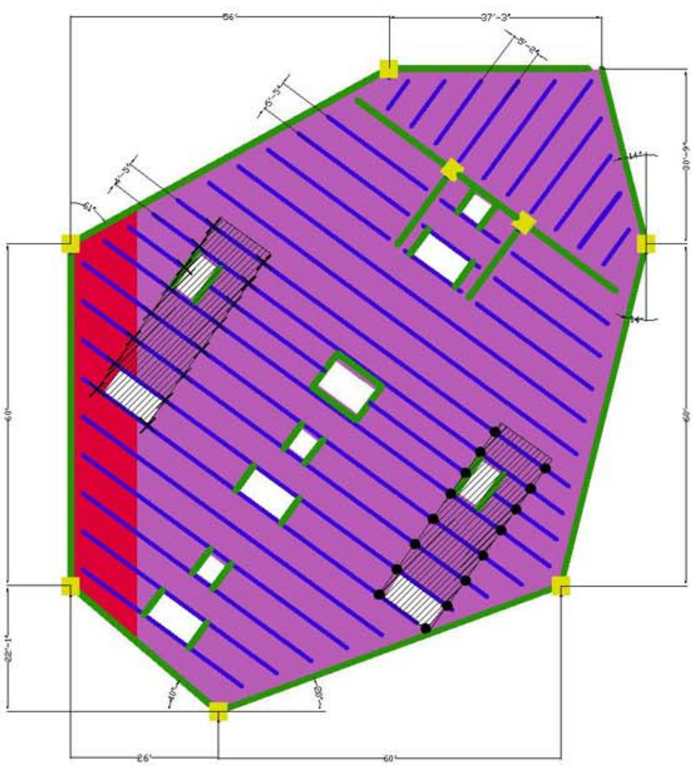




Rooftop Unit 2 Structural Bay



Rooftop Units 3 and 4 Structural Bay

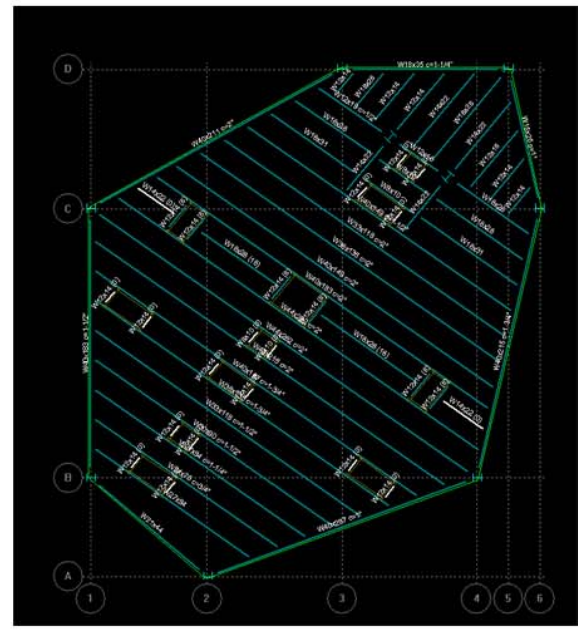


1.5" x 18 GUAGE DECK
TOP OF DECK EL. 90'- 6"
TOP OF STEEL EL. 90'-4"

3" x 18 GUAGE DECK W/ 3'-4" LIGHT CONCRETE
TOP OF DECK EL. 90'- 6"
TOP OF STEEL EL. 90'-4"

RTU-3 WEIGHT = 17,500 LBS
RTU-4 WEIGHT = 17,300 LBS

X POINT LOADS = 1,094 LBS (TYP 16)
● POINT LOADS = 1,081 LBS (TYP 16)



Appendix F: Electrical Schedules

Existing Panelboard 'EHVPAWG'

PANEL 'EHVPAWG'

