Final Report

Analysis of Ground Source Heat Pumps and Chilled Beams

APPELL LIFE SCIENCES

York College of Pennsylvania

York, PA

Joshua R Martz

Mechanical Option

4/07/2011

Dr. Srebric-Faculty Advisor

APPELL LIFE SCIENCES

York College of Pennsylvania
York, PA

Primary Project Team

Owner:	York College Of Pennsylvania
Architect:	RLPS Architects, Ltd.
CM:	Kinsley Construction Company
Civil:	LSC Design, Inc.
Structural:	Macintosh Engineering
M.E.P.:	JDB Engineering
Lab Consult:	United Hospital Supply

General Building Info

Occupancy Type: Education
Size: 102,000 SF
Levels: 3 Above/4 Total
Construction: January 2010 to August6 2011
Bid Cost: ~ $16,000,000
Delivery Method: Design-Bid-Build/ CM provides GMP

Structural

- Foundation includes spread and stepped footing and concrete grade beams
- 14J6 joists typical for 1st to 3rd floor
- W36 beams typical for 1st to 3rd floor
- Roofing consists of metal decking and concrete slab
- 1st-3rd floors consist of metal decking and concrete slab

Architecture

- Life Sciences includes a Greenhouse Building
- Facade includes Brick Veneer, Low-e glazing, cast stone sills
- Greenhouse building includes curtain wall system and premanufactured enclosure
- Life Sciences includes offices, classrooms, computer labs, and various laboratories

Lighting/Electrical

- 15 kV Main Switch Substation
- 13.2 kV 3PH 3W primary and 480/277 V 3PH 4W secondary transformer services panelboards
- 300 kW/375kVA Emergnecy Generator
- Interior Lighting includes fluorescent & incandescent lamps
- Exterior Lighting consists of HID lamps

Mechanical

- 400 Ton water-cooled centrifugal chiller
- Heating provided by 3 2640 MBH gas-fired boilers
- 2 VAV AHU's and 3 Primary Air AHU's service Life Sciences
- Greenhouse heating provided by wall hung radiation units
- Cooling provided by evaporative coolers
- Offices serviced by VAV, Classrooms and Labs by Fan Coil Units

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http://www.engr.psu.edu/ae/thesis/portfolios/2011/jrm5182/index.html

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Credits/Acknowledgements

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Thanks to all my friends and family

Executive Summary

The life sciences building is a classroom and lab building for the York College of Pennsylvania. It also has several administrative and teacher offices. Along with the life sciences building there is a greenhouse building that also has laboratories. Because there are so many labs and computer labs in this building there electrical load is most likely higher than some regular school buildings, making the cooling load higher.

A VAV system is used to condition the office spaces. Fan coil units are used to condition the lab and classroom spaces. The fan coil units were selected for the labs and classrooms because they are better at ventilation than VAV systems. These systems are supplied with chilled water from a centrifugal chiller and supplied with hot water from three gas-fired boilers. Of great importance to the client are low operation costs, long equipment life, low maintenance, and ability for systems to be modified.

To help optimize the systems a ground source heat pump system will be analyzed to replace just the chillers and just the boilers. This study is being done to see which system, cooling or heating, would be more feasible to replace with ground source heat pumps. Along with this chilled beams will be employed to replace the fan coil units that condition the labs and classrooms. The AHUs for the fan coil units utilize a heat wheel to recover energy from the exhaust air. A run-around coil system will be analyzed to replace this to compare the energy savings of each.

Along with these studies a construction management breadth will be done to optimize the number of boreholes and their depth for each of the GSHP systems. Also included in this will be a life cycle cost analysis of the heat pumps and construction schedule changes. Another study being done will be an electrical breadth. This will be done because there is new equipment being added to the mechanical systems. New panelboards, feeders, feeder sizes, and switchboard sizes will need to be analyzed for the GSHP systems.

With the following analyses being done the best option for the life sciences building is to replace the chiller system with ground source heat pumps. Along with this chilled beams can be used to replace fan coil units because they reduce the supply air. However, the run-around coil system was found to use more energy than the already existing heat wheels.

Existing Project Conditions and Information

The Appell Life Sciences Building houses offices, classrooms, and laboratories for the York College of Pennsylvania. It is approximately a 102,000 SF building attached to another building that houses offices and classrooms, Campbell Hall. Also attached to the building is a Business Administration Wing which houses offices. The life sciences building also has a separate greenhouse building that is about 50-100 ft NW of the life sciences building. There are many different types of loads to be considered with the life sciences having computers, printers, lab equipment, etc.

The following site plan, Figure 1, shows the outline of the life sciences building and the location of the greenhouse building closeby.

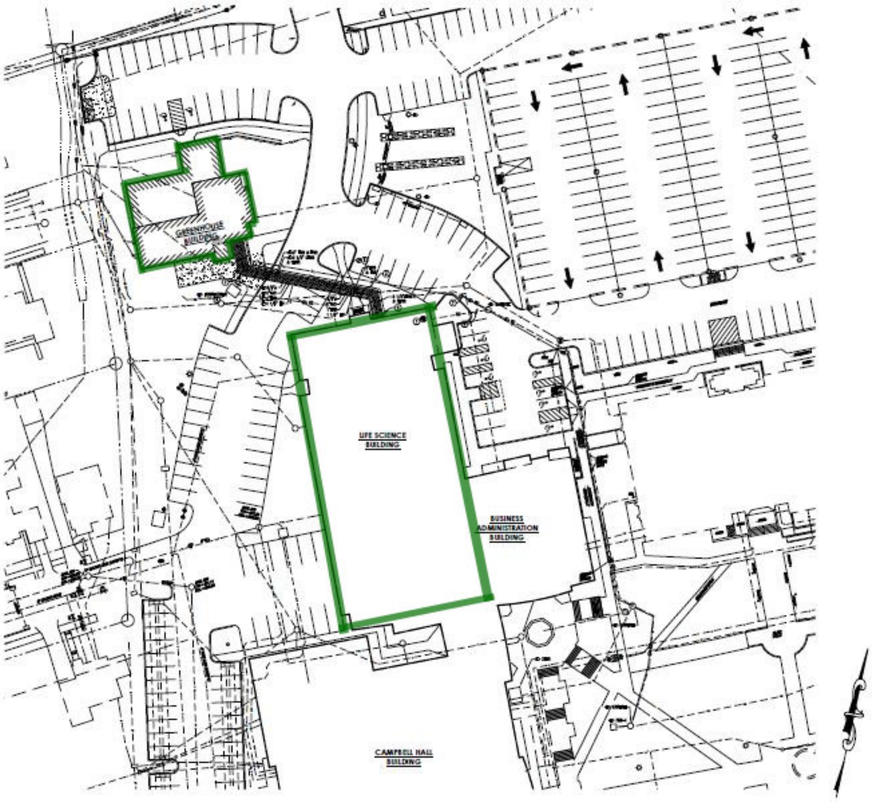


Figure 1: Site Plan (Life Sciences and Greenhouse Buildings Outlined)

Design Objectives and Requirements

The purpose of any HVAC system is to properly ventilate the building for the specified occupancy while maintaining a comfortable temperature and humidity level for the buildings occupants. The life sciences building has a large amount of laboratories that require appropriate ventilation and exhaust. The design of the systems for the laboratories allowed for proper ventilation and exhaust with having heat recovery wheels in the air handling units that service the laboratories. These are required because of the high exhaust rates that laboratories have. The rest of the requirements for the systems were met by the design engineer. The systems were also designed with the budget of the college in mind.

