FINAL THESIS REPORT

  

Water Bottling Facility

Mid-Atlantic, US

Mechanical System Renovation with Acoustical and Architectural Breadths

The Pennsylvania State University
Architectural Engineering
Mechanical Option

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Water Bottling Facility

Mid-Atlantic
United States

Project Information

Owner/Occupant	Water Bottling Company
Architect & Engineer	Haskell Architects/Engineers
Mechanical Contractor	HT Lyons & JS Thomas
Electrical Contractor	Westside Hammer
Occupancy Type	Office/Factory/Warehouse
Gross Building Area	517,000 ft^2
Number of Stories	2 in parts storage, else 1
Total Cost	$132,000,000
Dates of Construction	August 2006 – March 2007
Delivery Method	Design-Build

Mechanical Systems

The mechanical system of is made up of:

- 6 roof top units, 1 of which is equipped with a humidifier for the QC lab
- 17 VAV boxed that regulate the Office and QC Lab
- 8 make-up air-handling units ensure enough air is being circulated within the warehouse and packaging areas
- 9 unit heaters, 4 gas and 5 electric
- 2 Gravity hoods in the Chiller Room
- 36 Exhaust Fans and 16 Supply Fans regulate air in all spaces except the office

Electrical/Lighting Systems

- The power service enters the building through a 12.47 kVA switchgear. It then moves though 5 12.47kVA-480/277V transformers. The power is then distributed though 4 480V switchboards and 1 4160V switchboard
- Lights are required to produce 50 foot-candles in the production area and 35 in the warehouse
- Both the office and warehouse use occupancy sensors
- Site lighting control is based on time clocks

Structural Systems

Foundation

- Varying thicknesses of concrete slab from 4" to 10"

Structure

- 50' x 50' bays throughout warehouse and packaging
- Metal floor deck 1 ½" – 22 GA. Galvanized Composite
- High strength structural steel

Roof

- Metal roof deck 1 ½" deep, wide rib, galvanized - 22 GA

Architectural Features

- **Entryway features clerestories and blue metal roof**
- **LEED Gold Achieved setting new minimum for future construction**

Mechanical Option | Fall 2012
Advised by Dr. William Bahnfleth

Justyne Neborak

http://www.engr.psu.edu/ae/thesis/portfolios/2013/jsn136/index.html

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Acknowledgements

I would like to take this page to thank everyone who has supported me through this process, be it academically, emotionally, or spiritually. This semester has had many trials that I would not have overcome without the support of many important people in my life.

Personally, I recognize my family and friends who helped me persevere even when completing the tasks seemed daunting.

Academically, I share a special thank you to the team at the Water Bottling Facility, who has been a constant source of information.

Jack Neborak

Ron Hendeson

Chris Hoffner

Thank you for all of your help and wealth of knowledge.

I would also like to thank the AE department along with the office staff for always having a stapler that could punch through the reports with too many pages for mine.

Executive Summary

The analyses performed in this report are a result of information collected over the past two semesters. Gathering background information about the Water Bottling Facility gave way to the potential for modifications of the mechanical, acoustical, and electrical systems of the building. These analyses were run to give the author of this report a greater understanding of building systems in an environment that adapted to the student's interests.

The mechanical depth portion of the report focuses on the main subject of incorporating a ground-coupled heat pump into the HVAC system with smaller analyses of duct changes and exhaust additions.

The GCHP analysis found that the Water Bottling Facility could save over half of a million dollars annually if they were to replace the current HVAC system in the building with the researched system. The incorporation of the GCHP would use the buildings existing duct layout and internal controls while replacing the air-handling units with rooftop heat pumps. In order to implement this system the south parking lot would have to be decommissioned for the duration of construction because it is the location of the well field. After adding the system to the building, the Water Bottling Facility will see a reduction in energy costs as well as know that they are reducing their emissions by over 25% on the mechanical side.

After examining the fabric duct issues in the Water Bottling Facility it became evident that the design was not the problem, but the material used in the design. After research into different duct options, the conclusion was drawn that the best option was to keep the original duct layout and update the duct to a more durable solution that meets USDA standards.

Looking at different exhaust options gave way to the idea of controlled louvers with a hood to block weather. These vents will provide a means for heat to escape from the building without using much more electricity than is already used with the potential to offset the amount of time that the HVAC system is required to run by reducing the buildings load.

The acoustical evaluation found that the sound levels in the production area were higher than recommended by OSHA. To correct this it was suggested that, FDA and USDA approved acoustical baffles should be hung from the ceiling. The addition of 6,000 baffles will reduce the sound level of the space by 10 dBA, which will make the space fall below OSHA's recommendation.

The Electrical Analysis focused on the use of photovoltaics to contribute to the energy supplied to the Water Bottling Facility. In this analysis, it was found that due to the enormous electrical

demand of the building, a photovoltaic array would not contribute much to the electrical supply. It was also found that the payback period for the array would be infinite and therefore not a feasible option for the Water Bottling Facility currently.

Building Overview

The Water Bottling Facility located in the Mid-Atlantic region of the United States, has three major faculties: office, production, and warehouse. All of these components are combined in one building using walls and visual indicators to separate the different use zones. In Figure 1, below, the green section represents the warehouse, the blue production, and the orange office space. All of these spaces combined make up the over 510,000 square feet of the single story building. The celling heights in the warehouse and production areas are 30-foot clear height and 23-foot 6-inch with Draft Curtain respectively. Ceilings in the office areas range from 8 to 20 feet.

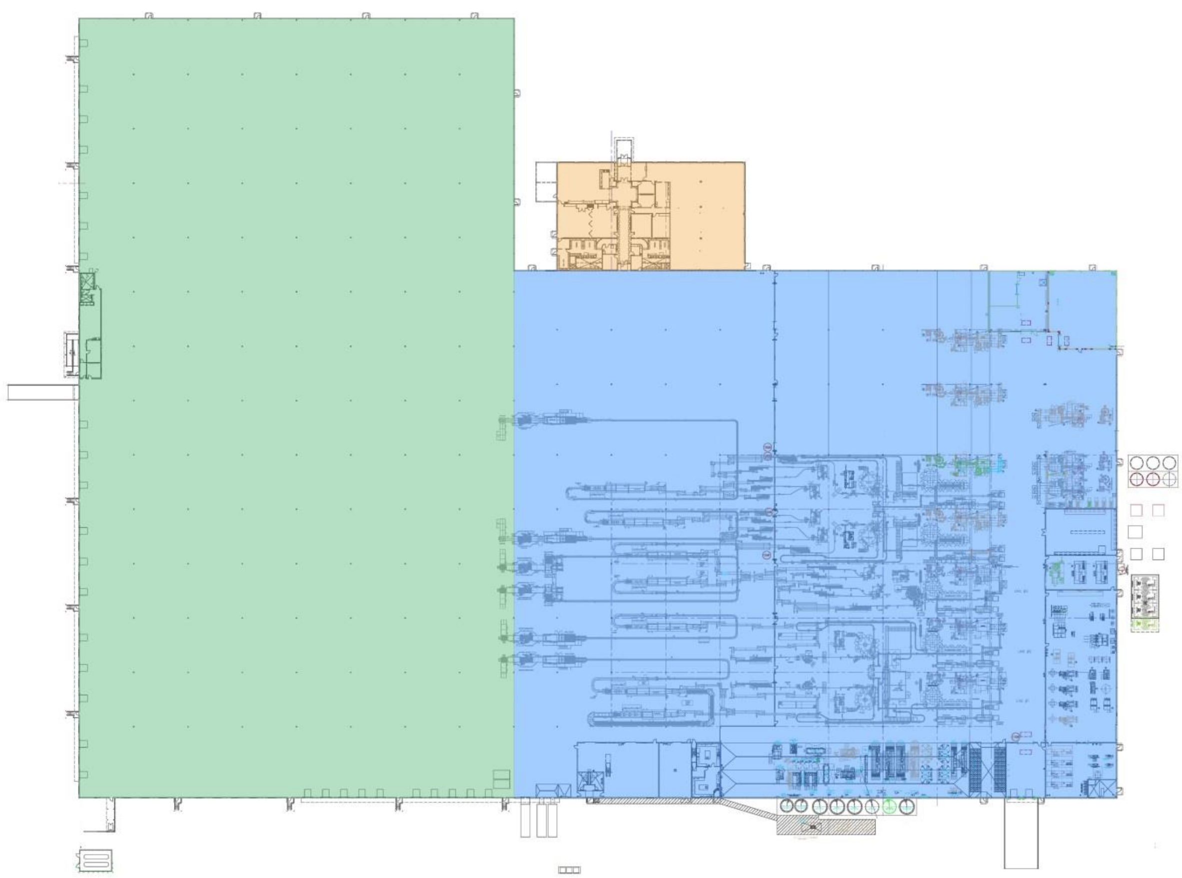

Figure 1 - Building Uses Floor Plan

Construction

Construction of the Water Bottling Facility was completed quickly, built in less than 8 months between August of 2006 and March of 2007. This rapid construction was completed using a bid build method with an already established a design using tilt-up walls for quick installation.

Electrical

The Water Bottling Facility receives its electricity from the local electric company. It is equipped with five 12.47 kV transformers as well as 4 480kV switchgears and 1 4160kV switchgear.

Lighting

Lighting levels must reach 50 foot-candles in the production areas and 35 in the warehouse of the Water Bottling Facility. Within the warehouse and office spaces, vacancy sensors are used to reduce energy use when spaces are not occupied.

Structural

The structural system of the Water Bottling Facility is acknowledges live loads of 27 psf for the roof as well as 250 psf for the quality Assurance mezzanine. Wind loads are based on a basic wind speed of 90 mph with an importance factor of one. The building has an exposure category C and an internal pressure coefficient of +/- 1.08. Snow loads for the facility's ground snow load are 30 psf while the flat roof snow load is 27 psf. The Water Bottling Facility is in seismic group I.

Fire Protection

A foam suppression system is used in the flavor room of the Water Bottling Facility. All other spaces are equipped with a water suppression system.

Telecommunications

The Water Bottling Company has its own telecommunications company, which has servers connected in Arizona and Texas.

Existing Mechanical System Summary

Introduction

The Water Bottling Facility's mechanical system is made up of six roof top air-handling units. Each of these units is assigned to one of the five conditioned areas of the facility. Cooling is provided by cooling towers in conjunction with ammonia chillers, while heating is provided by gas, electric, or a combination for each of the units. 17 VAV terminal units provide the airflow to the offices spaces. The production space is conditioned with direct ducting to the space. The warehouse space is ventilated with 8 make up air handling units and supply fans.

Design Objectives and Requirements

For the Water Bottling Facility, the main design objective was to create a building that could be easily replicated, constructed in different locations across the United States, and built rapidly. The other large design consideration was LEED® certification to both have a positive impact on the environment and to disprove the common belief that bottling water is bad for the environment. With these design considerations in mind, the mechanical systems were made to use 100% outside air and an enthalpy economizer cycle.

Outdoor and Indoor Design Conditions

The 2009 AHSRAE Handbook of Fundamentals provides weather data for the region in which the Water Bottling Facility is located. Table 1 shows the design day temperatures used in the Carrier Hourly Analysis Program (HAP) calculation. The spaces within the Water Bottling Facility have different design requirements based on their use as shown in Table 2.

	Summer Design Cooling (0.4%)	Winter Design Heating (99.6%)
OA Dry Bulb (°F)	88°F	5°F
OA Wet Bulb (°F)	72°F	-

Table 1 - Outdoor Air Design Conditions

	Conditioned Process	Offices, QC Lab, & Parts Office	Warehouse & Packaging	Storage, Maintenance & Mechanical
Cooling Set Point	85°F	72°F	95°F	95°F
Heating Set Point	65°F	72°F	48°F	60°F
Relative Humidity	-	45%	-	-

Table 2 - Indoor Air Design Conditions

Heating Water System

Although the building is equipped with boilers, these are used for manufacturing purposes rather than for thermal comfort. Heat is generated for the manufacturing equipment within the building using three gas-fired boilers. These boilers produce steam at a 100 psi maximum that is distributed to heat exchangers and equipment that heats the spring water to be bottled while it extracts it from the outdoor silos in order to minimize the amount of condensation that forms due to temperature differences between the water and the interior of the building.

Deaerated water is pumped into the boilers, which produce steam. Some of the steam condenses quickly and is drained into a runoff tank. The water that remains steam makes its way to the heat exchangers. The heat exchangers increase the temperature of the spring water that had been stored in silos outside as it makes its way in, to be bottled. The water is heated so that condensation does not form on the outside of the equipment of bottles because condensation would interfere with the manufacturing and packaging processes. The water that condenses after it passes though the heat exchangers is recirculated though the same process of deaeration and boiling. It is important for the water to pass through a deaerator because bubbles in the water can cause serious damage to the boilers.

The heat produced for the building is created using gas and electric make up units as well as heating elements in the air-handling units. The Water Bottling Facility generates so much heat that heating is only required under extreme circumstances.

Chilled Water System

Cooling is generated for the building using three ammonia chillers. These chillers, in combination with the four outdoor cooling towers, provide chilled water for the air handling units as well as other equipment within the manufacturing process.

Water is circulated from the cooling towers to the chillers, which then returns to the cooling towers as the cycle continues. This allows the chillers to remove heat from the water that is going to the roof top units by transferring the heat to the tower water. The cooling towers cool the water so that they will accept as much heat as possible from the chillers so that they can cool the chilled water more efficiently.

Design Ventilation Requirements

The ventilation rate for the office space of the Water Bottling Facility complies with the requirements set by ASHRAE Standard 62.1-2007 Section 6. Using the equations found in the standard and data found in the mechanical drawings it was discovered that RTU-1 exceeds the minimum requirements for ventilating the space based on occupancy. The unit provides 14,000 cfm while only about 3,500 cfm is required for the people in the space. Other loads that would influence the higher ventilation rate include computers, projectors, vending machines, and refrigerators.

Existing system Design Load Estimation

To analyze the load on the Water Bottling Facility, Carrier Hourly Analysis Program v4.6 (HAP) was used. This allowed the results to account for loads based on location, building materials, occupancy, and equipment. HAP was selected over other load calculating programs because of the user's previous experience and its availability. The energy analysis accounts for an entire year's worth of data, finding the peak design cooling and heating loads for the system.

Block Load Elements

Block analysis was used to minimize the amount of inputs into the load calculation program. The increased speed for entry, minimization of mis-entry, and smaller file size makes block analysis a good choice compared to space-by-space analysis, especially because it provides equally accurate results. Blocks for this analysis were selected based on location and zone requirements resulting in 8 blocks. These areas can be seen in Figure 2.

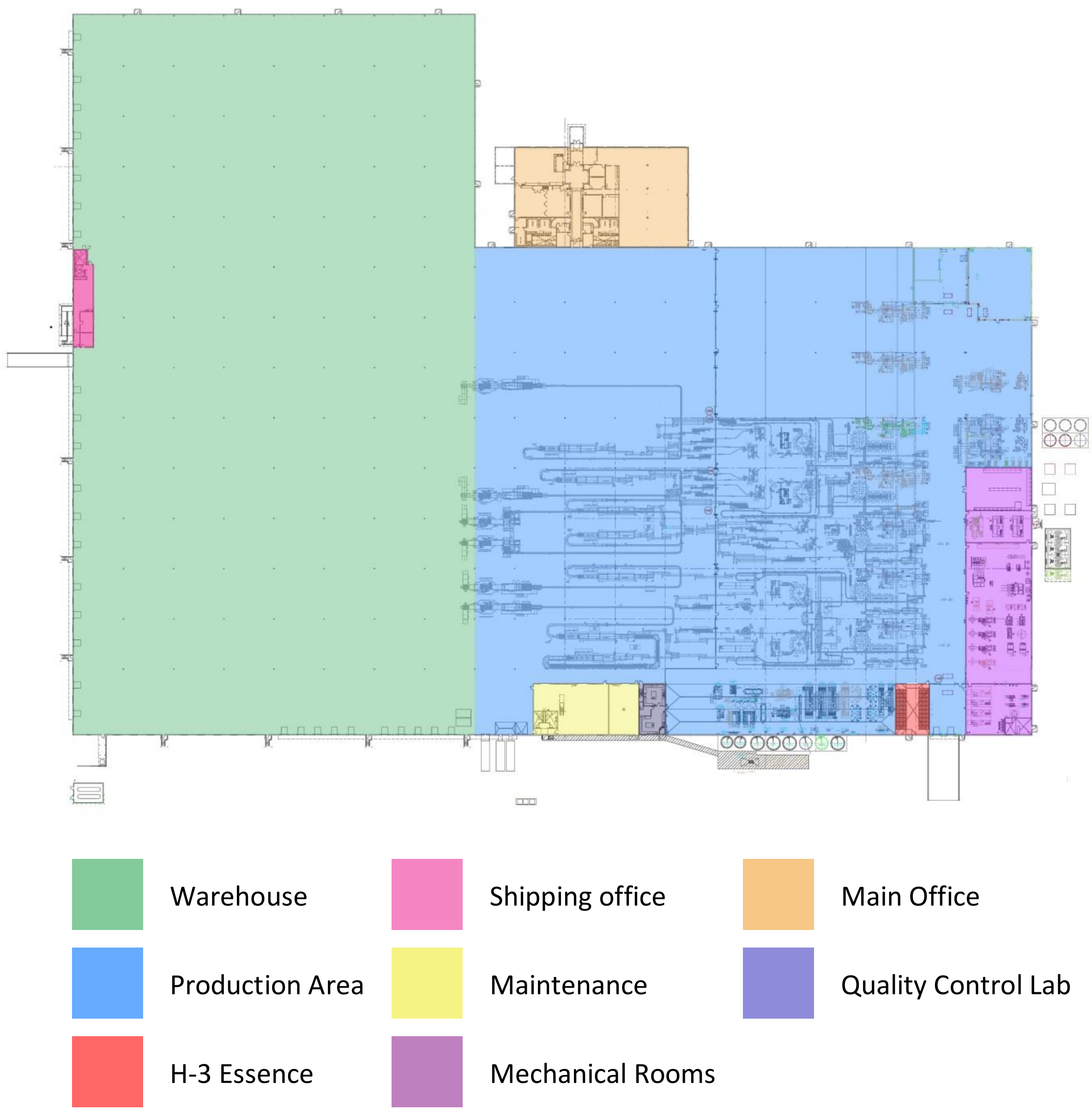

Figure 2 - Block Load Floor Plan

Load Sources and Molding Information

The requirements found for each block in the block analysis were collected from the building specifications provided by the owner. Table 3 shows how each of the spaces compare to the others based on their use.