277/480 VOLT 3 PHASE 4 WIRE 400A MLO SURFACE MOUNTED

DESCRIPTION	KVA / ø Aø	KVA / ø Bø	KVA / ø Cø	BRKR POLE	BRKR AMP	CIRCUIT	Aø	Bø	Cø	CIRCUIT	BRKR POLE	BRKR AMP	KVA / ø Aø	KVA / ø Bø	KVA / ø Cø	DESCRIPTION
AHU–A1 SUPPLY FAN	7.1					1				2			19.6			ELEVATOR SE 3
–		7.1		3	50	3				4	3	125		19.6		–
–			7.1			5				6					19.6	–
ELEVATOR SE 4A	16.2					7				8			11.2			AHU–A3 SUPPLY FAN
–		16.2		3	125	9				10	3	60		11.2		–
–			16.2			11				12					11.2	–
15KVA XFMR FOR	0.2					13				14			11.2			PANEL EHVPAW1
PANEL ELVPAWG		0.5		3	30	15				16	3	100		11.5		–
–			0.0			17				18					9.1	–
METHANE MOTOR	3.0					19				20			11.2			AHU–A4 SUPPLY FAN
CONTROL CENTER		3.0		3	20	21				22	3	60		11.2		–
–			3.0			23				24					11.2	–
SPACE	–			1	–	25				26	1	–	–			SPACE
SPACE		–		1	–	27				28	1	–		–		SPACE
SPACE			–	1	–	29				30	1	–			–	SPACE
	26.5	26.8	26.3										53.2	53.5	51.1	

TOTAL CONNECTED KVA: 237.4

Redesign Panelboard 'EHVPAWG1'

PANEL 'EHVPAWG1'

277/480 VOLT 3 PHASE 4 WIRE 400A MLO SURFACE MOUNTED

DESCRIPTION	KVA / ø Aø	KVA / ø Bø	KVA / ø Cø	BRKR POLE	BRKR AMP	CIRCUIT	Aø	Bø	Cø	CIRCUIT	BRKR POLE	BRKR AMP	KVA / ø Aø	KVA / ø Bø	KVA / ø Cø	DESCRIPTION
AHU–A1 SUPPLY FAN	9.7					1				2			19.6			ELEVATOR SE 3
–		9.7		3	50	3				4	3	125		19.6		–
–			9.7			5				6					19.6	–
ELEVATOR SE 4A	16.2					7				8			4.2			AHU–A3 SUPPLY FAN
–		16.2		3	125	9				10	3	20		4.2		–
–			16.2			11				12					4.2	–
15KVA XFMR FOR	0.2					13				14			11.2			PANEL EHVPAW1
PANEL ELVPAWG		0.5		3	30	15				16	3	100		11.5		–
–			0.0			17				18					9.1	–
METHANE MOTOR	3.0					19				20			4.2			AHU–A4 SUPPLY FAN
CONTROL CENTER		3.0		3	20	21				22	3	20		4.2		–
–			3.0			23				24					4.2	–
AHU–A2 SUPPLY FAN	12.5					25				26	1	–	–			SPACE
–		12.5		3	60	27				28	1	–		–		SPACE
–			12.5			29				30	1	–			–	SPACE
	41.6	41.9	41.4										39.2	39.5	37.1	

TOTAL CONNECTED KVA: 240.7

New Panelboard 'EHVPAWG2'

PANEL 'EHVPAWG2'

277/480 VOLT 3 PHASE 4 WIRE 400A MLO SURFACE MOUNTED

DESCRIPTION	KVA / ø Aø	KVA / ø Bø	KVA / ø Cø	BRKR POLE	BRKR AMP	CIRCUIT	Aø	Bø	Cø	CIRCUIT	BRKR POLE	BRKR AMP	KVA / ø Aø	KVA / ø Bø	KVA / ø Cø	DESCRIPTION
AHU–A1 EXHAUST FAN	3.9					1				2			3.0			CHILLER/HEATER
–		3.9		3	20	3				4	3	20		3.0		–
–			3.9			5				6					3.0	–
AHU–A3 EXHAUST FAN	2.2					7				8			11.1			COOLING TOWER
–		2.2		3	20	9				10	3	50		11.1		–
–			2.2			11				12					11.1	–
AHU–A4 EXHAUST FAN	2.2					13				14	1	–	–			SPACE
–		2.2		3	20	15				16	1	–		–		SPACE
–			2.2			17				18	1	–			–	SPACE
AHU–A2 EXHAUST FAN	6.1					19				20	1	–	–			SPACE
–		6.1		3	30	21				22	1	–		–		SPACE
–			6.1			23				24	1	–			–	SPACE
SPACE	–			1	–	25				26	1	–	–			SPACE
SPACE		–		1	–	27				28	1	–		–		SPACE
SPACE			–	1	–	29				30	1	–			–	SPACE
	14.4	14.4	14.4										14.1	14.1	14.1	