Equipment Summary

The primary systems for the life sciences building include VAV for offices, FCU's for laboratories and classrooms, and Wall Hung Radiation Units and Evaporative Coolers, heating and cooling respectively, for the Greenhouses. These systems are supplied with chilled water by a water-cooled centrifugal chiller, seen in Table 1. There are two cooling towers on the roof that supply water to the chiller, seen in Table 2. They are supplied with hot water by three gas-fired boilers, seen in Table 3. The chiller and boilers are located in the central plant in the basement of the life sciences building. Along with the chiller and boiler there is a plate and frame heat exchanger used as a water-side economizer, seen in Table 4. Also located in the central plant are the chilled water and hot water pumps, seen in Table 5. They are run on a primary secondary loop. The secondary pumps, seen in Table 6, for the greenhouse building are located in the basement mechanical room of that building because of limited space.

Air Handling Units provide air to the VAV boxes and FCU's for the spaces in the life sciences building. There are five AHU's total for servicing the different spaces included in the life sciences building, seen in Table 7. The main air supply for the greenhouse building labs is from FCU's, seen in Table 8, with OA brought in from directly outside. For the greenhouses heating is done by Wall Hung Radiation Units, seen in Table 9. Cooling for the greenhouses is done by a combination of natural ventilation and Evaporative Coolers, seen in Table 10.

Table 1: Chiller

Chiller				
Symbol	Capacity	kW/ton	Evaporator	Condenser
			EWT/LWT	EWT/LWT
CH-1	400	0.57	53.99/44	85/94.19

Table 2: Cooling Towers

Cooling Towers				
Symbol	Capacity (GPM)	EWT/LWT (^{o}F)	Airflow (CFM)	Fan HP
CT-1	700	95/85	62,790	10
CT-2	700	95/85	62,790	10

Table 3: Boilers

Boilers			
Symbol	Output MBH	GPM	Thermal Efficiency
B-1	2640	250	88%
B-2	2640	250	88%
B-3	2640	250	88%

Table 4: Heat Exchanger

Heat Exchanger				
Symbol	Hot Side		Cold Side	
	GPM	EWT/LWT (F)	GPM	EWT/LWT (F)
HX-1	200	57/45	700	43/46

Table 5: Life Sciences Building Pumps

Pumps					
Symbol	GPM	Impellar Size	Water Temp	Motor HP	Note
CHWP-1	960	7.75	45	15	Primary
CHWP-2	900	11.25	45	40	Secondary
CHWP-3	900	11.25	45	40	Secondary
CDWP-1	1200	10.5	85	15	Condenser Water
CTWP-1	700	11.625	95	40	Cooling Tower
CTWP-2	700	11.625	95	40	Cooling Tower
HWP-1	250	5.625	180	2	Boiler Circulator
HWP-2	250	5.625	180	2	Boiler Circulator
HWP-3	250	5.625	180	2	Boiler Circulator
HWP-4	1000	8.875	180	10	Primary
HWP-5	1000	8.875	180	10	Primary
HWP-6	400	11.5	180	20	Secondary
HWP-7	400	11.5	180	20	Secondary

Table 6: Greenhouse Building Pumps

Pumps					
Symbol	GPM	Impellar Size	Water Temp	Motor HP	Note
CHWP-4	60	6.75	45	2	Secondary
HWP-8	85	6.75	180	3	Secondary
HWP-9	85	6.75	180	3	Secondary

Table 7: Air Handling Units

Air Handling Units							
Symbol	Supply CFM	Min. O.A. CFM	Cooling Coil Capacity		Heating Coil Capacity MBH	Supply Fan HP	Exhaust Fan HP
			Total MBH	Sensible MBH			
AHU-1	4200	1300	215.3	133.3	112.2	7.5	2
AHU-2	6900	6900	380	218	256.6	15	7.5
AHU-3	8000	8000	410.2	253.7	219.9	15	5
AHU-4	8100	8100	497.4	267.6	309.5	15	5
AHU-5	7550	7550	409.4	236.6	234.3	15	5

Table 8: Greenhouse Building Fan Coil Units

Fan Coil Units						
Symbol	Supply CFM	O.A. CFM	Cooling Coil Capacity		Heating Coil Capacity MBH	Supply Fan HP
			Total MBH	Sensible MBH		
FC-1	1200	420	47.6	31.1	58	1
FC-2	800	200	27.5	19.3	35.3	3
FC-3	200	80	7.3	5.3	12.1	1
FC-4	1600	560	54.4	37.7	75.6	1
FC-5	200	50	6.8	4.9	11.5	1
FC-6	1200	420	47.6	31.1	58	1
FC-7	1200	300	37.8	27.2	53.7	1
FC-8	200	50	6.8	4.9	11.5	1
FC-9	600	60	11.6	10.8	21.8	1
FC-10	1600	0	36.9	32.9	62.6	1

Table 9: Greenhouse Wall Hung Radiation Units

Wall Hung Radiation Units				
Symbol	Length	BTUH	GPM	Height
WH-1	20 feet	10,840	1.1	16 inches
WH-2	15 feet	8460	2.8	16 inches
WH-3	26 feet	14664	2.8	16 inches
WH-4	4 feet	2256	2.8	16 inches
WH-5	4 feet	2256	2.8	16 inches
WH-6	4 feet	2160	1	16 inches
WH-7	4 feet	2160	1	16 inches
WH-8	4 feet	2160	1	16 inches
WH-9	4 feet	2160	1	16 inches
WH-10	3 feet	1620	1	16 inches
WH-11	3 feet	1620	1	16 inches
WH-12	4 feet	2216	1.9	16 inches
WH-13	4 feet	2216	1.9	16 inches
WH-14	18 feet	9972	1.9	16 inches
WH-15	6 feet	3324	1.9	16 inches
WH-16	6 feet	3240	1	16 inches

Table 10: Greenhouse Evaporative Coolers

Evaporative Coolers		
Symbol	Supply CFM	Supply Fan HP
EC-1	2400	1
EC-2	2000	1
EC-3	2400	1
EC-4	2400	1
EC-5	3200	3

Design Conditions

The outdoor design conditions used for the energy model are for Harrisburg, PA, which is the closest location from the ASHRAE Fundamentals to the site of the building. The conditions can be seen below in Table 11.