Space	Max Cooling Dry Bulb	Cooling Dew Point/Max	Relative Humidity	Min Heating Temperature
Warehouse	80°± 2°F	48°F/50°F	-	60°F
Shipping Office	74°F	-	45%	68°F
Main Office	74°F	-	45%	68°F
Production	80°± 2°F	48°F/50°F	-	60°F
Maintenance	104°± 2°F	-	45%	60°F
QC Lab	75°F	59°F/64°F	-	68°F
H-3 Essence	80°± 2°F	48°F/50°F	-	50°F
Mechanical	80°± 2°F	48°F/50°F	-	60°F

Table 3 – Space Requirements

System Load Analysis Results

Table 4 shows the cooling, heating, supply, and ventilation requirements for the Water Bottling Facility. The supply data was gathered from the AHU schedule within the drawings. There were no calculations provided by the engineers.

	Cooling (ft^2/ton)	Heating ($Btu/h*ft^2$)	Supply Air (cfm/ft^2)	Ventilation Air (cfm/ft^2)
Block Calculation	17.99	0	0.78	0.04
Data Supplied	3.33	2.80	0.57	0.14

Table 4 – Block Load Calculations vs. Actual Rates

The variations seen in this table compared to those found in the mechanical schedule could be a result of missing information and a very low cooling requirement for most spaces.

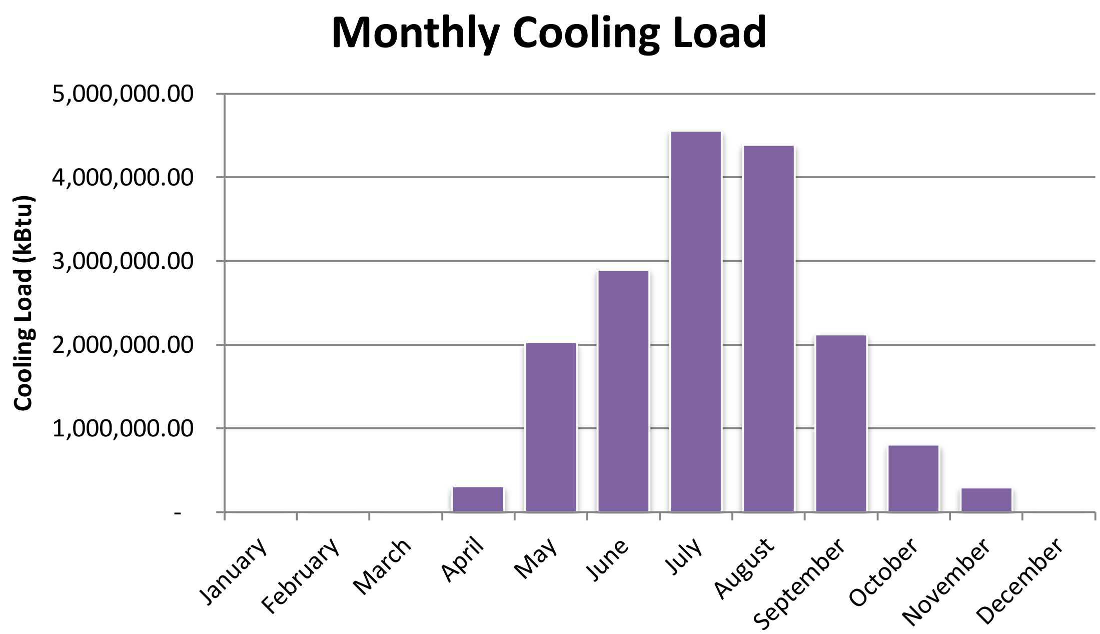

Figure 3 - Monthly Cooling Load

As seen in the Figure 3, the summer requires a much greater mechanical output while the cooler months hardly have any load requirements. This is because the processing produces such a large amount of heat that heating is unnecessary unless the facility is not running in the case of a holiday or other scheduled or unscheduled shutdown. These days were neglected in the load calculation because they only occur about twice a year. This results in a total demand of 17,429,535 kBtu annually. The peak cooling load occurs in July requiring 6,125 kBtu/h, while the heating load is nonexistent because the equipment in the building generates so much heat.

Existing System Energy Consumption & Operating Costs

Energy cost and consumption were taken into account in the HAP model based on the load calculation. The cooling for the roof top units was provided by chillers, which run on electric. The heating via mechanical systems had no impact on the total energy usage because of the amount of heat generated by the equipment in the production portion of the facility.

Function	Energy (kW)	Total Energy (%)
HVAC	27,354,233	28.1
Lighting	12,686,111	12.1
Electrical Equipment	64,583,837	61.7

Table 5 – Energy Consumption Breakdown

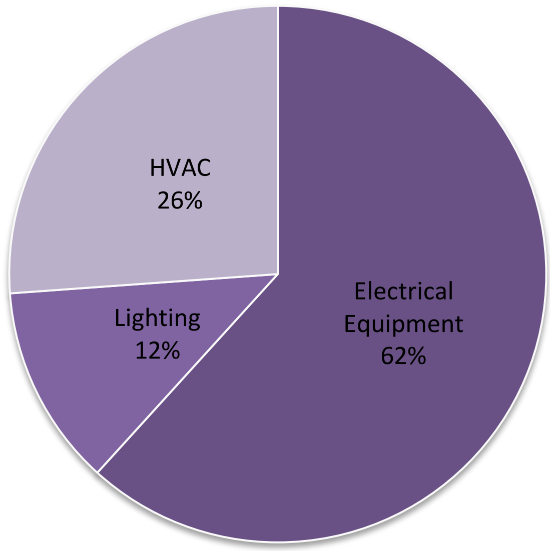

Figure 4 - Energy Consumption Pie Chart

A monthly break down of energy use can be seen in Figure 5, which shows that the summer months have the greatest energy consumption. This higher electrical demand is a result of the cooling load demanded by the building. The electrical loads for other aspects of the building stay consistent throughout the year because the Water Bottling Facility works on a 24-hour schedule.

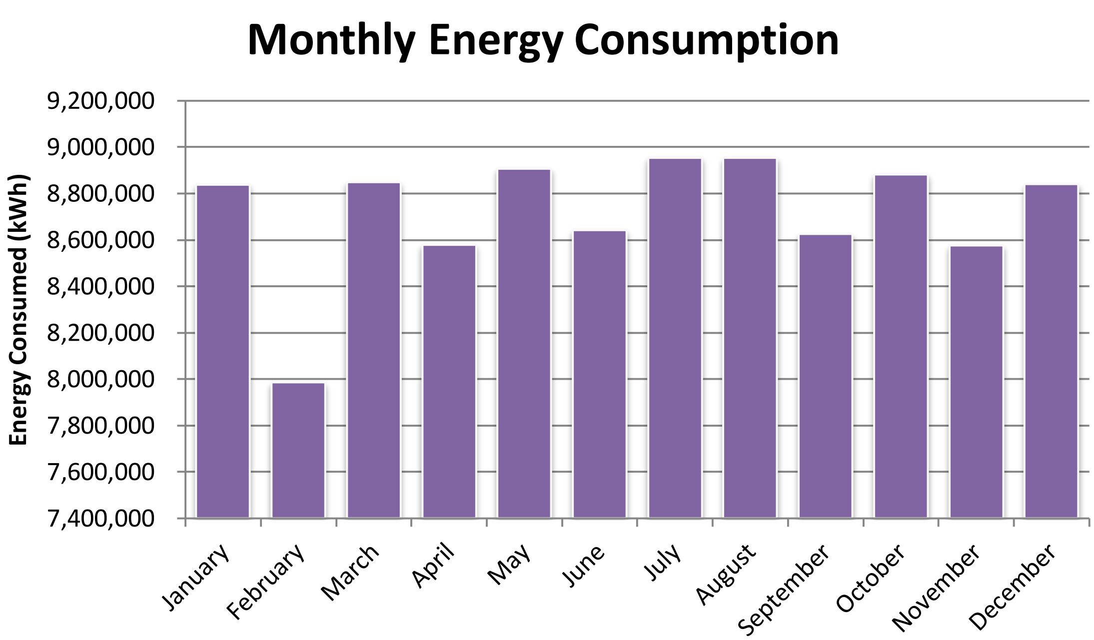

Figure 5 - Monthly Electrical Energy Consumption

The power company from which the Water Bottling Facility receives its electricity has developed a plan with the company negotiating a constant electrical rate of 7.13¢/kWh regardless of peak demand times.

The total utilities cost for electricity consumed is just under $7.9 million annually. HVAC comprised about $2 million worth of that total. Are equivalent to costing the Water Bottling Facility 9.96 $\$/ft^2$ for all electrical loads and 3.52 $\$/ft^2$ for all HVAC required electricity.

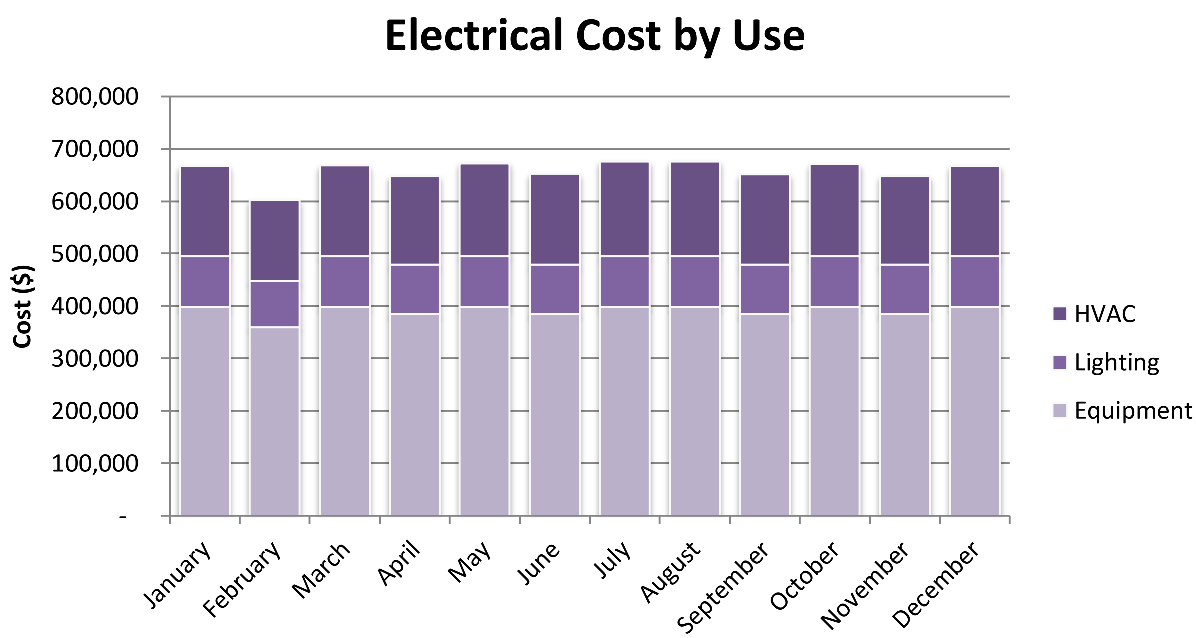

Figure 6 - Monthly Building Electricity Costs by Use

Building Energy and Cost Analysis Results

The data generated by the block analysis shows that the major contributor to the Water Bottling Facility's electric bill is the equipment used in production. Lighting also contributes a significant amount. During the summer months, the HVAC system uses a larger percentage of electricity than it does in the winter months because the equipment in the facility generates enough heat to only require a cooling load, even in the winter. The building requires 17.43 GBtu/yr.

The estimated operating cost was also calculated using the block calculations and produced value of $5,873,466 annually with 28.1% of this consumption accredited to HVAC systems. This total gives the building an operating cost of 13.486 $\$/ft^2$ total with 3.526 $\$/ft^2$ of that attributed to HVAC systems.

Research Introduction

The proposed mechanical redesign includes incorporating a ground-coupled heat pump to replace the air-handing unit used to condition the main office. This will use less energy and prevent the air-handling units in the production area from being overloaded by allowing the office air-handing unit to act as a backup on days of extreme heat. Fabric ducts will also be researched to find one that is durable enough to stay intact with little maintenance while providing an antimicrobial surface. A maintenance plan will be explored to increase ease of access to the fabric duct. The excess heat produced by the production equipment will be exhausted to the outside in the summer months and used as free heating for the packaging area in the winter.

Ground Coupled Heat Pump – Mechanical Depth

Background

The environmental aspects of the Water Bottling Facility are important to the company that runs it. Incorporating an environmentally friendly heating and cooling system, that uses less energy than the current air-handling units, can satisfy this desire. The large heating load on design temperature days, when the facility is running at full capacity, can sometimes prove to be too much for the air-handling units designated for the production area. At those times, the comfort of the occupants of the office has to be sacrificed to keep the equipment from overheating and malfunctioning. With the air redirected to the production area, production is not interrupted, but the productivity in the office is. With the excess heat, people do not work as well because they become tired and uncomfortable.

Rather than adding a larger air-handling unit to compensate for those hot days in the summer, adding a ground couple heat pump to the system can take over the main role of the office's air-handing unit. This heat exchanger uses the constant temperatures of the earth (45°F to 75°F) to both heat and cool the spaces in the building. Using refrigerant conditioned by passing through pipes at least 20ft deep in the earth's surface, the heat exchangers are more efficient than those using outside air because the earth is cooler than the air in the summer and warmer than the air in the winter. This system uses natural conduction to change the temperature and therefore required less energy than a traditional heat exchanger.

Analysis

To determine the proper pump and heat pumps to use for the system a site analysis had to be conducted along with the load analysis shown previously.

Site

The location of the Water Bottling Facility plays an important role when selecting a ground coupled heat pump system. The many colors on the geological map of the United States in Figure 7 indicate different types of rock constituting the regions geological landscape. Figure 8 shows the exact location of the Water Bottling Facility and its surrounding geological makeup. The rock composition surrounding the plant is Limestone, the properties of which can be seen in Table 6. The properties of the rocks in the area affect the rate of heat transfer between the system and the earth. Having rocks with a greater conductivity would require less pipe length than those with low conductivity because more time is needed to transfer the heat.