TOTAL CONNECTED KVA: 85.5

Existing Switchboard S8

MALL SWITCHBOARD: S8

(1) 3000A, 3ø, 4W., 277/480V. MAIN BREAKER WITH GROUND FAULT PROTECTION

BRANCH CIRCUIT		EQUIPMENT SERVED	DESIGN KVA	CONNECTED KVA	DEMAND KVA	CONDUIT AND WIRE SIZE
AMPERE	POLE					
200 (4)	3	AHU–A1	151.4	151.4	69.0	3 #3/0 & #6 GRD. IN 2" CONDUIT
250 (4)	3	AHU–A3	193.0	193.0	137.1	3 #250MCM & #4 GRD. IN 2 1/2" CONDUIT
1200 (2)	3	CATERING 13300	942.2	942.2	807.6	(4) EMPTY 3" CONDUITS
60 (5)	3	PANEL HVLHUBAG	31.1	31.1	16.1	4#6 & #8 GRD. IN 1" CONDUIT
100 (4)	3	MXTV	45.0	45.0	45.0	4 #3 & #8 GRD. IN 1 1/4" CONDUIT
60 (4)	3	PANEL HVLAWG	30.7	30.7	15.7	4 #6 & #8 GRD. IN 1" CONDUIT
350 (5)	3	PANEL HVPAWG	241.8	241.8	228.4	4 #500MCM & #3 GRD. IN 4" CONDUIT
100 (5)	3	LIFE SAFETY ATS LSAW	20.3	20.3	20.3	4 #3 & #8 GRD. IN 1 1/4" CONDUIT
400 (5)	3	MECH. EQUIP. ATS MEAW	279.9	279.9	237.4	4 #500MCM & #3 GRD. IN 4" CONDUIT
250 (4)	3	AHU–A4	193.0	193.0	137.1	3 #250MCM & #4 GRD. IN 2 1/2" CONDUIT
225 (5)	3	PANEL HVLAW1	159.4	159.4	104.4	4 #4/0 & #4 GRD. IN 2 1/2" CONDUIT
350 (5)	3	PANEL HVPAW2	231.0	231.0	218.1	4#500MCM & #3 GRD. IN 4" CONDUIT
TOTAL			2518.8	2518.8	2036.2	

Redesign Switchboard S8

MALL SWITCHBOARD: S8

(1) 2500A 3ø, 4W., 277/480V. MAIN BREAKER WITH GROUND FAULT PROTECTION

BRANCH CIRCUIT		EQUIPMENT SERVED	DESIGN KVA	CONNECTED KVA	DEMAND KVA	CONDUIT AND WIRE SIZE
AMPERE	POLE					
–	–	–	–	–	–	–
95 (5)	3	PANEL HVPAWG2	85.5	85.5	80.7	4 #4 & #10 GRD. IN 1.5" CONDUIT
1200 (2)	3	CATERING 13300	942.2	942.2	807.6	(4) EMPTY 3" CONDUITS
60 (5)	3	PANEL HVLHUBAG	31.1	31.1	16.1	4#6 & #8 GRD. IN 1" CONDUIT
100 (4)	3	MXTV	45.0	45.0	45.0	4 #3 & #8 GRD. IN 1 1/4" CONDUIT
60 (4)	3	PANEL HVLAWG	30.7	30.7	15.7	4 #6 & #8 GRD. IN 1" CONDUIT
250 (5)	3	PANEL HVPAWG1	240.7	240.7	227.2	4 #250 MCM & #4 GRD. IN 2.5" CONDUIT
100 (5)	3	LIFE SAFETY ATS LSAW	20.3	20.3	20.3	4 #3 & #8 GRD. IN 1 1/4" CONDUIT
400 (5)	3	MECH. EQUIP. ATS MEAW	279.9	279.9	237.4	4 #500MCM & #3 GRD. IN 4" CONDUIT
250 (4)	3	AHU–A4	193.0	193.0	137.1	3 #250MCM & #4 GRD. IN 2 1/2" CONDUIT
225 (5)	3	PANEL HVLAW1	159.4	159.4	104.4	4 #4/0 & #4 GRD. IN 2 1/2" CONDUIT
350 (5)	3	PANEL HVPAW2	231.0	231.0	218.1	4#500MCM & #3 GRD. IN 4" CONDUIT
TOTAL			2065.8	2065.8	1772.5	