Table 11: ASHRAE Design Conditions

Design Conditions		
Heating Design Temperature	Cooling Design Temperature	
10.4 F DB	92.8 F DB	74.7 F WB

System Operations and Schematics

Airside:

Note: These operations are for occupied cycles.

For the VAV system for the life sciences building, the supply fan is turned on minimum than set to maximum in about a 60 second period. After this the supply fan will be modulated to maintain the supply duct static pressure setpoint in AHU-1 and AHU-3. For ventilation control the outside air and return dampers are modulated to maintain the minimum outdoor airflow setpoint. The economizer will take control of the dampers when a greater airflow is needed for space cooling. The economizer will also take control whenever the outdoor air temperature falls below the setpoint of 55 F. For the cool down cycle the supply air should be fixed to maintain 55 F. For the warm-up cycle the supply air temperature should be fixed to maintain 70 F. For the Reheat-VAV boxes, on a rise in space temperature the supply air will be modulated to cooling maximum. On a decrease in space temperature the supply air will be modulated to the cooling minimum. For a continuous fall in space temperature, the supply air will be modulated to the heating setpoint and the unit reheat coil control valve will be modulated to maintain the setpoint. For the parallel-fan powered, the only difference is that on a continuous fall in space temperature the unit fan will be started and the heating coil control valve will be modulated to maintain the heating setpoint.

Fan coil units will be served by AHU's 2, 4, and 5. The unit supply and exhaust fans will run continuously. Prior to starting fans the outside and exhaust air dampers should be opened. The AHU's are equipped with energy recovery wheels because of the high exhaust rates of the laboratories. For a rise in outdoor air enthalpy greater than return air enthalpy, or for heating, close the bypass dampers and turn on the energy recovery wheel. Whenever the outside air temperature is below 40 F the same process should be followed. For supply air temperature when the outdoor air temperature is above 55 F, the setpoint should be 55 F. When the outdoor temperature is below 55 F the setpoint should be a minimum 55 F and maximum 68 F. For the fan coil units themselves, the unit fan should operate continuously. On a rise in space temperature, the cooling coil control valve should be opened to maintain the space cooling setpoint. For a fall in space temperature, the heating coil control valve should be opened to maintain the space heating setpoint. For ventilation the return air damper should be closed to its minimum position.

Waterside:

Hot Water Heating System

There are three boilers to supply hot water to the systems. The boilers use internal controls to maintain the water temperature setpoint in the boiler. The setpoint in the boiler shall be 2 F greater than the hot water supply temperature. The lead boiler pump, HWP-1, should be started first and after a time delay the lead boiler, B-1, should be started to run continuously. When the hot water supply temperature falls by at least 5 F below the setpoint the first lag boiler pump, HWP-2, and boiler, B-2, should be started. This should only happen after the lead boiler has been running for at least 10 minutes.

The same sequence is to happen for the second lag boiler pump, HWP-3, and boiler, B-3. This should only happen if the lead and first lag boiler have been running for at least 10 minutes. After a rise in temperature of 2 F above the setpoint and after a time delay of 10 minutes the last boiler and pump started should be stopped. This should happen until only the lead boiler and its associated pump are operating. The hot water supply temperature should be 180 F if outdoor air temperature is 0 F, and it should be 140 F if the outdoor air temperature is 60 F. The three hot water pumps associated with the boilers are circulators for the boilers.

The hot water supply pumps are run on a primary secondary loop. The primary pumps, HWP-4 and HWP-5 shall be run on a central plant hot water system operating schedule. The lead hot water pump, HWP-4, should be started and run continuously. Upon a failure of this pump, the lag pump, HWP-5, should be started on a time delay as the lead pump is de-energized and removed from the sequence. The primary hot water pumps should be alternated on cumulative run-time, or at least on a monthly basis.

The secondary pumps for the life sciences building, HWP-6 and HWP-7, should be run according to the Life Sciences hot water system operating schedule. The lead secondary pump, HWP-6, should be started and ramped up to the minimum speed of 25 Hz. The pump speed should be modified to maintain the minimum chilled water building differential pressure setpoints. Upon a failure of the lead pump the lag pump, HWP-7, should be started on a time delay while the lead pump is de-energizied and removed from the sequence.

The greenhouse building secondary pumps, HWP-8 and HWP-9, should be run on a similar sequence to that of the life sciences building secondary pumps. These two secondary pumps supply hot water to the greenhouse wall hung radiation units and fan coil units.

Chilled Water Cooling System

The chiller, CH-1, for the life sciences building can either be run on a refrigeration cycle or a free-cooling cycle. The chiller will be operated when the outdoor air temperature is at or above 50 F. First start the chillers associated evaporator, CHWP-1, and condenser, CDWP-1, water pumps. These pumps will operate continuously with the associated chiller operation. After they have been running the chiller will be started. The chiller itself will be started and run based on things such as schedule, load demand, and temperature. The chiller will have controls that will help it maintain the chilled water supply setpoint of 44 F. The condenser water temperature should maintain a temperature of 60 F when entering the chiller. If the temperature of that water rises above 60 F the control vale, CV-1, should be opened to the cold well in the sump tank. This will supply colder water to the chiller. When the temperature of the water gets to 60 F the control valve can be closed again.

The secondary pumps, CHWP-2 and CHWP-3, for the chilled water system will operate according to a user-defined operating schedule. The lead secondary pump will be started and ramped up to minimum speed of 25 Hz. The pump speed should be modulated to maintain the minimum chilled water building differential pressure setpoint. When the lead secondary pump fails the lag pump will be started after a time delay to prevent a false failure. The lead pump will then be removed from the sequence. If both pumps are working they should be alternated about every month to maintain a longer life. The secondary pump, CHWP-4, for the greenhouse building will operate continuously according to the schedule for cooling. From the secondary pump the supply water goes to the evaporative coolers and fan coil units in the greenhouse building.

When cooling with a refrigerant cycle control valves, CV-2, CV-4, and CV-6 should be closed. The control valves, CV-3, CV-5, and CV-7 should be opened. During a free cooling cycle the opposite should happen, control valves that were open for refrigeration will close and ones that were closed will open. The free cooling cycle allows for the use of a heat exchanger, HX-1, as a waterside economizer.

Cooling Tower Water System

Chiller Mode:

The cooling towers and cooling tower pumps will be operated according with the chilled water and free cooling user-defined schedules. When the temperature in the cooling tower water sump rises above the setpoint of 70 F, the lead cooling tower pump, CTWP-1 should be started. It should be started after a time delay of 5 minutes. On a continued rise in temperature above 72 F the lag cooling tower pump, CTWP-2, should be started. This should run until the temperature of the water decreases to 70 F, then turned off.

Waterside Economizer Mode:

When the temperature of the water in the cooling tower sump rises above the setpoint of 41 F, cooling tower pump, CTWP-1, should be started after a 5 minute time delay. When the temperature in the sump reaches below the setpoint of 39 F the pump can be stopped. If this pump should fail then stop it and start pump CTWP-2 as if it were the first cooling tower pump.