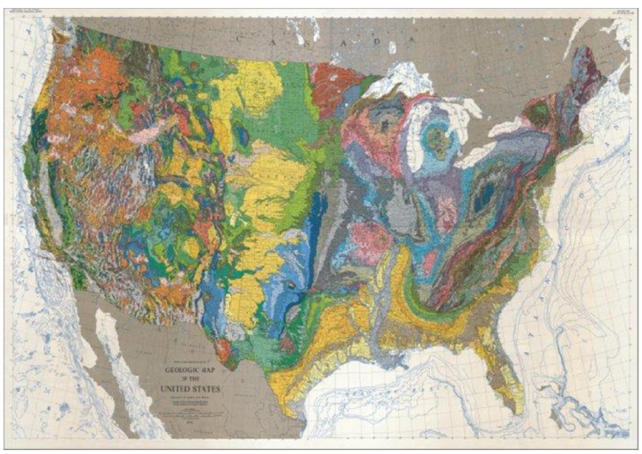

Figure 7 - Geological Map of the United States

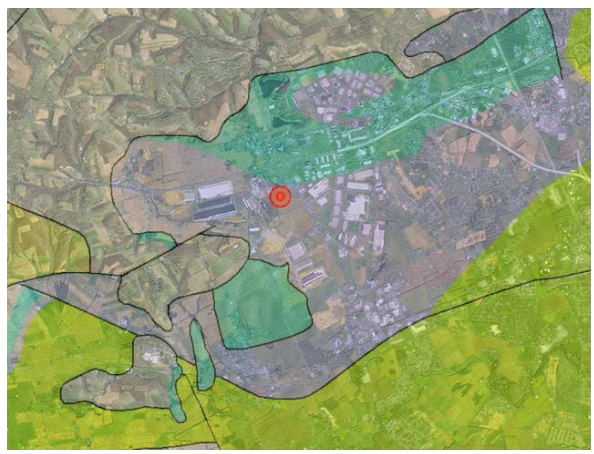

Figure 8 - Geological Map of the Water Bottling Facility

Rock Type	Dry Density (lb/ft^3)	Conductivity (Btu/h·ft·°F)	Diffusivity (ft^2/day)
Limestone	150 to 175	1.4 to 2.2	0.9 to 1.4
Average Value	162.5	1.8	1.15

Table 6 – Thermal Properties of Rocks

The ground temperature of the Water Bottling Facility is also important to sizing the system. The region highlighted in blue of Figure 9 indicates the region in which the Water Bottling Facility is located. Has an average ground temperature of 53°F. Each contour on the map represents 2°F change in temperature.

Figure 9 - Ground Temperature Map

Sizing

Before calculating the information needed to size the ground coupled heat pump system's utilities, the orientation of the system must be selected. Both horizontal and vertical piping configurations have different benefits. Horizontal layouts provide an easier and less expensive installation while a vertical layout requires more specialized equipment to drill deep into the earth. However, more advantages fall in the scope of the vertical layout, which needs less space, does not affect the thermal properties of the ground, and used less pipe as well as pump energy. Because of the space and energy efficiency factors of the vertical layout, this will be used for the design. Along with this layout comes the decision of bore diameter, U-tube diameter, and backfill type. For this case, the bore will have a diameter of 6 inches with a U-tube diameter of 1 inch. The bore fill will be a composition of 15% bentonite and 85% SiO_2 sand. These values were chosen to have a higher conductivity while being conscious of cost.

To determine the proper pipe length for the ground couple heat pump system equations 1 and 2 must be compared. These equations produce pipe length values for both cooling and heating loads. The larger number must be used to be able to me the requirements of the season with the greater demand. The values used in these equations can be seen at the end of this section in Table 8. These values are then described in detail further along in the report.

$$L_c = \frac{q_a R_{ga} + (q_{lc} - 3.41W_c)(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p} \qquad (1)$$

$$L_h = \frac{q_a R_{ga} + (q_{lh} - 3.41W_h)(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p} \qquad (2)$$

Short-Circuit Heat Loss Factor, F_{sc}

The short circuit heat loss factor is based off the number of bores per loop and the flow rate of the loop. For the GCHP system of the Water Bottling Facility, there will be one bore per loop, which will have a flow rate of 3gpm. With these values the short-circuit heat loss factor is 1.04 increasing the length of the loop.

Required Bore Length, L_c (Cooling), L_h(Heating)

Equations 1 and 2 solve for the length of the bore required to meet the demand loads for heating and cooling. These values are compared and the one resulting in the longer length is used in the design in order to meet the building load requirements.

Part-Load Factor during Design Month, PLF_m

The part load factor adjusts the value of the ground's thermal resistance to be more accurate on a month-to-month basis. This number will only reduce the length of the bore because it would increase the conductivity. Because the value is unknown, a value of 1.0 will be used in calculations to include a safety factor that maximizes length.

Net Annual Average Heat Transfer to Ground, q_a

The net annual average heat transfer to the ground is represented by the difference between the heating and cooling loads. Because the heating load is nonexistent, this number is the same as the cooling load, 6,125,519 Btu/h.

Building Design Block Load, q_{lc}(Cooling), q_{lh} (Heating)

The building design block loads for both heating and cooling were calculated earlier in this report using Carrier's Hourly Analysis Program. This resulted in zero heating load because the equipment in the Water Bottling Facility produces a large amount of heat. The peak cooling load for the building is 6,125,519 Btu/h.

Effective Thermal Resistance of Ground, R_{ga} (Annual), R_{gd} (Daily), R_{gm} (Monthly)

This value must be calculated based of the thermal diffusivity of the ground, the time of operation, and the bore diameter resulting in a Fourier number:

$$Fo = \frac{4\alpha_g \tau}{d_b^2}$$

Where τ varies for the annual, monthly, and peak daily is defined as:

τ_1 = 3650 days τ_2= 3650 +30 = 3680 days τ_f= 3650 + 30 + 0.25 = 3680.25 days

The Fourier is then transformed for each operation length:

$$Fo_f = \frac{4\alpha_g \tau_f}{d_b^2} \qquad Fo_1 = \frac{4\alpha_g(\tau_f - \tau_1)}{d_b^2} \qquad Fo_2 = \frac{4\alpha_g(\tau_f - \tau_2)}{d_b^2}$$

To calculate the ground's thermal resistance the equations below must be used:

$$R_{ga} = \frac{G_f - G_1}{k_g} \qquad R_{ga} = \frac{G_1 - G_2}{k_g} \qquad R_{ga} = \frac{G_2}{k_g}$$

The G-Factor must be determined using **Error! Reference source not found.** along with the calculated Fourier numbers.

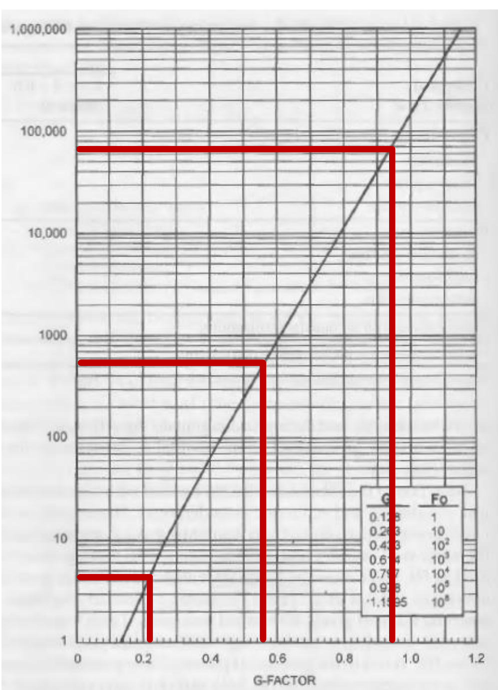

Figure 10 - Fourier/G-Factor Graph for Ground Thermal Resistance

Time Pulse	Fourier Number	G-Factor	Thermal Resistance (ft·h·°F/Btu)
Annual	67,716.6	0.94	0.211
Monthly	556.6	0.56	0.183
Daily Peak	4.6	0.22	0.122

Table 7 – Thermal Resistance Calculations

Thermal Resistance of Bore, R_b

The thermal resistance of the bore is dependent on the diameter of the bore, the conductivity of the bore fill, and the diameter of the U-tube. The bore chosen has a 6-inch diameter with a fill conductivity of 1.00 to 1.10 from a bentonite SiO_2 sand mixture. The U-tube will have a diameter of 1 inch resulting in a thermal resistance of 0.10 Btu/h·ft·°F

Undisturbed Ground Temperature, t_g

As seen in the site analysis earlier in this section the average undisturbed ground temperature around the Water Bottling Facility is 53°F.

Temperature Penalty for Interference of Adjacent Bores, t_p

The temperature penalty for interference of adjacent bores is a result of the closeness of the closeness of the bores in relation to one another. The tradeoffs of distance between bores and area needed to accommodate the loads need to be weighed to find the best spacing. Based on the Long Term Temperature Penalty Table for a 10 by 10 grid with a 100-ton load that can be seen in Appendix B the value of 1.8°F was used in the calculations. This was selected based off the ground temperature closest to that of the area and the bore separation of 20ft requiring a bore depth of 195ft.

Liquid Temperature at Heat Pump, t_{wi} *(Inlet),* t_{wo} *(Outlet)*

The liquid temperature at the heat pump's inlet and outlet should be relative to the ground temperature. The inlet temperature should be 20 to 30°F higher or 10 to 20°F lower for cooling and heating respectively. Since there is no heating load for the building, the inlet temperature was selected to be 68°F. The outlet temperature should result in a 10°F increase to 78°F.

System Power Input at Design Load, W_c *(Cooling),* W_h *(Heating)*

The system power was estimated to be 112,000 W for both heating and cooling. This number was found in conjunction with the pump based on the pump's horsepower. When corrected for the true value of the pumps horsepower there was little effect on the length of the system and the total number of bores.

Results

	Cooling Value	Heating Value	Units
F_{sc}	1.04		-
PLF_m	1.0		-
q_a	6,125,519		Btu/h
q_l	6,125,519	0	Btu/h
R_{ga}	0.211		ft·h·°F/Btu
R_{gd}	0.183		ft·h·°F/Btu
R_{gm}	0.122		ft·h·°F/Btu
R_b	0.10		ft·h·°F/Btu
t_g	53		°F
t_p	1.8		°F
t_{wi}	78	38	°F
t_{wo}	88	48	°F
W	10,000	10,000	W
L	**125,020**	**0**	**ft**

Table 8 – Bore Length Calculation Values

Layout

The total bore length required by the Water Bottling Facility's peak load 120,510 ft. This length is then divided by depth of the bores. A depth of 400ft was chosen for this application to reduce the area of the well field. The resultant is a field with 300 bores. Since the well field is located under the southern parking lot of the building, it needed to follow a narrow grid of 5 by 60 to reach the desired 300 bores.

This location was selected to have the least impact on the functions of the Water Bottling Facility. The parking lot disturbed by construction is used as over flow parking for the employees of the facility. The only important access along this side of the building is that of the water tanks. For construction, an alternate path will need to be made to allow tanker trucks to provide the necessary spring water for production.

Figure 11 shows the proposed well field layout overlaid on a picture of the site. The connections to the building are located within the mechanical rooms of the Water Bottling Facility.

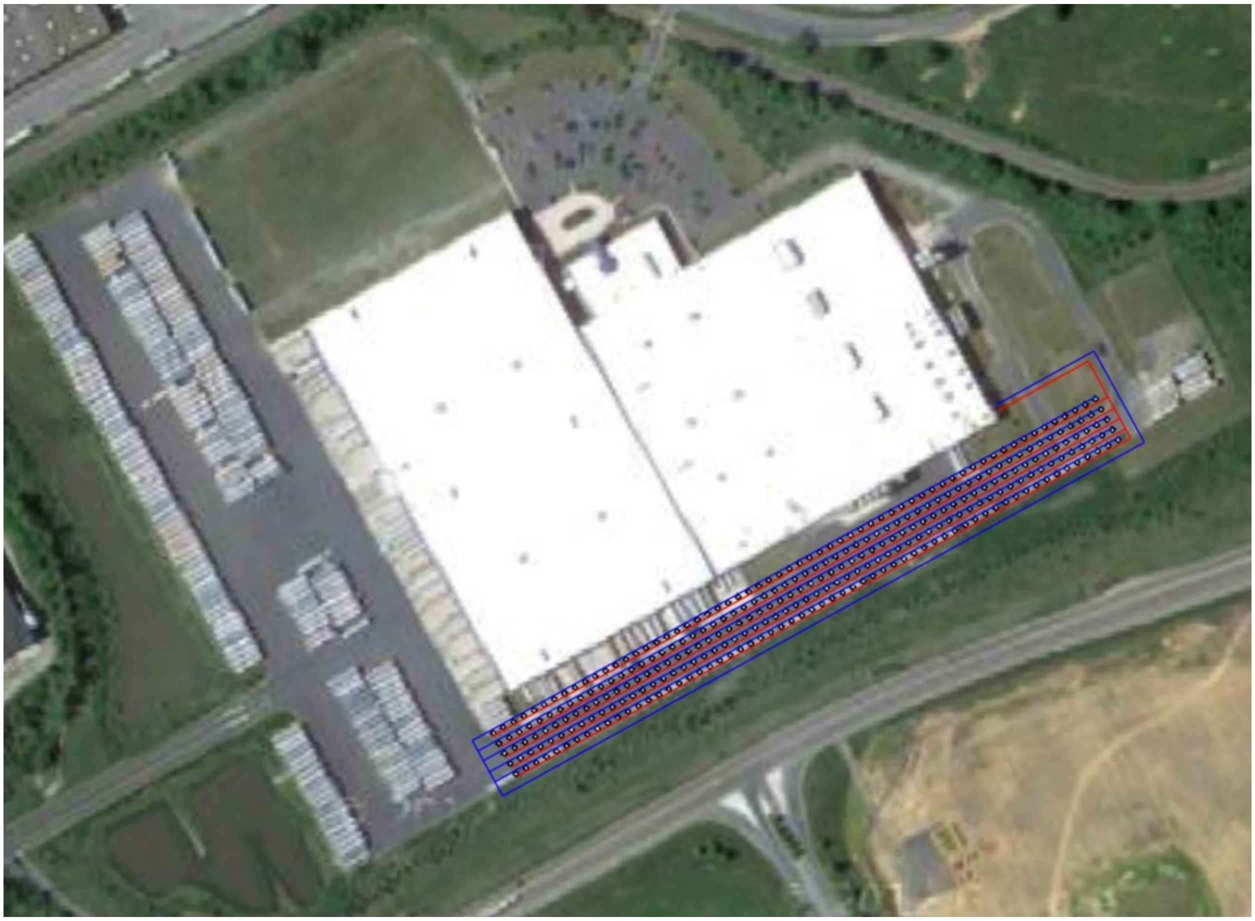

Figure 11 - Well Field Bore Hole Layout

Equipment Selection

Head Loss Calculations

To calculate the head loss of the system the lengths of each of the bores as well as the branches need to be considered. Because the layout of the well field is reverse return, each bore should have the same head loss. The branch loops have a U-tube diameter of 1 inch with main header of constant diameter of 8 inches.

	Length (ft	Multiplicity	Total Length (ft)	Head Loss (ft/100 ft)	Total Head Loss (ft)
Bore	400	2	800	2.5	20
Longest Branch	20	60	1200	2.5	30
Tee-Fittings	7	2	14	2.5	0.35
Elbows	4	4	14	2.5	0.35
				Total	50.7

Table 9 – Equivalent Lengths of Bores and Branches

The calculations for head loss for the rest of the system can be seen in Table 22 in Appendix B. The head loss for the rest of the system came to about 203.3 ft, which when combined with the head loss of the bores produces a total head loss of 254 ft. From this information the pumps and heat pumps were selected

Pump Selection

From the information gathered it is evident that a pump needs to have a capacity of 1531 gpm and account for a head loss of 254ft. To accommodate these needs the pump, the pump catalog of the manufacturer Bell & Gossett was used. Pump selected is a Series HSC[3] that has a 3500 RPM motor to account for the desired flow rate and head loss. Two of these pumps would be installed for redundancy in the case that one fails or needs to be repaired, the other will be able to maintain the system. Charts regarding the sizing of this pump can be seen in Figure 30 and Figure 31 of Appendix B.