Existing Switchboard S26

MALL SWITCHBOARD: S26

(1) 4000A. 3ø, 4W., 277/480V. MAIN BREAKER WITH GROUND FAULT PROTECTION

BRANCH CIRCUIT		EQUIPMENT SERVED	DESIGN KVA	CONNECTED KVA	DEMAND KVA	CONDUIT AND WIRE SIZE
AMPERE	POLE					
500 (4)	3	BROADCAST LIGHTING	287.4	287.4	287.4	(2) SETS OF 4 #250MCM & #2 GRD. IN (2) 2 1/2" C.
1200 (4)	3	EXT LED	709.0	709.0	509.7	(4) SETS OF 4 #350MCM & #3/0 GRD. IN (4) 3" C.
2500 (4)	3	INT LED	1761.8	1761.8	882.3	(7) SETS OF 4 #500MCM & #350MCM GRD. IN (7) 4" C.
200 (4)	3	PANEL HVSLAEG	93.4	93.4	75.0	4 #3/0 & #6 GRD. IN 2" CONDUIT
–	–	–	–	–	–	–
–	–	–	–	–	–	–
225 (4)	3	AHU–A2	177.5	177.5	69.0	3 #4/0 & #4 GRD. IN 2 1/2" CONDUIT
100 (4)	3	AHU–B7	72.0	72.0	32.3	3 #3 & #8 GRD. IN 1 1/4" CONDUIT
100 (4)	3	AHU–B8	72.0	72.0	32.3	3 #3 & #8 GRD. IN 1 1/4" CONDUIT
–	–	–	–	–	–	----
–	–	–	–	–	–	----
–	–	–	–	–	–	----
TOTAL			3173.0	3173.0	1888.0	

Redesign Switchboard S26

MALL SWITCHBOARD: S26

(1) 2500A 3ø, 4W., 277/480V. MAIN BREAKER WITH GROUND FAULT PROTECTION

BRANCH CIRCUIT		EQUIPMENT SERVED	DESIGN KVA	CONNECTED KVA	DEMAND KVA	CONDUIT AND WIRE SIZE
AMPERE	POLE					
500 (4)	3	BROADCAST LIGHTING	287.4	287.4	287.4	(2) SETS OF 4 #250MCM & #2 GRD. IN (2) 2 1/2" C.
1200 (4)	3	EXT LED	709.0	709.0	509.7	(4) SETS OF 4 #350MCM & #3/0 GRD. IN (4) 3" C.
2500 (4)	3	INT LED	1761.8	1761.8	882.3	(7) SETS OF 4 #500MCM & #350MCM GRD. IN (7) 4" C.
200 (4)	3	PANEL HVSLAEG	93.4	93.4	75.0	4 #3/0 & #6 GRD. IN 2" CONDUIT
–	–	–	–	–	–	–
–	–	–	–	–	–	–
–	–	–	–	–	–	–
100 (4)	3	AHU–B7	72.0	72.0	32.3	3 #3 & #8 GRD. IN 1 1/4" CONDUIT
100 (4)	3	AHU–B8	72.0	72.0	32.3	3 #3 & #8 GRD. IN 1 1/4" CONDUIT
–	–	–	–	–	–	----
–	–	–	–	–	–	----
–	–	–	–	–	–	----
TOTAL			2995.5	2995.5	1819	