Schematics

The following figures, Figure 1 and Figure 2, are a hot water heating schematic and chilled water schematic, respectively.

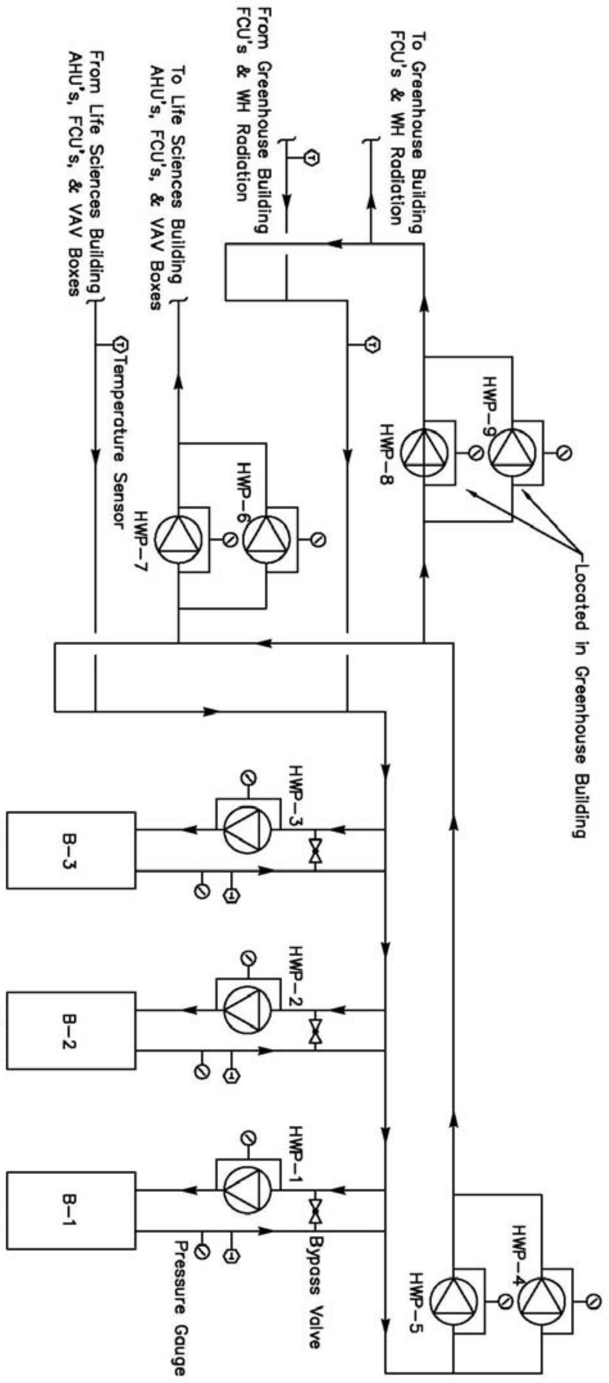


Figure 2: Hot Water Piping Schematic

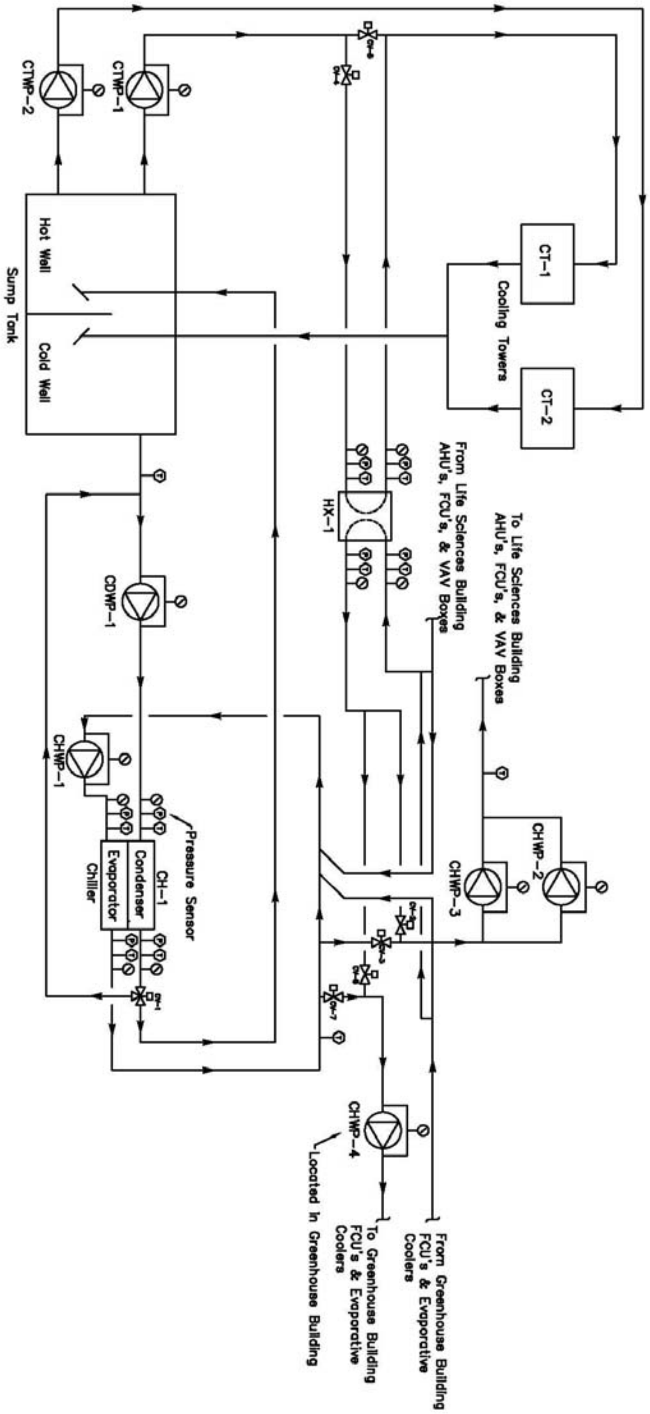


Figure 3: Chilled Water Piping Schematic

Mechanical System First Cost

The mechanical systems first cost for the life sciences building will be taken from the bid cost given by the lead design engineer on the project. The price for mechanical systems in the greenhouse building was $870,720. The cost for mechanical systems in the life sciences building was $4,150,000. This brings the total cost of mechanical systems to $5,020,720. The cost per square foot for mechanical systems ends up being about $49.22/sf.

Data from Previous Tech Reports

Design Ventilation Requirements

To verify that the life sciences building is providing the proper ventilation air for its occupancy, an ASHRAE 62.1 analysis was done on each of the air handling units. For this analysis the rates from each diffuser and areas of spaces were tabulated to see if the ventilation rates matched or were close to the minimum from ASHRAE Standard 62.1.