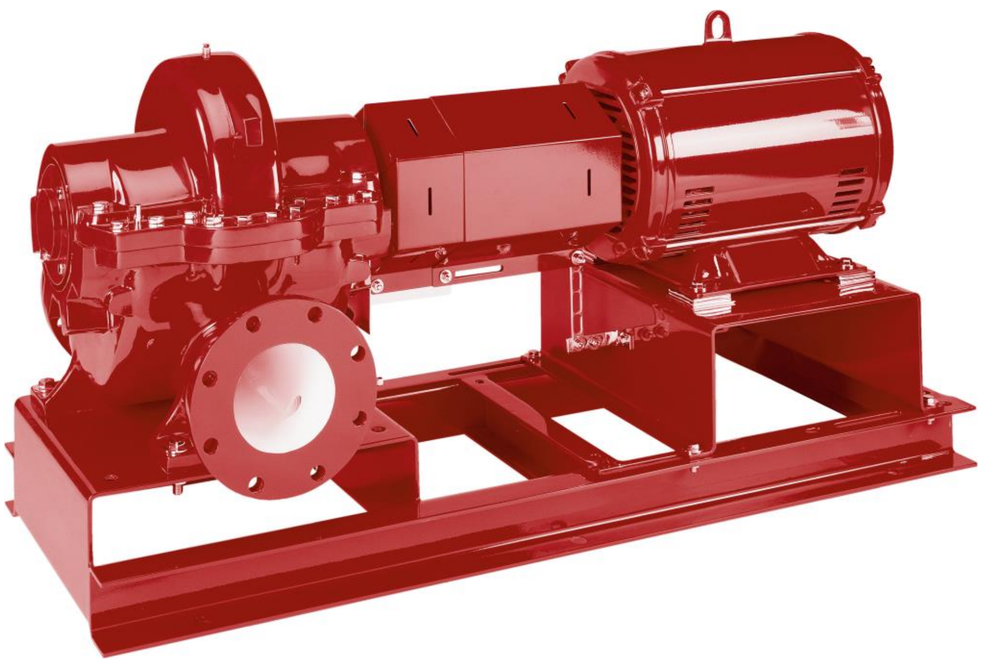

Figure 12 - Bell & Gossett Split Case Pump

Manufacturer	Model	Flow Rate (gpm)	Head (ft)	Impeller Diameter (in)	RPM	HP
Bell & Gossett	4x6x10M HSC[3]	1531	254	8.3	3565	150

Table 10 – Pump Data

Heat Pump Selection

Water Source heat pumps need to be selected to replace the current roof top units. These units must be sized similarly to the units currently in place. Rooftop Water source heat pumps range in size from 3 to 25 tons, since the system is about 510 tons, there need to be 21 units, 4 of which are 25 tons units and one 10 ton unit. The electrical specifications for these units can be seen in Table 24 of Appendix B.

Table 11 - Rooftop Water Source Heat Pump

Energy, Cost, & Emissions Comparison

After developing the design for a ground coupled heat pump system, the original simulation created in Carrier's HAP was adapted to use a ground-coupled system to meet load requirements. Because the system was designed to fit the peak demand load, no makeup heating or cooling was needed to pair with the GCHP system. Table 12 shows the comparison of the original design and the depth design. The implementation of a ground-coupled heat pump would reduce the Water Bottling Facility's energy consumption for HVAC systems by nearly 30% saving them over $615,000 annually

Design	Energy Usage (kWh)	Electric Cost
Original	27,354,230	$ 2,065,428
Ground Source Heat Pump	19,201,080	$ 1,449,730
Difference	8,153,150	$ 615,698

Table 12 – HVAC Simulation Report Comparison

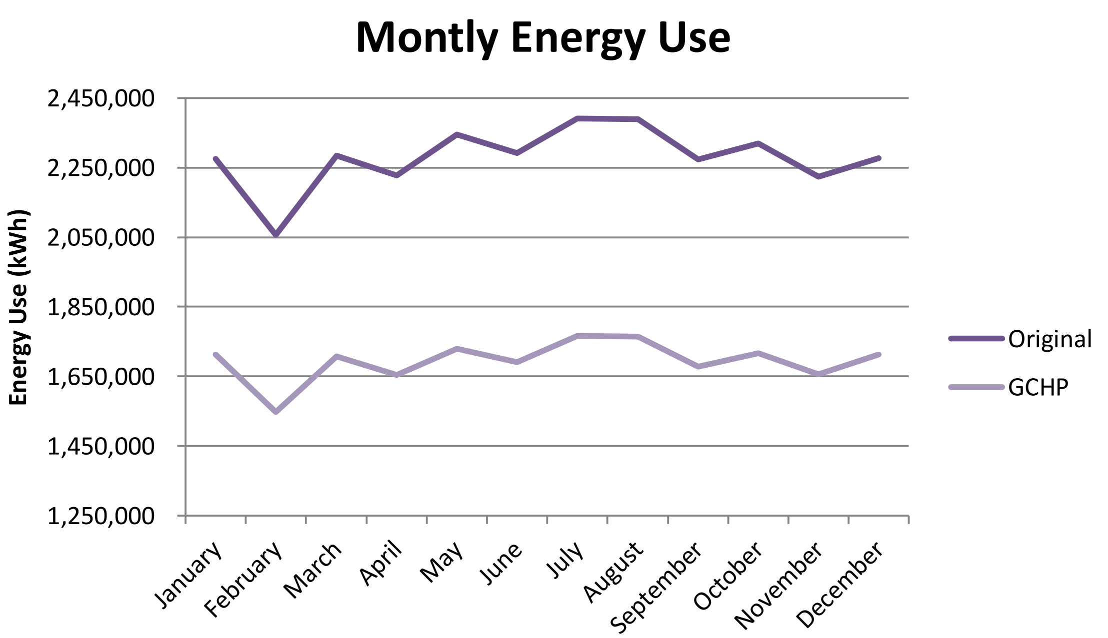

Figure 13 - Energy Use: Original vs. GCHP

The comparison of the monthly electrical loads due to mechanical loads follows are relatively consistent trend. Each month has an average energy savings of 585,000 kWh. Even though the graph appears to have a constant difference between the original and new energy use totals the differences actually vary 116,000 kWh.

Month	Original Energy (kWh)	GCHP Energy (kWh)	Difference (kWh)
January	2,275,032	1,713,184	561,848
February	2,056,716	1,547,770	508,946
March	2,285,022	1,707,854	577,168
April	2,228,204	1,654,628	573,576
May	2,344,024	1,729,509	614,515
June	2,291,104	1,690,252	600,852
July	2,390,752	1,765,344	625,408
August	2,389,709	1,764,376	625,333
September	2,273,169	1,677,335	595,834
October	2,319,265	1,715,919	603,346
November	2,223,874	1,655,288	568,586
December	2,277,362	1,712,482	564,880
		Largest Difference	116,462
		Average Value	585,024

Table 13 – Energy Consumption Comparison

The reduction in energy use means a reduction in emissions related to the energy use of the Water Bottling Facility. Changing the mechanical system can reduce the amount of pollutants the building produces by a minimum of 25% when observing only the mechanical systems.

Pollutant	Regional Grid Emission Factors 2007 (lb/kWh)	Calculated Emissions (lb/year)		Reduction in Emissions
		Original	GCHP	
CO2e	1.74E+00	3.96E+06	2.98E+06	25%
CO2	1.64E+00	3.37E+06	2.54E+06	25%
CH4	3.59E-03	8.20E+03	6.13E+03	25%
N2O	3.87E-05	8.62E+01	6.40E+01	26%
NOX	3.00E-03	7.03E+03	5.19E+03	26%
SOX	8.57E-03	1.96E+04	1.45E+04	26%
CO	8.54E-04	2.04E+03	1.51E+03	26%
TNMOC	7.26E-05	1.73E+02	1.28E+02	26%
Lead	1.39E-07	3.16E-01	2.33E-01	26%
Mercury	3.36E-08	7.79E-02	5.77E-02	26%
PM10	9.26E-05	2.06E+02	1.53E+02	26%
Solid Waste	2.05E-01	4.67E+05	3.51E+05	25%

Table 14 – Emissions Calculations and Comparison

Duck Sock Redesign – Mechanical Depth

Background

Currently the production area is ducted using a fabric duct that hangs just below the ceiling above major heat producing pieces of equipment. This fabric duct, while good in theory, has posed a problem for the efficiency of the mechanical system. Because of its elevation and location, maintenance is a challenge. Having little to no maintenance in combination with using a material that may have been improperly selected has caused several tears to occur and go unfixed.

Solution

When selecting an alternative ducting method three things need to be considered: durability, food safety, and ease of installation. The conjunction of these requirements narrowed the duct selection down to the Microbe-X™ fabric duct created by the DuctSox™ Corporation. In comparison with its competing fabric duct manufacturers, the DuctSox™ Corporation was the only manufacturer that had the USDA backing needed in a food production zone.

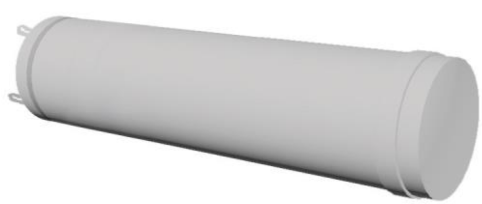

Figure 14 - DuctSox

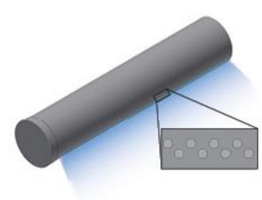

Figure 15 - Linear Vents

To prevent production downtime for the Water Bottling Facility, following the same path as the pervious duck is key. The same dimension fabric duct with a stronger material and structure was selected to reduce any issues that could arise with installation. To increase the ducts durability, it is important to find a duct that can handle the airflow demanded of it. The Microbe-X™ fabric duct has heavy weight collars to reinforce joints and create a smooth airflow. The duct's material is treated with a non-leaching, permanent antimicrobial. Air quality is important to the Water Bottling Facility, which already incorporates HEPA filters into the airflow.

In addition to meeting these requirements, the fabric duct also provides uniform air distribution that standard metal ducts do not. Because there are vents located along the duct in a pattern that optimizes airflow rates and throw these ducts can efficiently cool the high demand spaces without suffering from a large amount of pressure drop due to the long distance.

Heat Exhaust System – Mechanical Depth

Within the Water Bottling Facility's production area, an abundance of heat is generated in both the summer and winter months by the equipment used to create the preforms of the water bottles, to create the finished bottles, and to fill those bottles with water. Although the preform and blow-molding equipment all have internal, cooling systems to prevent overheating, temperatures in this portion of the facility can reach 85°F before the air-handling units are set to cool the space.

To reduce the energy cost the stack effect will be used in the production area. Openings in the roof can act as a chimney to draw heat out of the building as it rises due to natural convection. This system will have its own controls for the louvered openings.

Set points for the system will be at the thermal comfort level of 72°F. This set point is not the same as that of the air conditioning system because it is being used as a preventative that can reduce the need to condition the space. Along with this set point, there will be a manual over ride to close the louvers in the case of severe weather that could penetrate the building

The louvered openings will have coverings that prevent normal occurrences of rain from entering the building while allowing air to pass freely though the opening. Figure 16 shows an example of a dampered roof mounted exhaust. This design gives adequate space for airflow while separating the outdoors from the indoors.

Figure 16 - Dampered Vent for Roof Mount Exhaust

Nine of vents will be installed, one over each of the major heat producing pieces of equipment. This will not only remove excess heat from the space but increase ventilation.

Acoustical Breadth

Background

Employees of the Water Bottling Company that work specifically in the production, packaging, and warehouse spaces participate in a twelve hour shifts four to five days a week. During their time at work, the employees are exposed to high levels of noise in the production and space where sound levels can reach 101 dBA with many spaces averaging in the high 80 to low 90dBA range. These levels are above the maximum value of 90 dBA for an eight-hour workday permitted by the Occupational Safety and Health Administration. Table 15 below indicates the maximum sound level for differing exposure times. Based on an extrapolation of the data from the permissible noise exposure table the maximum sound level for continuous exposure over twelve hours is 87dBA.

Duration Per Day Hours	Sound Level dBA
8	90
6	92
4	95
3	97
2	100
1 ½	102
1	105
½	110
¼ or less	115

Table 15 - Permissible Noise Exposures

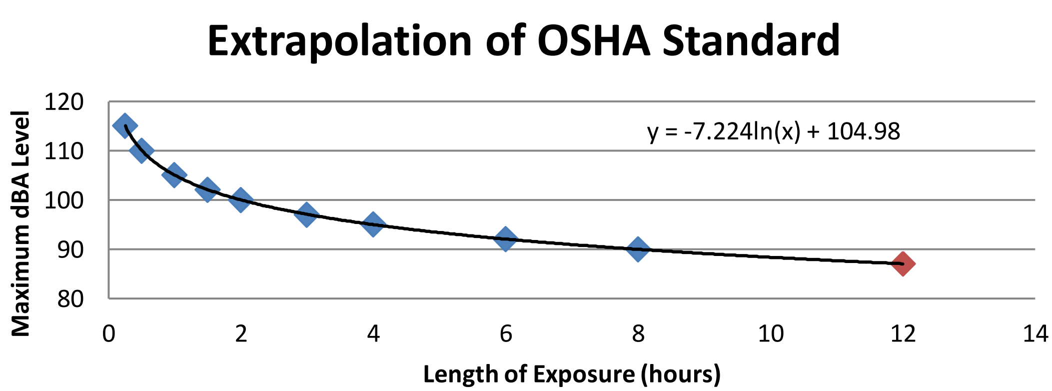

Figure 17 - Extrapolation of OSHA Standard

To conform to the OSHA requirements the Water Bottling Facility provides multiple options for hearing protection for its employees and performs yearly hearing checks to monitor the potential for hearing loss. Providing these devices and services only reduces the chance of hearing loss if the hearing protection is used and used properly. Reducing the overall sound level of the space will create a better work environment by making it safer and more efficient.

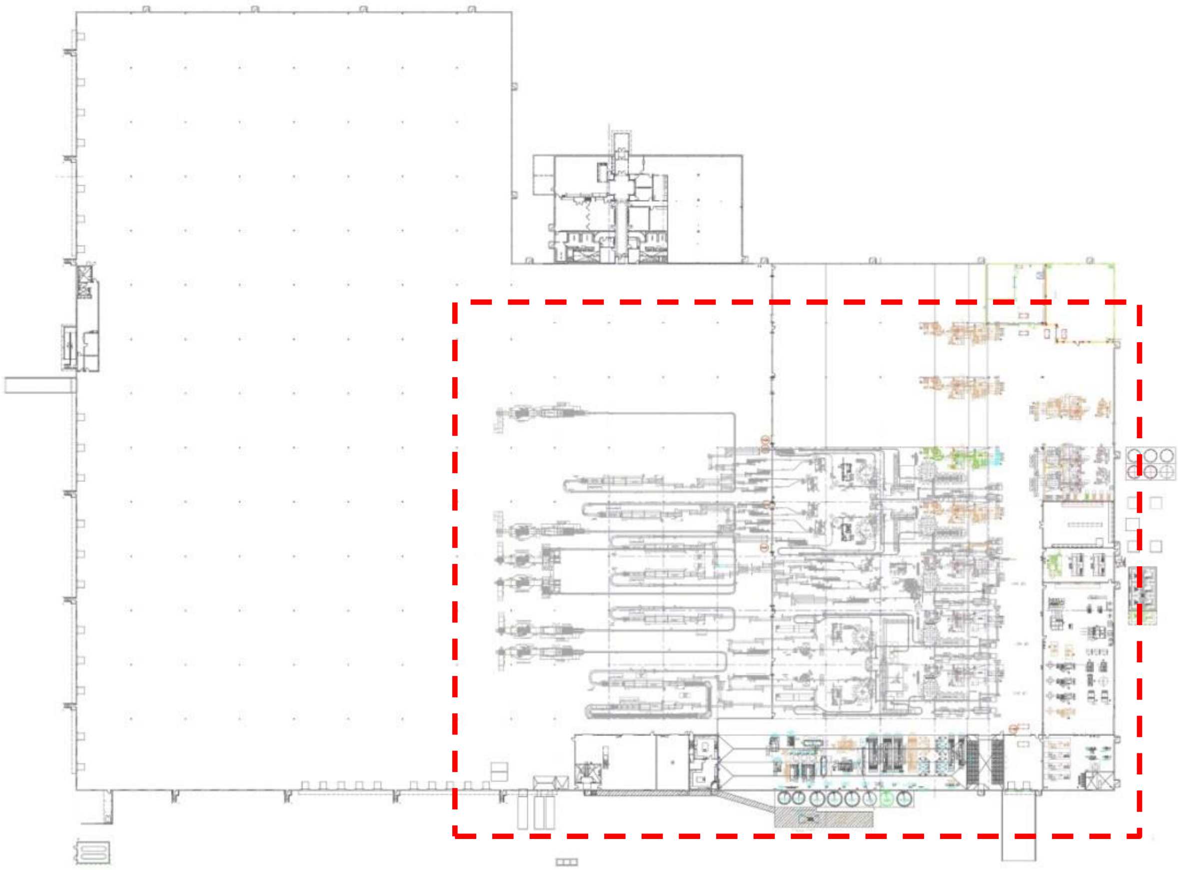

Figure 18 - Floor Plan

Figure 18 highlights the location of focus for the acoustical analysis. In this area are many loud pieces of equipment that contribute to the high sound levels. On the following page is a sound map of the Water Bottling Facility. This map shows the sound level in dBA for each measured location marked. The numbers are highlighted based on their sound level according to potential danger ranges.