The overall rates from the tabulation were as follows: AHU-1, 1151 OA cfm; AHU-2, 5974 OA cfm; AHU-3, 1632 OA cfm; AHU-4, 4644 OA cfm; and AHU-5, 4196 OA cfm. The design documents specify the following rates for each AHU: AHU-1, 1300 OA cfm; AHU-2, 6900 OA cfm; AHU-3, 8000 OA cfm; AHU-4, 8100 OA cfm; and AHU-5, 7550 OA cfm. The rates for the air handling units serving the labs could be a lower than the design because they were oversized to make an adequate amount of outdoor air was supplied to the laboratories. AHU-3 design is a much larger value than that of the calculated value. This could be because this particular AHU services two floors and needs to be oversized for this reason. It also could be oversized like this because the offices it serves are located on the two floors that have multiple laboratories.

Design Heating and Cooling Loads

The heating and cooling loads for the life sciences building were simulated using Carrier HAP. As seen from Table 12 below, the computed loads and the design document loads are relatively similar. The computed cooling load is within 2% of the documented cooling load. The computed heating load is much lower than the documented load, being within 31%. This could be due to the fact that the systems that I ran for the greenhouses could be much different than the systems that were run for the design documents. The greenhouses were most likely modeled inaccurately because it was difficult to model wall hung radiation units and horizontal unit heaters in Carrier HAP. The heating load from the greenhouses should have made the overall heating load larger, because they are enclosed in glass and the area the building is located normally has a large heating load for the winter months. The computed supply air rate is within 6% of the documented supply air rate. The computed ventilation rate is within 25% of the documented ventilation rate. This is most likely from AHU-3 which serves the second and third floor offices. The ventilation rate from the design documents is lower than the computed rate. The model for this system that was computed was taken from the design documents saying that AHU-3 needed the same amount of outdoor air as total supply cfm. This value was input into the system for ventilation cfm so this could be why they are different.

Table 12: Load and Ventilation Comparison

Load and Ventilation Comparison				
	Cooling (ft^2/ton)	Heating (BTU/hr-ft^2)	Supply Air (cfm/ft^2)	Ventilation (cfm/ft^2)
Design Document	325.9	32.75	0.61	0.41
Computed	320.6	22.4	0.65	0.55

Annual Energy Usage

The designer annual energy usage is not available for this report because an energy analysis was not run by the design engineer. This is because none of the systems, envelope or HVAC were in question. The annual energy consumption was calculated using the same model that was used for the load calculations. With the exception of the gas-fired boilers, the rest of the building is powered by delivered electric power.

Table 13 below shows the energy usage for the entire year separated into different loads for the building.

Table 13: Annual Energy Consumption

Annual Energy Consumption				
Load	Electricity (kWh)	Natural Gas (kWh)	Total (kWh)	% of Total
Heating				
Gas-Fired		2637639	2637639	31
Electric Heaters	190608		190608	2
Cooling				
Chiller	1991808		1991808	23
Cooling Tower	727097		727097	8
Condenser Pump	56390		56390	1
Auxiliary				
Supply Fans	221632		221632	3
Pumps	1573235		1573235	18
Lighting	703482		703482	8
Receptacles	487998		487998	6
		Total	8589889	100

The values above were computed using the energy model with equipment inputs taken from the design documents for the building.

From this analysis it can be seen that the largest load is from heating at 31%. This could be due to a number of things including, the buildings location, orientation, and boilers being the main supply for hot water to all the various systems in this project.

The buildings location is in York, PA, which can have very cold winters. The orientation of the building is mostly north, which is not the best for winter solar gain. The boilers supply a large amount of hot water to ahu's, fan coil units, horizontal unit heaters, wall hung radiation units, vav boxes, and cabinet unit heaters.

The second largest load is from cooling at 23%. This is most likely because of the large amounts of various equipment in the computer labs, office, laboratories, and workroom/mail facilities.

As seen in Chart 1 and Chart 2 below, the energy usage for natural gas and electricity changes throughout the year with the seasons. For electric energy consumption the highest peaks are during the warmer months. This is most likely because the chilled water pumps are working much harder to supply chilled water. The natural gas consumption is peaked during the winter months because of the boilers.

Chart 1: Monthly Electrical Energy Consumption

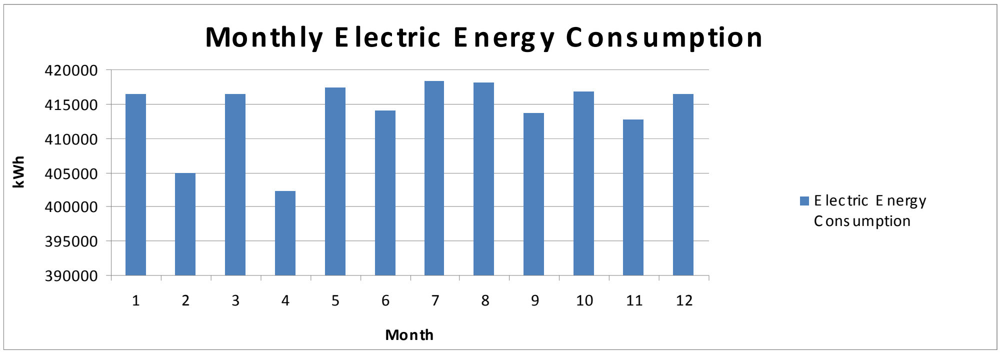
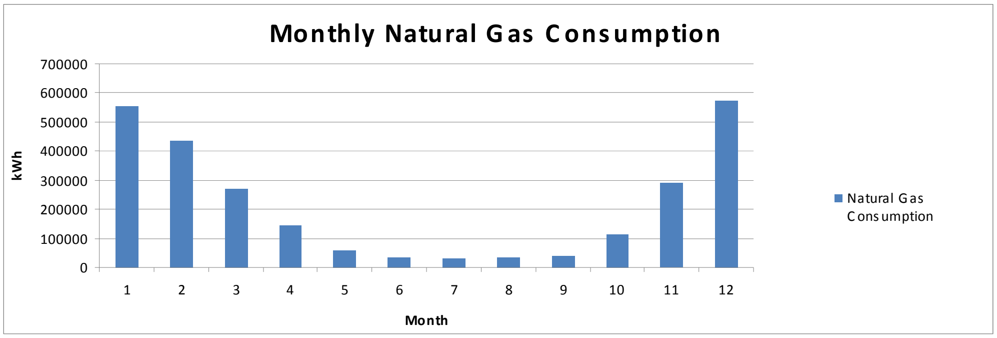


Chart 2: Monthly Natural Gas Consumption



Proposed Alternate Systems

Mechanical System Redesign

I have had the opportunity to learn more about the design behind the life sciences building by studying the design documents and completing this semester's technical reports. After research on the buildings systems they were found to be efficient, low in maintenance, and operating cost. Since the design engineer has meet the requirements set forth by the college, the life sciences building systems were not in question.

The mechanical design changes will focus on using a GSHP system to replace the chillers in the basement. Along with this the GSHP system will be implemented separately to just replace the boilers as a feasibility study. These analyses will be compared to see which one is found to be most efficient and cost effective for the college. The laboratories will be conditioned using chilled beams, replacing the fan coil units to see if any energy consumption can be saved, along with helping to meet the ventilation loads required by laboratories. To help with dehumidification when needed, a run-around coil system will be analyzed for the air handling units that serve the labs.

Construction Breadth

Since the use of a GSHP system is being implemented the schedule cost and schedule will change. An analysis of the schedule of the cost to the construction schedule and changing of the schedule will be done. Excavation is a big part of adding the GSHP system so this will most likely add time to the construction schedule, with drilling bore holes and repaving the parking lot. Along with this a life cycle cost analysis of the GSHP system will be done to ensure that it is efficient.

Electrical Breadth

Since the use of a GSHP system is being implemented there are many pumps being added to the system. The adding of these pumps will change the electrical demand from the mechanical systems. Changing the sizes of the feeders that will go to the pumps will have to be done and also more will have to be added. The size of the main switchboard will most likely change, so it will have to be resized accordingly.

Integration of Studies

With the implementation of a GSHP system comes a high first cost and addition to construction time. The construction breadth will be done to ensure that GSHP's are a good choice to replace the chiller/boiler plant. Along with the implementation of the ground-source heat pumps should come a smaller electrical demand depending on how many pumps are needed. The electrical breadth will be done to design a new electrical system to supply the mechanical systems.

Active Chilled Beams

The objective of this study is to compare the cfm's and energy from the fan coil units already in place in the building and chilled beams. The run-around coil system was used to replace the heat wheels already in place to compare the energy usage of the two options.

Chilled Beams

Active chilled beams are an advanced application of an older technology, induction units. They are more sophisticated, but they rely on the same technology as convection having cooler denser are fall to the ground and the warm air rising into the chilled beam to be cooled again. Active chilled beams were chosen over passive because of their ability to have higher heating and cooling capacities, as well as providing ventilation air. Ventilation needs for passive beams must be provided in some other manner as they only rely on convection to cool a space. Some advantages of chilled beams include their lower operating cost, high-efficiency, require low maintenance, and low amount of noise. Active chilled beams also have some disadvantages including they are not as great at heating spaces and sometimes need supplementary heating systems. They also are not well known systems by many contractors and commissioners. One of the biggest disadvantages of a chilled beam is that condensation can form on them if the humidity is too high or the water temperature is too low. This will cause water to drip from the equipment in most cases and could also damage the equipment and equipment in that particular space. Image 1 below shows an active chilled beam in cooling and heating mode.

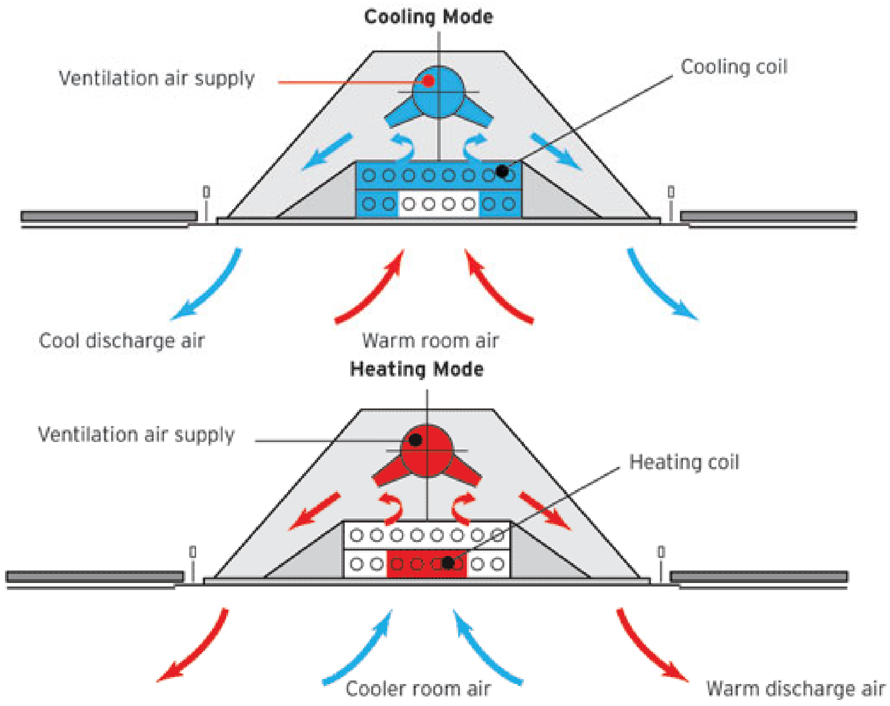


Image 1: Active Chilled Beam in Cooling And Heating Mode

Run-around Coil System

Run-around coil systems act as a heat exchanger between the supply air and exhaust air of an air handling unit. Typically finned tube coils are placed in both the supply and exhaust airstreams in an air handling unit. The coils are connected in a closed loop system through which an intermediate heat transfer fluid is pumped, usually water or glycol. Some advantages of the run-around coil system are that the two airstreams do not need to be adjacent to each other, relatively space efficient, heating and cooling equipment sizes could be reduced, and there is no cross-contamination between the airstreams. Some disadvantages of the system include it adds to the first cost because it requires a pump and more fan power to overcome the coil pressure drop. It also requires adding a pump, piping, expansion tank, and control valves for the glycol or water heat transfer system. Also both airstreams must be relatively clean or filtration will be required. Image 2 below shows a typical run-around coil system.