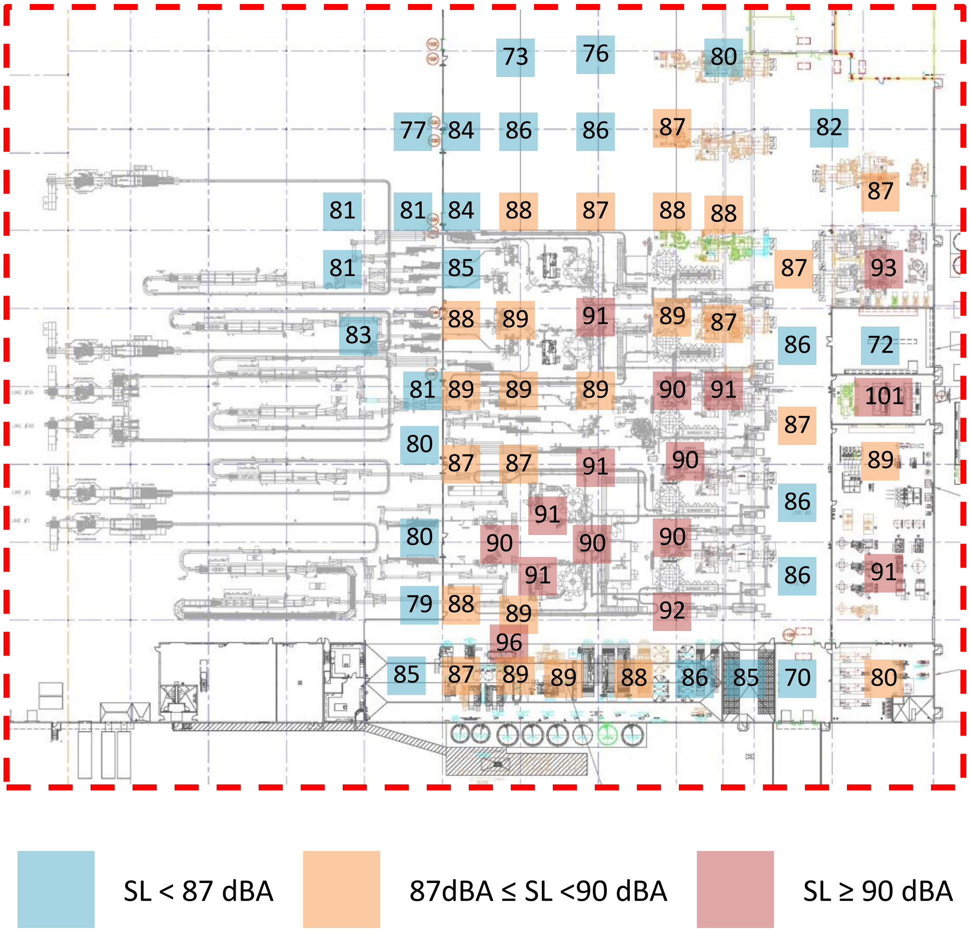

Figure 19 - Sound Map

Solution

To reduce the sound level in the production area hanging acoustical baffles can be hung from the ceiling. The baffles used in this analysis are manufactured but Kinetics Noise Control, a company that focused on acoustics and vibration isolation. The baffle itself is the KINETICS™ Sound Control Baffles Model KB-803. This model was selected because it can be manufactured using an FDA and USDA approved covering, which is important in the Water Bottling Facility, because it is bottling water for human consumption.

To select the appropriate number of baffles the surface area of the walls celling and floor must be taken to find the total surface area. The surfaces must then be assessed for hardness. From this, a nomogram is used to calculate the number of baffles required to have the desired noise reduction. Because sound levels reach up to 96 dBA in the main area and the goal is to have sound levels under 87 dBA, it is desirable to have a 10 dBA reduction in sound level.

Step 1: Determine Surface Area

Surface	Dimensions (ft)	Number of Surfaces	Area (ft^2)
Walls:	23.5 x 315 23.5 x 439	2 2	14,805 20,633
Floor:	315 x 439	1	138,285
Ceiling:	315 x 439	1	138,285
Total:			312,008

Table 16 - Surface Area of Production

Step 2: Overall Acoustical Character

Surface	Acoustical Characteristic
Walls:	Hard x 5 (Concrete) Medium x 1 (stacked pallets)
Floor:	Hard (Concrete)
Ceiling:	Hard (Steel)
Combined Characteristic:	Medium Hard

Table 17 - Wall Character Analysis

Steps 3 - 5: Plot Information from Previous Steps on Nomogram

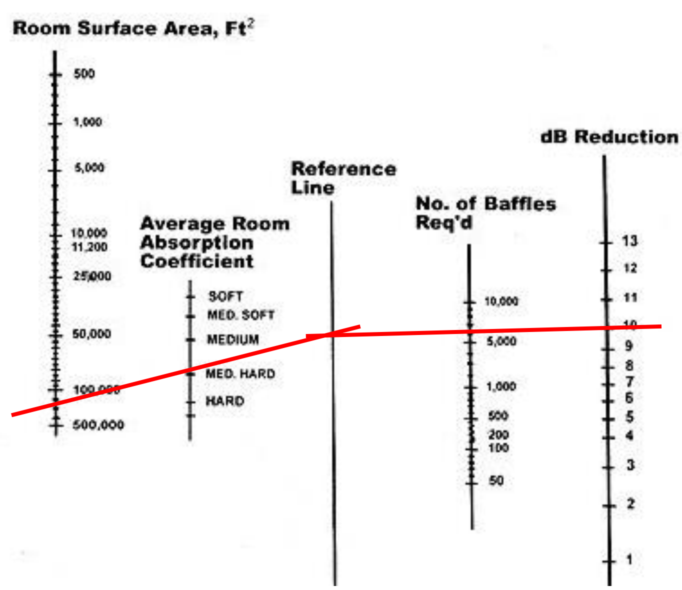

Figure 20 - Nomogram Analysis

Based on the information collected using the nomogram, 6,000 baffles are needed to reduce the sound levels to under 87 dBA in the production area. Using the 24" x 48" size baffle, two hanging methods are available both using the same suspension cable layout. The Honeycomb and Parallel patterns can be seen below.

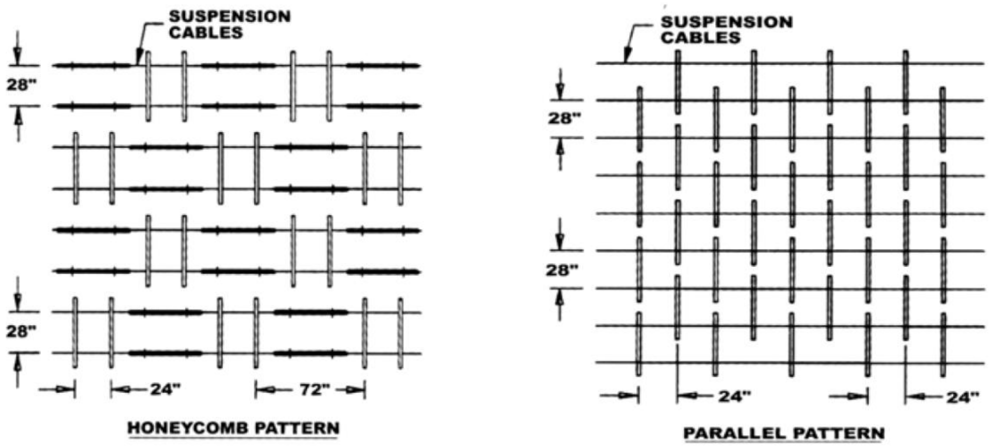

Figure 21 - Baffle Layout Options

The baffle densities for these patterns are 13.5 baffles/100 ft^2 for the honeycomb pattern and 12 baffles/100 ft^2 for the parallel pattern. Either of these densities is acceptable for hanging the baffles from the ceiling because the room only requires a density of 2 baffles/100 ft^2. The floor plan in Figure 22 shows the proposed baffle layout that will provide the best noise control based on sound levels in the areas.

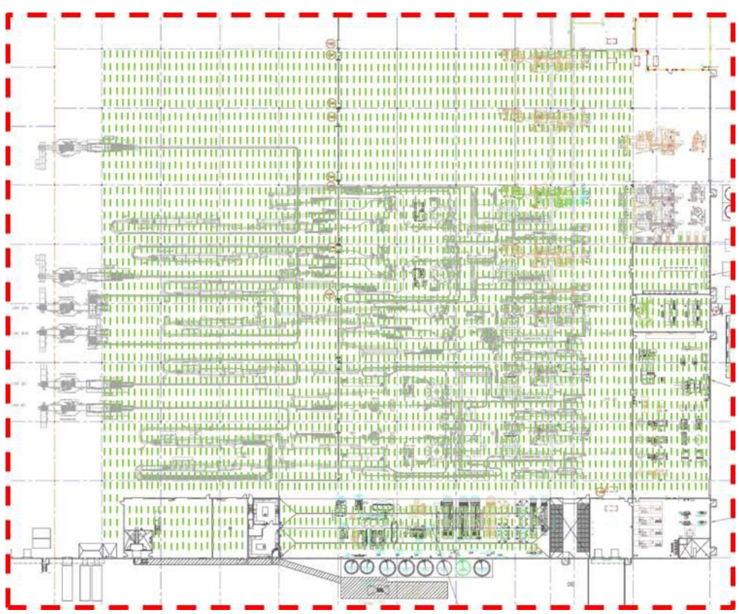

Figure 22 - Baffle Layout

Photovoltaic Breadth

Background

As previously seen in the energy use analysis of the Water Bottling Facility, the peak load for the building is 1,334,638 kWh in the peak cooling load month of July. To make up for some of that energy use it is recommended that the Water Bottling Facility add a photovoltaic system to its roof to contribute to the grid power.

Solution

To calculate the amount of electricity that can be produced in a photovoltaic array the average daily solar radiation was calculated and can be seen in Figure 23. These values were collected using the System Advisor Model program with location input information.

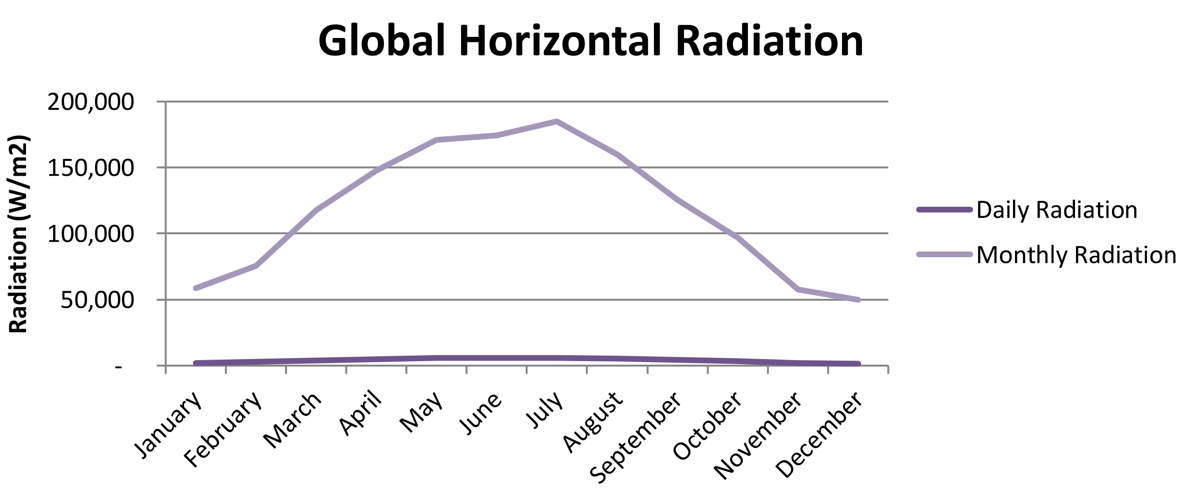

Figure 23 - Global Horizontal Radiation by Month

After finding the radiation, a solar module must be selected. In this case, a Sharp 300 Watt Multi-Purpose Module was analyzed. This module's specifications can be seen in Appendix E. To determine the electrical output of these arrays the total area of the roof was calculated to be 214,500 ft^2 excluding space occupied by other equipment on the roof. To prevent inter row shading calculations were performed which can be seen along with their results in Table 18.

Panel Width	Array Tilt Angle	Height From Ground	Horizontal Length	Distance Between Panels	Row Spacing
77.6 in	33°	21.3 in	32.8 in	63.9 in	**96.7 in**

Table 18 – Array Spacing Calculations

Because of the orientation of the building modules were mounted facing the south east with a 33° tilt. This angle was selected to allow the panel to collect the most incident radiation. With this spacing and area, 7695 modules were arranged in 405 strings of 19. These strings were then wired in 5 parallel groups of 81 strings, each group with its own inverter to increase array output. The layout of these modules can be seen in Figure 24.

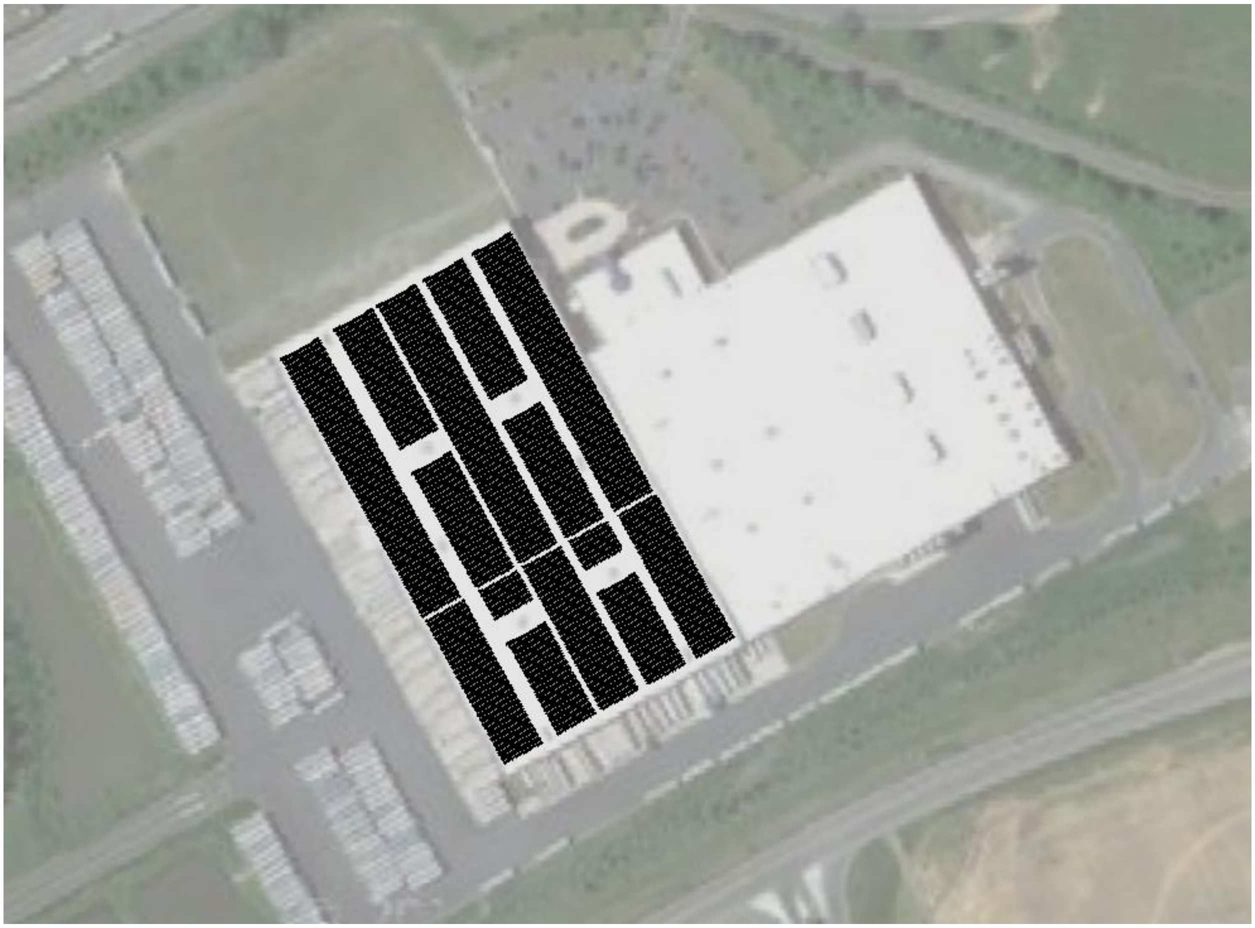

Figure 24 - PV Array Layout

As can be seen in Table 19 - Solar RadiationTable 19 the direct radiation is accompanied by diffuse radiation to energize the photovoltaic array. Also evident in this table is the difference in net output between the DC and AC sides of the inverter. During the inversion process, electricity is lost converting the power from direct current to alternating current. AC current is the type of electricity used in the United States because, although it takes a loss in energy, it is much safer. If an accident were to occur and a person were electrocuted, the alternating current would allow the person to break free of the electrical current while a direct current would hold the person to itself not giving them the opportunity to escape.