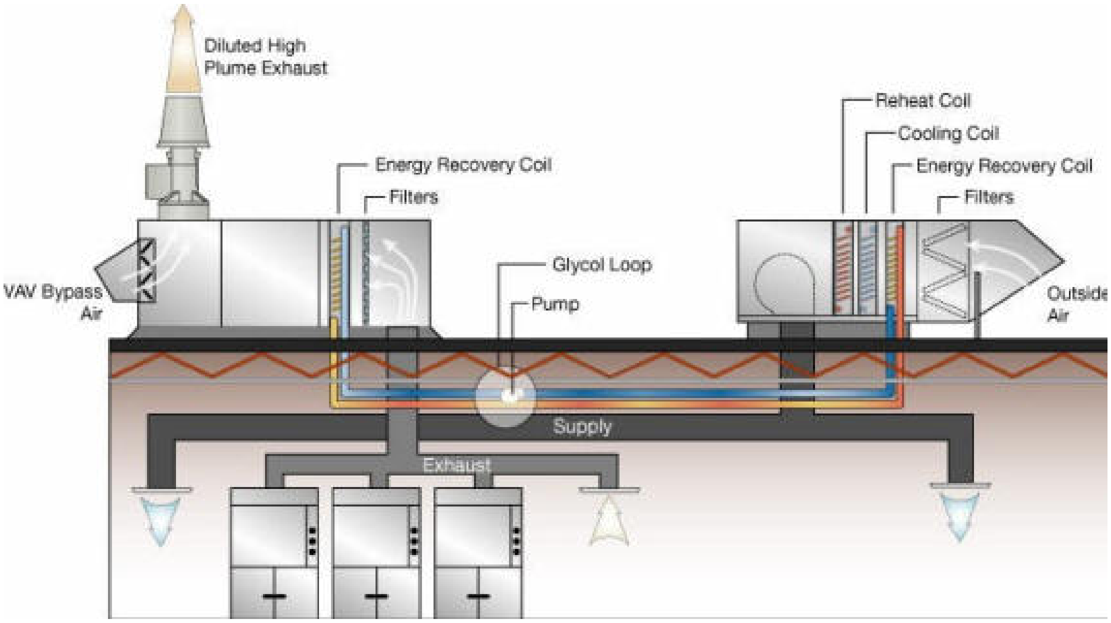
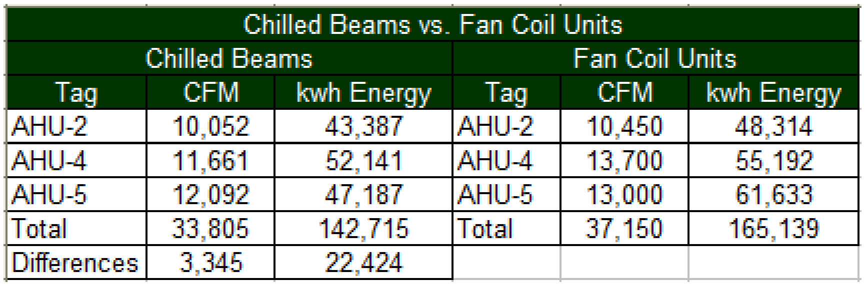


Image 2: Run-around Coil System

Chilled Beam Results

The following table has the total cfm required by the chilled beam system and the fan coil unit system already in place. Also in this table are the kwh of energy used by each system. From the table it can be seen that the annual energy decreases by a good amount, about 14%, while the supply air cfm amount decreases by about 9% from the fan coil units to the chilled beams. Table 14 below shows chilled beams vs. fan coil units.

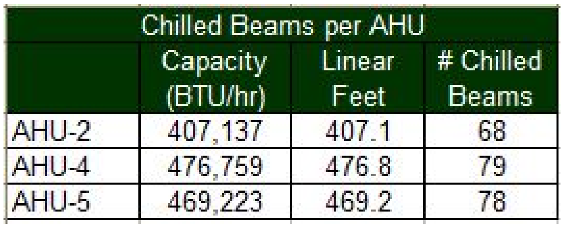
Table 14: Chilled Beams vs. Fan Coil Units



Chilled Beams vs. Fan Coil Units					
Chilled Beams			Fan Coil Units		
Tag	CFM	kwh Energy	Tag	CFM	kwh Energy
AHU-2	10,052	43,387	AHU-2	10,450	48,314
AHU-4	11,661	52,141	AHU-4	13,700	55,192
AHU-5	12,092	47,187	AHU-5	13,000	61,633
Total	33,805	142,715	Total	37,150	165,139
Differences	3,345	22,424			

Chilled beams produce about 1000 BTU/hr/ft of cooling capacity for a space. The following study shows the number of chilled beams that will be needed to condition the laboratory spaces. The study will be done per air handling unit. Table 15 below shows the total btu/hr of cooling capacity per AHU, the number of linear feet of chilled beam required, and the total number of chilled beams per AHU based on a 6 foot linear unit.

Table 15: Chilled Beams per AHU



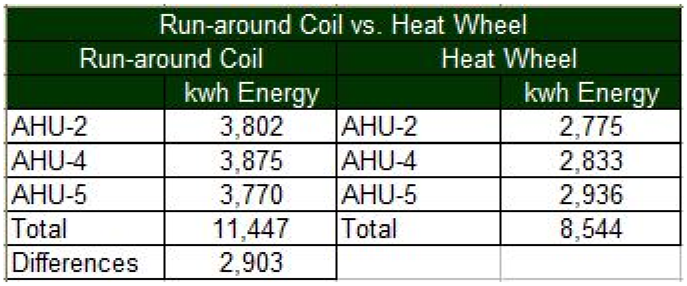
Chilled Beams per AHU			
	Capacity (BTU/hr)	Linear Feet	# Chilled Beams
AHU-2	407,137	407.1	68
AHU-4	476,759	476.8	79
AHU-5	469,223	469.2	78

There was no specific first cost found for chilled beams, so an installation cost that was found will be used to analyze first cost and life cycle cost of the chilled beams. The cost used for this analysis is $0.22/(BTU/hr). The total cost for the chilled beams came out to be $297,686. A life cycle cost analysis will be done similar to that of the GSHPs in the construction breadth. The annual maintenance cost will be $10,200. The energy cost for the chilled beams is $13,343. It will be analyzed over 20 years. The life cycle cost for the chilled beams is $587,328.

Run-around Coil Results

The following table shows the energy usage in kwh of the run-around coils compared to the heat wheels. The run-around coil system was found to use about 34% more energy than the heat wheels already in place. This is most likely because the run-around coils are on average about 20% less efficient than heat wheels and also require extra power from the pump needed. Table 16 below shows the comparison in energy usage.

Table 16 Run-around Coils vs. Heat Wheel



Run-around Coil vs. Heat Wheel			
Run-around Coil		Heat Wheel	
	kwh Energy		kwh Energy
AHU-2	3,802	AHU-2	2,775
AHU-4	3,875	AHU-4	2,833
AHU-5	3,770	AHU-5	2,936
Total	11,447	Total	8,544
Differences	2,903		

Ground-Source Heat Pumps

The objective of this study is to model ground source heat pump systems to replace the cooling equipment (chiller, cooling towers, pumps) and to replace the heating equipment (boilers, pumps). These studies are being done separately because of the limited space available for boreholes around the building. Also too see which system, cooling or heating, is more cost effective and efficient to replace according to energy usage.

Ground Study

A ground study for the area of the life sciences building was not done. However, information on a ground study done in Elizabethtown, PA, about 20 miles from York, was used to help size the bore length for the ground source heat pump system. The information used included ground temperature, thermal conductivity, and thermal diffusivity of the ground. These preceding values can be seen in Table 17

Table 17: Values From Elizabethtown Ground Test

Ground Temp. (F)	Thermal Conductivity (Btu/hr*ft^2*F)	Thermal Diffusivity (ft^2/day)
53	1.78	1.22

Sizing Method

The method used to size the bore lengths for the GSHP system was taken from the *2007 ASHRAE HVAC Applications Handbook*. This method includes accounting for the change in thermal resistance of the ground per unit length over three heat pulses. The equation below calculates the required bore length for the GSHP system. Normally lengths are calculated both for heating and cooling and the longer one is chosen. For the following study both will be calculated and both will be used for their respective purposes to go along with the feasibility study of replacing just the chillers and just the boilers. The three heat pulses are represented in the various thermal resistance values which were calculated using equations below. Equation 1 and 2 are for calculating borehole lengths for cooling and heating loads, respectively.