Month	Beam Incident Radiation (kWh/m2)	Total Incident Radiation (kWh/m2)	Net DC Output (kWh)	Net AC Output (kWh)	Peak Daily HVAC Demand (kWh)	Difference (kWh)
January	55.95	90.61	50,402	41,602	42	41,560
February	50.55	97.46	84,698	75,567	98	75,469
March	76.06	134.88	154,112	142,010	2,973	139,037
April	79.07	146.97	226,988	212,703	91,122	121,581
May	77.37	153.18	274,686	258,784	595,540	-336,756
June	69.07	151.30	275,015	259,367	849,425	-590,058
July	83.74	163.15	295,087	278,953	1,335,638	-1,056,685
August	80.86	152.08	237,668	223,063	1,287,181	-1,064,118
September	74.28	134.93	165,337	153,409	623,408	-469,999
October	76.37	124.04	93,685	83,602	235,863	-152,261
November	43.55	80.11	55,004	46,542	86,774	-40,232
December	50.17	79.11	42,569	34,245	28	34,217

Table 19 - Solar Radiation and Energy Produced

Cost Analysis

The total cost of the addition of a photovoltaic array to the Water Bottling Facility is estimated to be over $10.66 million. This number was developed using the SAM 2913 program used earlier in the section.

	# of units	kW/unit	kW	$/W	Total
Module	7695	0.3	2307.76	2.05	$ 4,730,910.62
Inverter	5	500	2500	0.37	$ 925,000.00
Balance Of System, Equipment	-	-	-	0.43	$ 992,337.3
Installation Labor	-	-	-	0.48	$ 1,107,725.41
Installer Margin And Overhead	-	-	-	0.81	$ 1,869,286.64
Permitting	-	-	-	0.23	$ 530,785.09
Grid Interconnection	-	-	-	0.01	$ 23,077.61
Total				$ 4.62	$ 10,660,385.73

Table 20 – Cost Analysis

From this analysis it was determined that the payback period would take an infinite amount of time because of the deterioration of the PV modules. At this point in time, a PV array is not the best option for the Water Bottling Facility. When photovoltaic technology develops further and produces more efficient modules it may be a topic that should be considered again

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Haskel Architects and Engineers Engineering Reports

Water Bottling Facility Specifications and Images

Appendix A – Building Load Analysis Documents

Block	Area (ft^2)	# of People	Ceiling Height (ft)	Length Facing Compass Direction (ft^2) / Doors (ft^2) / Windows (ft^2)											
				NE/W			SE/S			SW/E			NW/N		
H-3 Essence	1650	17	19.5	-	-	-	675	21	16	-	-	-	-	-	-
Main Office	17414	395	8	2176	21	438	-	-	-	2176	0	680	3103	0	939
Maintenance Mezz.	6690	22	16	-	-	-	2893	0	0	-	-	-	-	-	-
Maintenance Shop	5311	53	12	-	-	-	1050	42	0	-	-	-	-	-	-
Mechanical	17385	58	23.5	-	-	-	-	-	-	9600	100	0	-	-	-
Processing	245176	2452	23.5	-	-	-	1280	221	0	6400	121	0	12240	84	0
Q.C. Lab	1378	14	10	-	-	-	265	21	0	-	-	-	-	-	-
Shipping Mezz.	1906	6	16	1930	0	0	-	-	-	-	-	-	-	-	-
Shipping Office	1906	19	8.5	1158	21	57	-	-	-	-	-	-	-	-	-
Warehouse	285530	571	30	9280	1926	0	16000	1105	0	24800	21	0	16000	105	0

Equipment	Number of Units	Power per Unit (W)	Total Power (W)
Blowmolder	6	767000	4,602,000
Packer	8	10000	80,000
Piovan	7	110000	770,000
Filler	6	21000	126,000
Labeler	6	37000	22,000
Husky	7	224000	1,568,000

Table 21 - Block Load Data

Appendix B – Ground Coupled Heat Pump Documents

2011 ASHRAE Handbook – HVAC Applications

Table 4 Summary of Potential Completion Methods for Different Geological Regime Types

Geological Regime Type	Grout 0.4 < k ≤ 0.8 Btu/h·ft·°F	Grout 0.8 < k ≤ 1.2 Btu/h·ft·°F	Grout k > 1.2 Btu/h·ft·°F	Backfill with Cutting	Two-Fill with Cuttings Below Aquifers	Two-Fill with Other* Below Aquifers
Clay or low-permeability rock,						
no aquifer	—	Yes	Yes	—	Yes	Yes
single-aquifer	—	Yes	Yes	—	—	Yes
multiple-aquifer	Yes	Yes	Yes	Yes	Yes	Yes
Permeable rock,						
no shallow aquifers	—	Yes	Yes	Yes	Yes	Yes
single-aquifer	—	Yes	Yes	Yes	Yes	Yes
multiple-aquifers	—	Yes	Yes	Yes	—	—
Karst terrains with secondary permeability	—	Yes	Yes	Yes	—	—
Fractured terrains with secondary permeability	—	Yes	Yes	Yes	Yes	Yes

*Use of backfill material that has thermal conductivity of $k \ge 1.4$ Btu/h·ft·°F

Yes = Recommended potentially viable backfill methods

install this length, and during cooling mode the efficiency benefits of an oversized ground coil could be used to compensate for the higher first cost.

Selection of the fill material for the borehole is a function of thermal, regulatory, and economic considerations. Historically, a relatively low-thermal-conductivity bentonite grout commonly used in the water well industry and, in some cases, drill cuttings have been used as fill. More recently, thermally enhanced materials have been developed. Nutter et al. (2001) contains a detailed evaluation of potential fills and grouts for vertical boreholes. Table 4 summarizes potential completion methods for various geological conditions. "Two-fill" refers to the practice of placing a low-permeability material in the upper portion of the hole and/or in intervals where it is required to separate individual aquifers, and a more thermally advantageous material in the remaining intervals.

Thermal resistance of the ground is calculated from ground properties, pipe dimensions, and operating periods of the representative heat rate pulses. Table 5 lists typical thermal properties for soils and fills for the annular region of the bore holes. Table 6 gives equivalent thermal resistance of the vertical high-density polyethylene (HDPE) U-tubes for two bore hole diameters d_b. Alternative methods of computing the thermal borehole resistance are presented by Bernier (2006), Hellström (1991), and Remund (1999).

The most difficult parameters to evaluate in Equations (2) and (3) are the equivalent thermal resistances of the ground. The solutions of Carslaw and Jaeger (1947) require that the time of operation, bore diameter, and thermal diffusivity of the ground be related in the dimensionless Fourier number (Fo):

$$\mathrm{Fo} = \frac{4\alpha_g \tau}{d_b^2} \qquad (4)$$

where

α_g = thermal diffusivity of the ground, ft²/day
τ = time of operation, days
d_b = bore diameter, ft

The method may be modified to permit calculation of equivalent thermal resistances for varying heat pulses. A system can be modeled by three heat pulses, a 10 year (3650 day) pulse of q_a, a 1 month (30 day) pulse of q_m, and a 6 h (0.25 day) pulse of q_h. Three times are defined as

$$\tau_1 = 3650 \text{ days}$$
$$\tau_2 = 3650 + 30 = 3680 \text{ days}$$
$$\tau_f = 3650 + 30 + 0.25 = 3680.25 \text{ days}$$

The Fourier number is then computed with the following values:

$$\mathrm{Fo}_f = 4\alpha\tau_f/d_b^2$$

Table 5 Thermal Properties of Selected Soils, Rocks, and Bore Grouts/Fills

	Dry Density, lb/ft³	Conductivity, Btu/h·ft·°F	Diffusivity, ft²/day
Soils			
Heavy clay, 15% water	120	0.8 to 1.1	0.45 to 0.65
5% water	120	0.6 to 0.8	0.5 to 0.65
Light clay, 15% water	80	0.4 to 0.6	0.35 to 0.5
5% water	80	0.3 to 0.5	0.35 to 0.6
Heavy sand, 15% water	120	1.6 to 2.2	0.9 to 1.2
5% water	120	1.2 to 1.9	1.0 to 1.5
Light sand, 15% water	80	0.6 to 1.2	0.5 to 1.0
5% water	80	0.5 to 1.1	0.6 to 1.3
Rocks			
Granite	165	[illegible]	[illegible]
Limestone	150 to 175	1.4 to 2.2	0.9 to 1.4
Sandstone		1.2 to 2.0	0.7 to 1.2
Shale, wet	160 to 170	0.8 to 1.4	0.7 to 0.9
dry		0.6 to 1.2	0.6 to 0.8
Grouts/Backfills			
Bentonite (20 to 30% solids)		0.42 to 0.43	
Neat cement (not recommended)		0.40 to 0.45	
20% bentonite/80% SiO_2 sand		0.85 to 0.95	
15% bentonite/85% SiO_2 sand		1.00 to 1.10	
10% bentonite/90% SiO_2 sand		1.20 to 1.40	
30% concrete/70% SiO_2 sand, s. plasticizer		1.20 to 1.40	

Source: Kavanaugh and Rafferty (1997).

Table 6 Thermal Resistance of Bores R_b for High-Density Polyethylene U-Tube Vertical Ground Heat Exchangers

U-Tube Diameter, in.	Bore Fill Conductivity,* Btu/h·ft·°F: 4 in. Diameter Bore 0.5	4 in. Diameter Bore 1.0	4 in. Diameter Bore 1.5	6 in. Diameter Bore 0.5	6 in. Diameter Bore 1.0	6 in. Diameter Bore 1.5
3/4	0.19	0.09	0.06	0.23	0.11	0.08
1	0.17	0.08	0.06	0.20	0.10	0.07
1 1/4	0.15	0.08	0.05	0.18	0.09	0.06

*Based on DR 11, HDPE tubing with turbulent flow

Corrections for Other Tubes and Flows

DR 9 Tubing	Re = 4000	Re = 1500
+0.02 Btu/h·ft·°F	+0.008 Btu/h·ft·°F	+0.025 Btu/h·ft·°F

Sources: Kavanaugh (2001) and Remund and Paul (2000).

Figure 25 - ASHRAE Handbook

$$Fo_1 = 4\alpha(\tau_f - \tau_1)/d_b^2$$

$$Fo_2 = 4\alpha(\tau_f - \tau_2)/d_b^2$$

An intermediate step in computing the ground's thermal resistance using the methods of Ingersoll and Zobel (1954) is to identify a G-factor, which is then determined from Figure 15 for each Fourier value.

$$R_{ga} = (G_f - G_1)/k_g \quad (5a)$$

$$R_{gm} = (G_1 - G_2)/k_g \quad (5b)$$

$$R_{gd} = G_2/k_g \quad (5c)$$

Ranges of the ground thermal conductivity k_g are given in Table 6. State geological surveys are a good source of soil and rock data. However, geotechnical site surveys are highly recommended to determine load soil, rock types, and drilling conditions.

Performance degrades somewhat because of short-circuiting heat losses between the upward- and downward-flowing legs of a conventional U-bend loop. This degradation can be accounted for by introducing the short-circuit heat loss factor [F_{sc} in Equations (2) and (3)] in the table below. Normally U-tubes are piped in parallel to the supply and return headers. Occasionally, when bore depths are shallow, two or three loops can be piped in series. In these cases, short-circuit heat loss is reduced; thus, the values for F_{sc} are smaller than for a single bore piped in series.

	F_{sc}	
Bores per Loop	**2 gpm/ton**	**3 gpm/ton**
1	1.06	1.04
2	1.03	[illegible]
3	1.02	1.01

Temperature. The remaining terms in Equations (2) and (3) are temperatures. The local deep-ground temperature t_g can best be obtained from local water well logs and geological surveys. A second, less accurate source is a temperature contour map, similar to Figure 16, prepared by state geological surveys. A third source, which can yield ground temperatures within 4°F, is a map with contours, such as Figure 17. Comparison of Figures 16 and 17 indicates the complex variations that would not be accounted for without detailed contour maps.

Selecting the temperature t_{wi} of water entering the unit is critical in the design process. Choosing a value close to ground temperature results in higher system efficiency, but makes the required ground coil length very long and thus unreasonably expensive. Choosing a value far from t_g allows selection of a small, inexpensive ground coil, but the system's heat pumps will have both greatly reduced capacity during heating and high demand when cooling. Selecting t_{wi} to be 20 to 30°F higher than t_g in cooling and 10 to 20°F lower than t_g in heating is a good compromise between first cost and efficiency in many regions of the United States.

A final temperature to consider is the temperature penalty t_p resulting from thermal interferences from adjacent bores. The designer must select a reasonable separation distance to minimize required land area without causing large increases in the required bore length (L_c, L_h). Table 7 presents the temperature penalty for a 10 by 10 vertical grid of bores for various operating conditions after 10 years of operation in a nonporous soil where cooling effects from moisture evaporation or water movement do not mitigate temperature change (Kavanaugh 2003; Kavanaugh and Rafferty 1997). Correction factors are included to find the temperature penalty for four other grid patterns. Note that the higher the number of internal bores, the larger the correction factor.

In the table, adjustments are made to the number of equivalent full-load hours (EFLHs) in cooling and heating that correspond to values consistent with the local ground temperature. To mitigate long-term heat build-up for small separation distances, the required heat exchanger length is extended to maintain good system efficiencies. Larger separation distances result in shorter required lengths and smaller temperature changes, because there is greater thermal capacity available and greater area to diffuse heat to the far field.

The table applies only to a limited number of specific cases and is not intended for application to actual designs. It is intended to demonstrate trends for various ground temperatures, hours of operation in heating and cooling, and bore separation distances. Note that values of t_p in the table are significantly different from those obtained using the approach presented by Bernier et al. (2008).

Smaller bore lengths per ton of peak block load result in larger temperature changes; the relationship between bore length and temperature change is inverse and linear.

Values in this table represent worst-case scenarios, and the temperature change is usually mitigated by groundwater recharge (vertical flow), groundwater movement (horizontal flow), and evaporation (and condensation) of water in the soil.

Groundwater movement strongly affects the long-term temperature change in a densely packed ground loop field (Chiasson et al. 2000). A related factor is the evaporative cooling effect experienced with heat addition to the ground. Although thermal conductivity is somewhat reduced with lower moisture content (see Table 5), the net effect is beneficial in porous soils when water movement recharges the ground to original moisture levels. A similar effect may be experienced in cold climates when soil moisture freezes and the heat of solidification mitigates excessive temperature decline. Because these effects have not been thoroughly studied, the design engineer must establish a range of design lengths between one based on minimal groundwater movement, as in very tight clay soils with

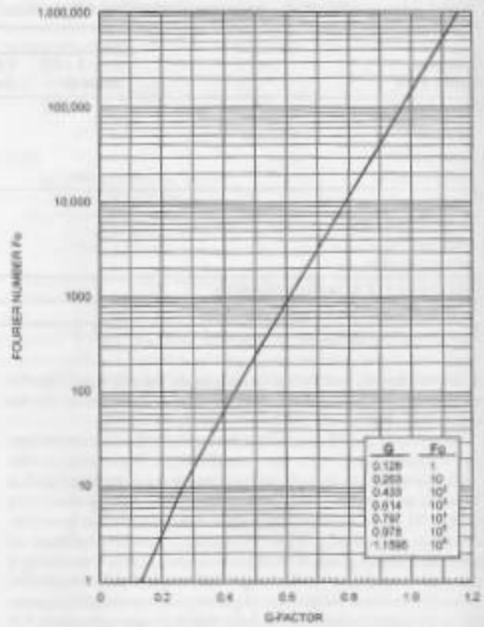


Fig. 15 Fourier/G-Factor Graph for Ground Thermal Resistance
(Kavanaugh and Rafferty 1997)

Figure 26 - ASHRAE Handbook

Geothermal Energy 34.17

Fig. 16 Water and Ground Temperatures in Alabama at 50 to 100 ft Depth
(Chandler 1987)

Table 7 Long-Term Temperature Penalty for Worst-Case Nonporous Formations for 10 × 10 grid and 100 ton Load

$EFLH_c$, h/yr	$EFLH_h$, h/yr	EER, Btu/W·h	COP	T_g, °F	Bore Separation, ft	Bore Length, ft	$T_{penalty}$, °F
250	1250	17.6	3.6	42	15	230	–1.3
		17.6	3.6		20	221	–0.7
		17.6	3.6		25	217	–0.4
500	1000	16.8	3.7	45	15	218	–1.4
		16.8	3.7		20	210	–0.7
		16.8	3.7		25	206	–0.4
750	750	14.3	4.0	55	15	206	3.4
		14.3	4.0		20	195	1.8
		14.3	4.0		25	190	1.0
1000	500	13.3	4.4	65	15	284	6.9
		13.3	4.4		20	248	3.8
		13.3	4.4		25	231	2.0
1250	250	13.0	4.6	68	15	362	10.0
		13.0	4.6		20	289	5.7
		13.0	4.6		25	256	3.0
0	1500	Not recommended without solar or thermal regeneration					
1500	0	Not recommended without fluid cooler or cooling tower assist					

Note:
k_g = 1.4 Btu/h·ft·°F, k_{grout} = 0.85 Btu/h·ft·°F, rated EER/COP = 20.0/4.2 (GLHP).

Correction Factors for Other Grid Patterns:

1 × 10 grid	2 × 10 grid	5 × 5 grid	20 × 20 grid
C_f = 0.36	C_f = 0.45	C_f = 0.75	C_f = 1.14

Fig. 17 Approximate Groundwater Temperatures (°F) in the Continental United States

Figure 27 - ASHRAE Handbook

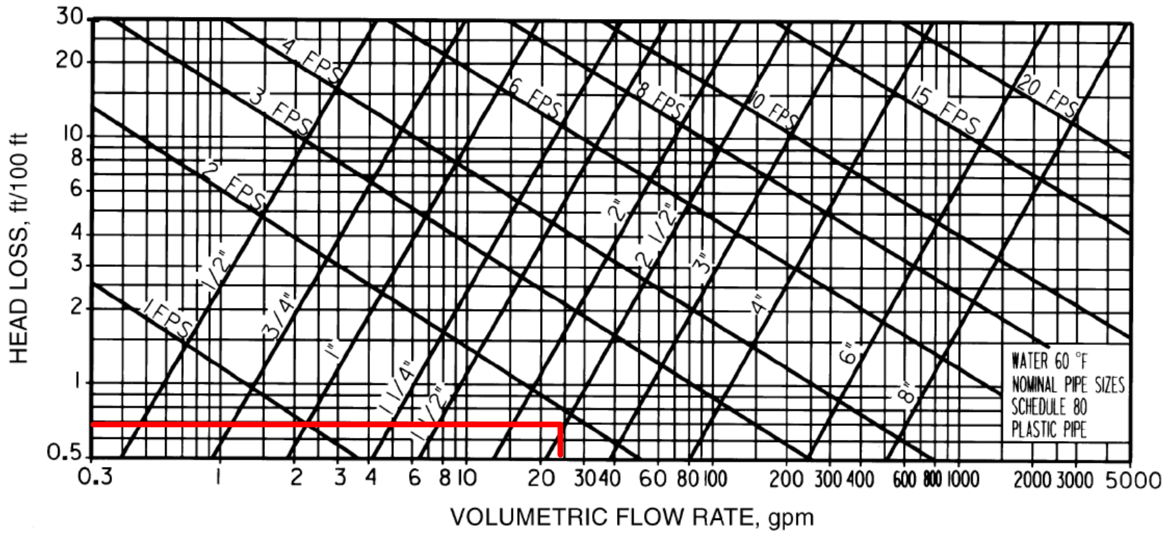


Fig. 6 Friction Loss for Water in Plastic Pipe (Schedule 80)

Figure 28 - Friction Loss for Branch Piping

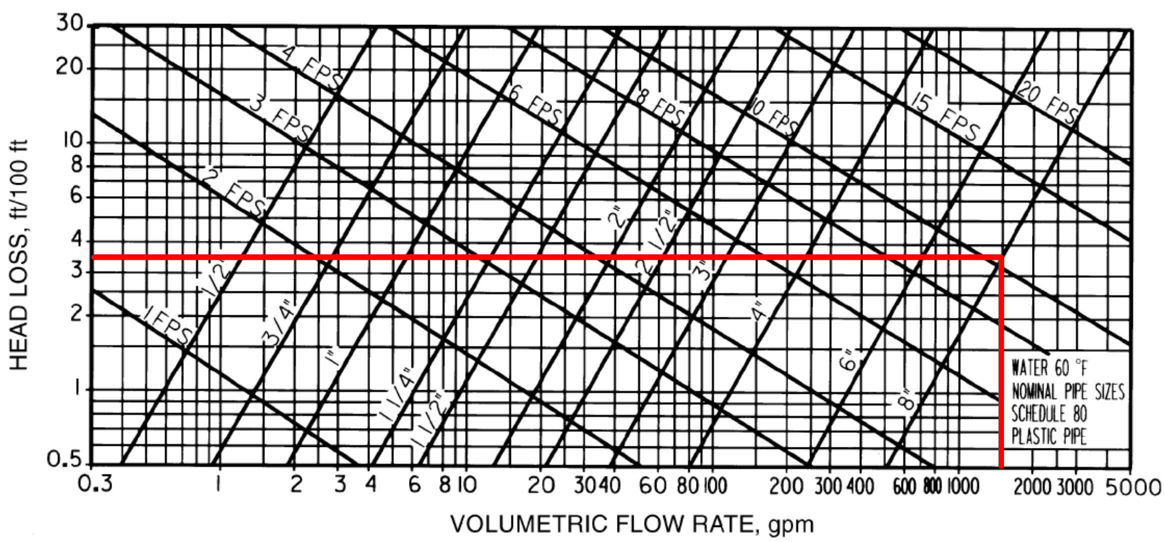


Fig. 6 Friction Loss for Water in Plastic Pipe (Schedule 80)

Figure 29 - Friction Loss for Main Header Piping

	Length (ft)	Flow Rate (gpm)	Fittings	Equivalent Length (ft)	Head Loss (ft/100ft)	Total Head Loss (ft)
Header	2800	1531	6 90° elbows	66	3.5	100.31
1	100	1505	2 Tees	14	3.5	3.99
2	100	1480	2 Tees	14	3.5	3.99
3	100	1455	2 Tees	14	3.5	3.99
4	100	1430	2 Tees	14	3.5	3.99
5	100	1405	2 Tees	14	3	3.42
6	100	1380	2 Tees	14	2.5	2.85
7	100	1355	2 Tees	14	2.4	2.736
8	100	1329	2 Tees	14	2.3	2.622
9	100	1304	2 Tees	14	2.2	2.508
10	100	1279	2 Tees	14	2.1	2.394
11	100	1254	2 Tees	14	2	2.28
12	100	1229	2 Tees	14	1.9	2.166
13	100	1204	2 Tees	14	1.8	2.052
14	100	1179	2 Tees	14	1.7	1.938
15	100	1154	2 Tees	14	1.6	1.824
16	100	1129	2 Tees	14	1.5	1.71
17	100	1104	2 Tees	14	1.5	1.71
18	100	1079	2 Tees	14	1.4	1.596
19	100	1054	2 Tees	14	1.4	1.596
20	100	1028	2 Tees	14	1.3	1.482
21	100	1003	2 Tees	14	1.3	1.482
22	100	978	2 Tees	14	1.3	1.482
23	100	953	2 Tees	14	1.3	1.482
24	100	928	2 Tees	14	1.2	1.368
25	100	903	2 Tees	14	1.2	1.368
26	100	878	2 Tees	14	1.1	1.254
27	100	853	2 Tees	14	1.1	1.254
28	100	828	2 Tees	14	1	1.14
29	100	803	2 Tees	14	1	1.14
30	100	778	2 Tees	14	1	1.14
31	100	753	2 Tees	14	1	1.14
32	100	727	2 Tees	14	0.9	1.026
33	100	702	2 Tees	14	0.9	1.026
34	100	677	2 Tees	14	0.8	0.912
35	100	652	2 Tees	14	0.8	0.912

36	100	627	2 Tees	14	0.7	0.798
37	100	602	2 Tees	14	0.7	0.798
38	100	577	2 Tees	14	1.8	2.052
39	100	552	2 Tees	14	1.7	1.938
40	100	527	2 Tees	14	1.6	1.824
41	100	502	2 Tees	14	1.5	1.71
42	100	477	2 Tees	14	1.3	1.482
43	100	452	2 Tees	14	1.2	1.368
44	100	426	2 Tees	14	1.2	1.368
45	100	401	2 Tees	14	1.2	1.368
46	100	376	2 Tees	14	1	1.14
47	100	351	2 Tees	14	0.9	1.026
48	100	326	2 Tees	14	0.8	0.912
49	100	301	2 Tees	14	0.8	0.912
50	100	276	2 Tees	14	0.6	0.684
51	100	251	2 Tees	14	0.5	0.57
52	100	226	2 Tees	14	2.5	2.85
53	100	201	2 Tees	14	2.5	2.85
54	100	176	2 Tees	14	2	2.28
55	100	151	2 Tees	14	0.8	0.912
56	100	125	2 Tees	14	0.8	0.912
57	100	100	2 Tees	14	0.8	0.912
58	100	75	2 Tees	14	1.5	1.71
59	100	50	2 Tees	14	0.7	0.798
60	100	25	2 Tees	14	0.7	0.798
					Total	**203.252**

Table 22 - Head Loss Calculations

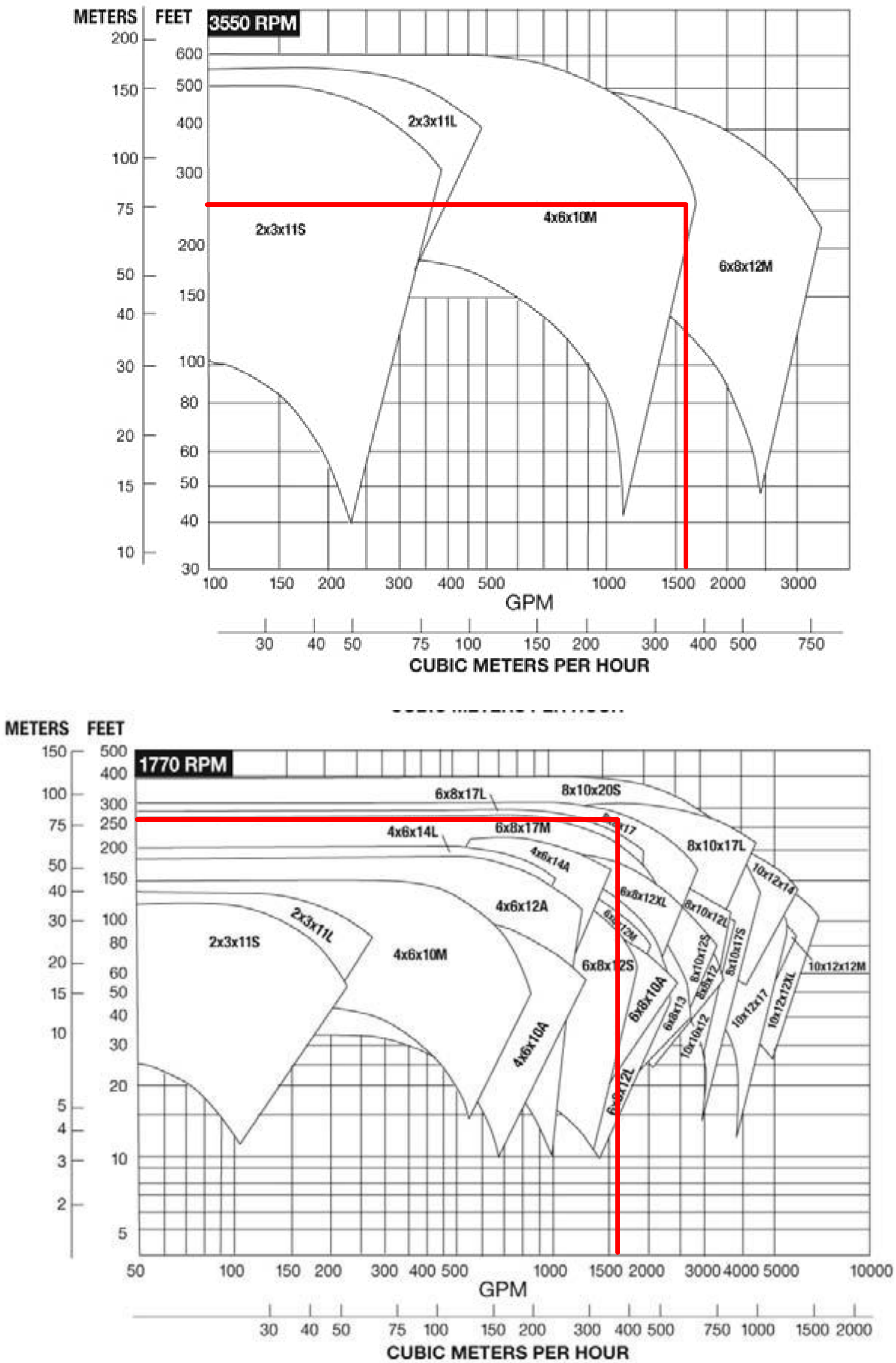


Figure 30 - Pump Selection Curves

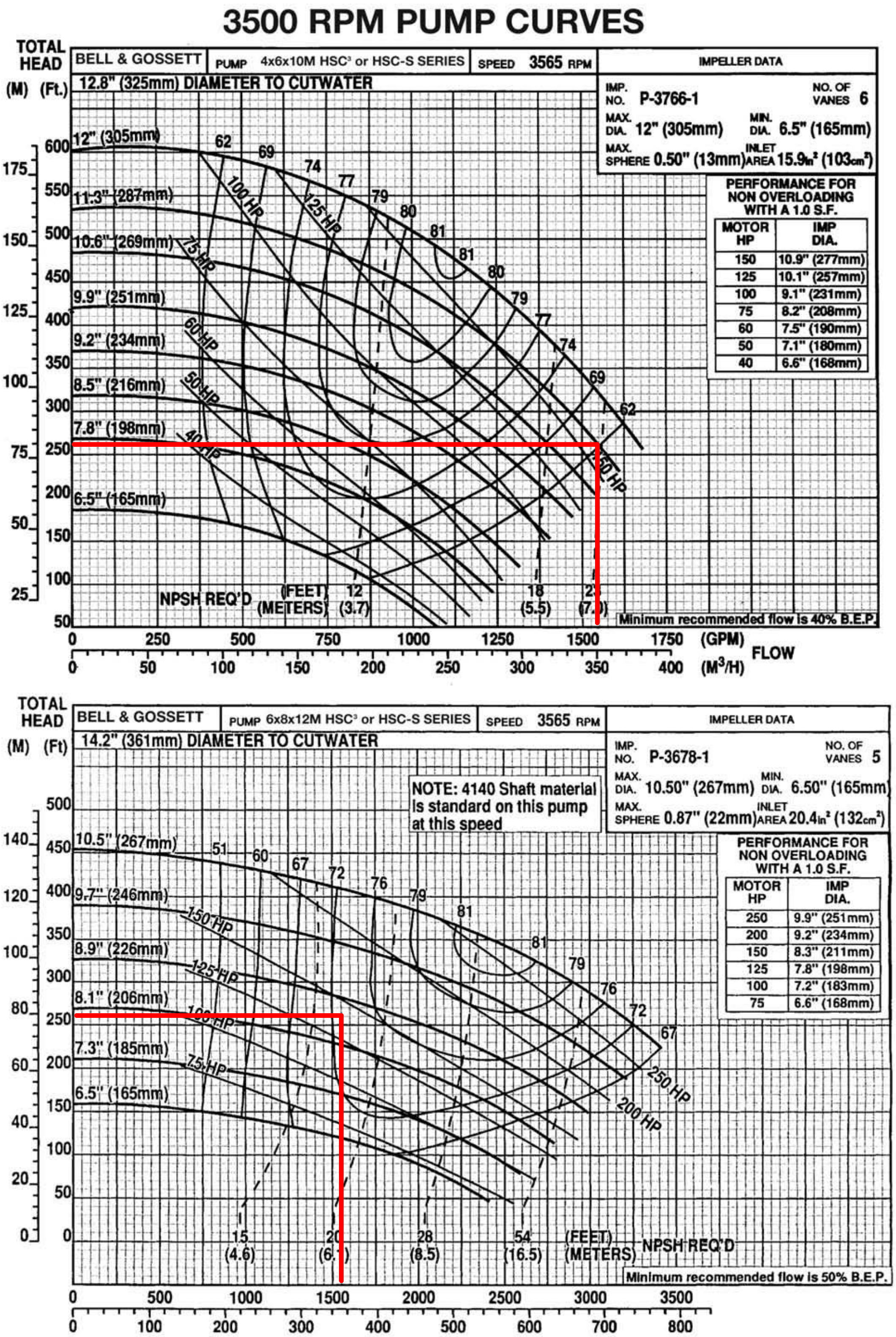


Figure 31 - Pump Performance Curve

STANDARD: 125# FF ANSI FLANGE (ANSI A21.10, AWWA C110 & ANSI B16.1 class 125)

	MOTOR	DIMENSIONS – INCHES (MM)													
PUMP SIZE	FRAME	HA	HB	HP	HR	CP	HC* MAX	HD	HO	S & Z	VH	VH1	W	X	YY
2x3x11	143-215	20.00	44.00 (1118)	6.00	2.25	18.62	39 (991)	15.25 (388)	22.05 (560)	5.50	6.80	–	11.31	9.00	10.00
S, L	254-365	(508)	54.00 (1372)	(152)	(57)	(473)	50 (1270)			(140)	(173)		(287)	(229)	(254)
4x6x10A	182-215	21.50	48.00 (1219)	6.00	2.88	19.93	50 (1270)	18.25 (464)	25.94 (659)	7.00	7.69	–	12.19	11.50	12.00
	254-324	(546)	54.00 (1372)	(152)	(73)	(506)	59 (1499)			(178)	(195)		(310)	(292)	(305)
	182-215		48.00 (1219)				43 (1092)								
4x6x10M	254-326	24.00	58.00 (1473)	6.00	4.62	22.81	52 (1321)	18.25 (464)	26.12 (664)	6.50	7.88	–	13.50	11.50	13.00
	364-405	(610)	64.00 (1626)	(152)	(117)	(579)	61 (1549)			(165)	(200)		(343)	(292)	(330)
	444-445		76.00 (1930)				68 (1727)	20.25 (514)	28.12 (714)						
	215	24.00	48.00 (1219)	6.00	4.62	22.81	43 (1092)			738	8.56		13.50	11.50	13.00
4x6x12A	254-326	(610)	58.00 (1473)	(152)	(117)	(579)	52 (1321)	18.25 (464)	26.81 (681)	(188)	(218)	–	(343)	(292)	(330)
	364-365		64.00 (1626)				61 (1549)								
	215-256		48.00 (1219)				45 (1143)								
4x6x14A	284-365	24.00	58.00 (1473)	6.00	3.25	20.62	54 (1372)	19.52 (489)	28.50 (723)	7.75	9.20	–	12.56	11.50	13.00
	404-405	(610)	68.00 (1727)	(152)	(83)	(524)	60 (1524)			(197)	(234)		(319)	(292)	(330)
	444		76.00 (1930)				64 (1625)	21.52 (547)	35.00 (889)						
4x6x14L	182-256	24.00	48.00 (1219)	6.00	3.25	20.62	45 (1143)	19.25 (489)	28.87 (733)	7.75	9.62	–	12.56	11.50	13.00
	284-365	(610)	58.00 (1473)	(152)	(83)	(524)	54 (1372)			(197)	(244)		(319)	(292)	(330)
	215-286	24.00	58.00 (1473)	6.00	10.75	29.19	56.38 (1432)			8.25	9.25		17.58	12.50	12.50
6x8x10A	324-326	(610)	64.00 (1626)	(152)	(273)	(741)	58.38 (1438)	21.25 (540)	30.50 (775)	(210)	(235)	–	(447)	(328)	(318)
	364-365		68.00 (1727)				60.38 (1534)								
6x8x12	182-256	21.50	48.00 (1219)	6.00	3.25	20.62	45 (1143)			9.00	9.60		12.56	14.00	14.00
S, L, XL	284-326	(546)	54.00 (1372)	(152)	(83)	(524)	51 (1295)	21.25 (540)	28.75 (730)	(229)	(244)	–	(319)	(356)	(356)
	364-365		60.00 (1524)				54 (1372)								
	254-326	24.00	58.00 (1473)	6.00	4.63	22.81	53 (1346)	21.25 (540)	30.85 (784)	9.00	9.60		13.50	14.00	14.00
6x8x12M	364-405	(610)	64.00 (1626)	(152)	(118)	(579)	61 (1549)			(229)	(244)	–	(343)	(356)	(356)
	444-447		76.00 (1930)				71 (1803)	23.25 (591)	32.85 (835)						
6x8x13	254-326	24.00	62.00 (1575)	6.00	5.63	26.19	56 (1422)	20.00 (508)	29.40 (747)	8.00	9.40	–	16.06	13.00	15.50
	364-405	(610)	68.00 (1727)	(152)	(143)	(665)	65 (1651)			(203)	(239)		(408)	(330)	(394)
6x8x17	284-326	24.00	62.00 (1575)	6.00	5.63	26.19	56 (1442)			9.00	11.75		16.06	14.00	16.00
M, L	364-405	(610)	68.00 (1727)	(152)	(143)	(665)	65 (1651)	21.25 (540)	33.00 (838)	(229)	(299)	–	(408)	(356)	(406)
	444-445		76.00 (1930)				71 (1803)								
8x8x12	254-326	24.00	62.00 (1575)	6.00	5.63	26.19	56 (1422)	20.00 (508)	30.25 (768)	8.00	10.25	–	16.06	14.00	16.50
	364-405	(610)	68.00 (1727)	(152)	(143)	(665)	65 (1651)			(203)	(260)		(408)	(356)	(419)
	324-365	24.00	66.00 (1676)	6.00	7.00	28.94	62 (1575)	21.75 (553)	33.75 (857)	9.50	12.00		17.56	15.00	16.50
8x8x17	404-445	(610)	76.00 (1930)	(152)	(178)	(735)	74 (1880)	23.75 (603)	35.75 (908)	(241)	(305)	–	(446)	(381)	(419)
	447-449		86.00 (2184)				82 (2083)								
8x10x12	254-286	24.00	62.00 (1575)	6.00	7.00	28.94	56 (1422)	21.50 (546)	32.00 (813)	8.50	10.50		17.56	14.00	17.00
S, L	324-365	(610)	66.00 (1676)	(152)	(178)	(735)	62 (1575)			(216)	(267)	–	(446)	(356)	(432)
	404-445		76.00 (1930)				74 (1880)	23.50 (597)	34.00 (864)						
8x10x17	324-365	24.00	66.00 (1676)	6.00	7.00	28.94	62 (1575)	23.25 (591)	36.06 (916)	10.00	12.81		17.56	16.00	18.00
S, L	404-445	(610)	76.00 (1930)	(152)	(178)	(735)	74 (1880)	25.25 (641)	38.06 (967)	(254)	(325)	–	(446)	(406)	(457)
	447-449		86.00 (2184)				82 (2083)								
8x10x20	324-365	26.00	66.00 (1676)	6.00	7.00	28.94	62 (1575)	27.25 (692)	49.50 (1257)	14.00	15.44	22.25	17.56	18.00	20.00
S, L	404-445	(660)	76.00 (1930)	(152)	(178)	(735)	74 (1880)	29.25 (743)	51.50 (1308)	(356)	(392)	(565)	(446)	(457)	(508)
	447-449		86.00 (2184)				82 (2083)								
10x10x12	284-365	24.00	68.00 (1727)	6.00	8.50	31.94	68 (1727)	22.50 (572)	33.69 (856)	9.00	11.19	–	19.06	16.00	18.00
	404-445	(610)	80.00 (2032)	(152)	(216)	(811)	81 (2057)	24.50 (622)	35.69 (907)	(229)	(284)		(484)	(406)	(457)
10x12x12	284-365	24.00	68.00 (1727)	6.00	8.50	31.94	68 (1727)	24.50 (622)	36.00 (914)	10.00	11.50	–	19.06	16.00	19.00
M, XL	404-445	(610)	80.00 (2032)	(152)	(216)	(811)	81 (2057)	26.50 (673)	38.00 (965)	(254)	(292)		(484)	(406)	(483)
	324-365	24.00	66.00 (1676)	6.00	7.00	28.94	62 (1575)	25.25 (641)	38.69 (983)	11.00	13.44		17.56	18.00	20.00
10x12x14	404-445	(610)	76.00 (1930)	(152)	(178)	(735)	74 (1880)	27.25 (692)	40.69 (1034)	(280)	(341)	–	(446)	(457)	(508)
	447-449		86.00 (2184)				82 (2083)								
	324-365	24.00	66.00 (1676)	6.00	7.00	28.94	62 (1575)	25.25 (641)	38.69 (983)	11.00	13.44		17.56	18.00	20.00
10x12x17	404-445	(610)	76.00 (1930)	(152)	(178)	(735)	74 (1880)	27.25 (692)	40.69 (1034)	(280)	(341)	–	(446)	(457)	(508)
	447-449		86.00 (2184)				82 (2083)								

Not for construction unless certified.

Table 23 - Pump Size

TRANE

Electrical Data

Table 83. Electrical performance

Model No.	Unit Volts	Total Unit FLA	Comp RLA (ea)	Comp LRA (ea)	No. of Compres.	Blower Motor FLA	Blower Motor HP	Fan Motor Num	Minimum Circuit Ampacity	Maximum Overcurrent Protective Device
GERE300	208/60/3	63.3	39.1	267.0	2	24.20	7.5	1	112.2	150
	230/60/3	63.3	39.1	267.0	2	24.20	7.5	1	112.2	150
	460/60/3	29.6	18.6	103.0	2	11.00	7.5	1	52.9	70
	575/60/3	24.4	15.4	160.0	2	9.00	7.5	1	43.7	50
GERE120	208/60/3	26.6	18.1	137.0	2	8.50	3.6	1	49.2	60
	230/60/3	26.6	18.1	137.0	2	8.50	3.6	1	49.2	60
	460/60/3	13.3	9.0	62.0	2	4.30	3.6	1	24.6	30
	575/60/3	11.1	6.8	50.0	2	4.30	3.6	1	19.6	25

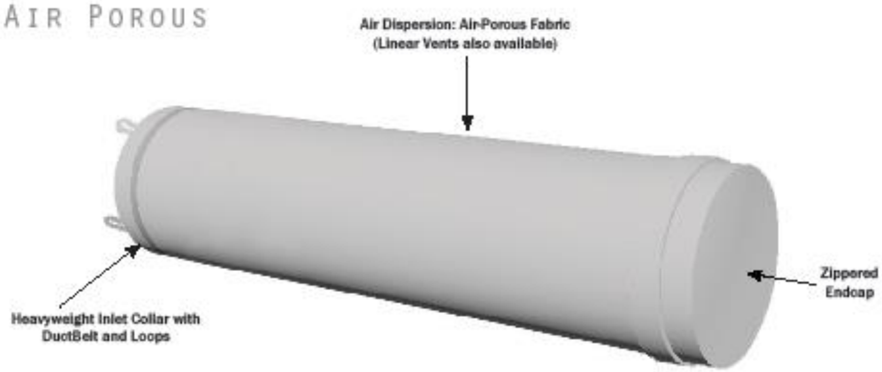
Table 24 - Heat Pump Data

Appendix C – Duct Redesign

FABRIC

MICROBE-X™

AIR POROUS



FABRIC

Developed for food processing, Microbe-X fabric offers a lightweight and highly launderable filament fiber construction. The polyester yarns are also treated with a non-leaching antimicrobial which controls the growth and transmission of harmful bacteria, fungi, and molds that can be found in food processing environments. Microbe-X is proven to be effective after 100 wash cycles. Construction features finished seams and a heavyweight inlet collar with an integral DuctBelt and attachment loops. Microbe-X is machine washable and available with all DuctSox suspension systems.

APPLICATION

Ideal for refrigerated/food processing environments and other applications requiring low velocity air delivery.

SPECIFICATIONS

Weave:	Fire Retardant Polyester, Filament/Filament Twill
Weight:	6 & 13: 6.9 oz/yd² (234g/m²) 29: 6.2 oz/yd² (210g/m²)
Porosity:	6, 13, 29 CFM/ft² @ 0.5" w.g. (30.5, 66, 147L/s/m² @ 125Pa)
Treatment:	Non-leaching, Permanent Antimicrobial
Codes:	Classified by Underwriters Laboratories in accordance with the requirements of NFPA 90A

COLOR OPTIONS

White

Custom Colors*

Custom colors available, but requires a premium charge and additional lead time.

CLASSIFIED UL
File R18858

DUCTSOX Textile Air Dispersion Products

Figure 32 - Fabric Duct Spec Sheet

Appendix D – Acoustical Breadth

KINETICS™

Sound Control Baffles

Model KB-803

Estimating Baffles

Use the following example to estimate the number of baffles for your application.

Example:
Consider an 80' L x 40' W x 20' H walls industrial plant.

Step 1 Determine surface area:

80 x 20 x 2 (walls)	= 3200
40 x 20 x 2 (walls)	= 1600
80 x 40 x 1 (ceiling)	= 3200
80 x 40 x 1 (floor)	= 3200
Total Surface	= 11200 sq. ft

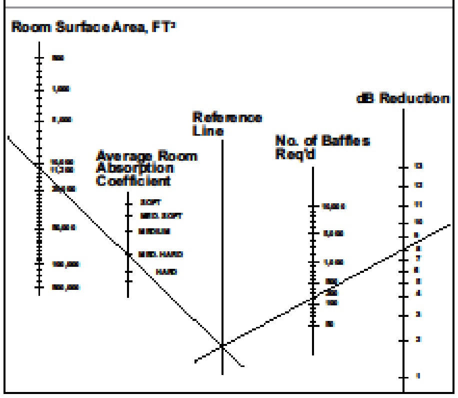
Step 2 Determine the overall acoustical character of the building. Assume this building is medium hard since the floors and walls are hard, and the ceiling is medium.

Step 3 Connect 11,200 ft.^{2} and medium hard on the nomogram. Extend the line to its intersection with the vertical reference line.

Step 4 If an 8 dB noise reduction is desired, connect a line between 8 on the "Reduction" scale, and the intersection point on the "Reference Line".

Step 5 Read 200 as the number of baffles required on the "Required" line.

Nomogram



Description

Kinetics Noise Control Baffles are used to reduce overall noise levels in industrial, recreational, and other high noise areas, and are suspended from above or from the structure near the noise source. Kinetics Noise Control Baffles are 2.7 pcf (43 kg/m^3) fiberglass, 24" x 48" (610 mm x 1219 mm), and 1-1/2" (38 mm) thick, and are sealed in a black or white fire-retardant vinyl film cover. When tested in accordance to UL-723, the cover material exhibits a flame spread of 15, and smoke development of 105; the fuel contribution is not determinable. The average absorption ratings for Kinetics Baffles are shown in the table. Actual room noise reduction can be up to 10 dBA depending on the configuration of the space and the absorption present before installing baffles. Baffles are packaged ten (10) per carton.

Baffles are available to meet USDA and FDA approved requirements using various available coverings.

Room/Building Acoustical Characteristics

Terminology	Description
Hard	All (6) Surfaces Brick, Concrete, Marble, Tile, Steel
Medium Hard	(5) Surfaces Hard, (1) Surface Absorptive – Carpet, Acoustical Tile, Drapes, or Open to the Outside.
Medium	(4) Surfaces Hard, (2) Surfaces Absorptive
Medium Soft	(3) Surfaces Hard, (3) Surfaces Absorptive
Soft	

Figure 33 - Acoustic Baffle Spec Sheet

Appendix E – Photovoltaic Breadth

SHARP.

solar electricity

300 WATT

MULTI-PURPOSE MODULE

NEC 2008 Compliant

ND-F4Q300

MULTI-PURPOSE 300WATT MODULE FROM THE WORLD'S TRUSTED SOURCE FOR SOLAR.

Using breakthrough technology, made possible by nearly 50 years of proprietary research and development, Sharp's ND-F4Q300 solar module incorporates an advanced surface texturing process to increase light absorption and improve efficiency. Common applications include commercial and residential grid-tied roof systems as well as ground mounted arrays. Designed to withstand rigorous operating conditions, this module offers high power output per square foot of solar array.

Business leaders install this module in large commercial applications, demonstrating financial astuteness and environmental stewardship.

ENGINEERING EXCELLENCE

High module efficiency for an outstanding balance of size and weight to power and performance.

DURABLE

Tempered glass, EVA lamination and weatherproof backskin provide long-life and enhanced cell performance.

RELIABLE

25-year limited warranty on power output.

HIGH PERFORMANCE

This module uses an advanced surface texturing process to increase light absorption **and improve efficiency.**

Sharp multi-purpose modules offer industry-leading performance for a variety of applications.

Improved Frame Technology

SHARP: THE NAME TO TRUST

The Sharp ND-F4Q300 module is covered by Sharp's 10 year materials or workmanship warranty. When you choose Sharp, you get more than well-engineered products. You also get Sharp's proven reliability, outstanding customer service and the assurance of our 25-year limited warranty on power output. A global leader in solar electricity, Sharp powers more homes and businesses than any other solar manufacturer worldwide.

BECOME POWERFUL

Figure 34 - Photovoltaic Module Spec Sheet