Cooling Length:

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

Heating Length:

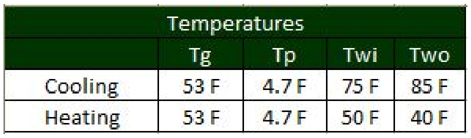
$$L_h = \frac{q_a * R_{ga} + (q_{lh} - 3.41W_h)(R_b + PLF_m * R_{gm} + R_{gd} * F_{sc})}{t_g - \frac{t_{wi} - t_{wo}}{2} - t_p} \qquad \text{Equation 2}$$

F_{sc}= *short circuit heat loss factor*
L_c= *required bore length for cooling, ft*
q_a= *net annual average heat transfer to ground, Btu/h*
$q_{lc,lh}$= *building design cooling/heating block load, Btu/h*
R_{ga}= *effective thermal resistance of ground (annual pulse), h-ft-°F/Btu*
R_{gd}= *effective thermal resistance of ground (daily pulse), h-ft-°F/Btu*
R_{gm}= *effective thermal resistance of ground (monthly pulse), h-ft-°F/Btu*
R_b= *thermal resistance of pipe and borehole, h-ft-°F/Btu*
t_g= *undistributed ground temperature, °F*
t_p= *temperature penalty for interference of adjacent bores, °F*
t_{wi}= *liquid temperature at heat pump inlet, °F*
t_{wo}= *liquid temperature at heat pump at outlet, °F*
$W_{c,h}$= *power input at design cooling/heating load, W*
PLF_m= *part load factor during design month*

Heat Pump Temperatures

The temperature of the ground for York, Pa is 53 F found from *Figure 17 from 2007 ASHRAE Handbook-HVAC Applications, Geothermal Energy*. The penalty temperature was found to be 4.7 F for boreholes 15 feet apart from *Table 7 in Chapter 32 of 2007 ASHRAE Handbook-HVAC Applications*. Temperatures in and out are shown in Table 18 below for the cooling and heating systems.

Table 18: Temperatures for Bore Length Calculations



	Temperatures			
	Tg	Tp	Twi	Two
Cooling	53 F	4.7 F	75 F	85 F
Heating	53 F	4.7 F	50 F	40 F

Thermal Resistances

Ground source heat pumps rely on their ability to transfer and extract heat from the ground. Minimizing the thermal resistances between the ground and the fluid is imperative for this to be effective. Thermal resistances are calculated for three heat pulses, for which a value τ is defined. The values for τ were set to one year, one month, and 6 hour day as suggested in *Chapter 32 of 2007 ASHRAE Handbook-HVAC Applications*. Once these values are found they are used to calculate the Fourier numbers. The Fourier numbers are then used to acquire the G-factors, (G_1, G_2, G_f), from Figure 15 in *Chapter 32 of 2007 ASHRAE Handbook-HVAC Applications.* These G-factors, along with the thermal conductivity of the ground, are used to calculate the thermal resistances for three heat pulses, (R_{gm}, R_{ga}, R_{gd}). The following equations, Equation 3, 4, 5, 6, 7, & 8, below are used to calculate thermal resistances.

$$F_{of} = 4 * \alpha * \tau_f / d_b^2$$ Equation 3

$$F_{o1} = 4 * \alpha * (\tau_f - \tau_1) / d_b^2$$ Equation 4

$$F_{o2} = 4 * \alpha * (\tau_f - \tau_2) / d_b^2$$ Equation 5

$$R_{ga} = (G_f - G_1) / k_g$$ Equation 6

$$R_{gm} = (G_1 - G_2)/k_g \qquad \text{Equation 7}$$

$$R_{gd} = G_2/k_g \qquad \text{Equation 8}$$

F_{of} = *Fouriers number for* τ_f
F_{o1} = *Fouriers number for* τ_1
F_{o2} = *Fouriers number for* τ_2
α = *Thermal diffusivity of the ground,* m^2*/day*
d_b= *Outside diameter of pipe, ft*
k_g= *Thermal conductivity of the ground*, *Btu /h-ft-°F*

These thermal resistances are used to account for the long term heating of the ground source. The thermal conductivity and diffusivity are mentioned earlier from the ground study. The thermal resistance of the borehole and pipe (R_b) was found using *Table 6 from Chapter 32 of 2007 ASHRAE Handbook-HVAC Applications.* The bore hole chosen was 6" in diameter and the U-tube pipe diameter used was 1-1/4". The value for R_b from Table 6 was found to be 0.09 h*ft*F/Btu.

Power Input ($W_{c,h}$)

The power inputs were found from the pumps sizes. The power input for the GSHPs for cooling system was found to be 16,499 W. The power input for the GSHPs for heating system was found to 14,061 W.

Part Load Factor (PLF_M)

Without specific building performance data for the life sciences building, the part load factor is not known. To ensure the ground source heat pump systems were not undersized the part load factor was assumed to be 1.

Length Results

After using the equations mentioned above the calculated length for the cooling system was 14,801 ft. The calculated length for the heating system was 16,905 ft. The depth of boreholes for each will be 212 ft. The cooling system will have 70 boreholes. The heating system will have 80 boreholes.

System Layout

Many variables were thought of for the layouts of the cooling and heating systems. They include the space available for the bore field, drilling cost, piping cost, and integration into the construction schedule. The optimum design for the cooling and heating systems are mentioned above after they were found in the Construction Management Breadth Section of this report. The layouts for each of the systems were based on the number of AHU's in the building. Each AHU was provided one GSHP based on its load required. The greenhouse building was also provided one GSHP based on its load required. The boreholes are laid out in the bore field per pump. The boreholes are spaced at 15 ft apart vertically and horizontally so that they are able to fit in the allotted space next to the life sciences building. The following figures, Figure 4 and 5, below show the layouts of boreholes for the cooling and heating systems, respectively.

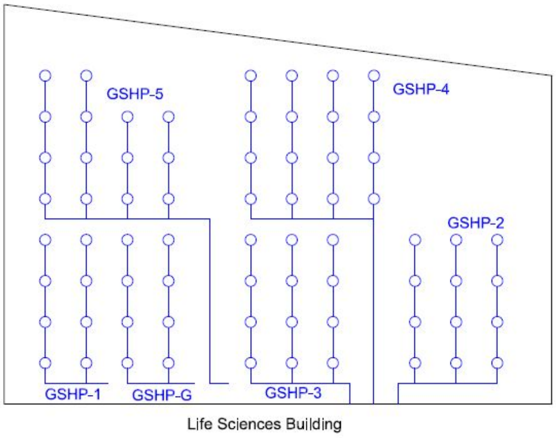


Figure 4: GSHP Cooling Layout

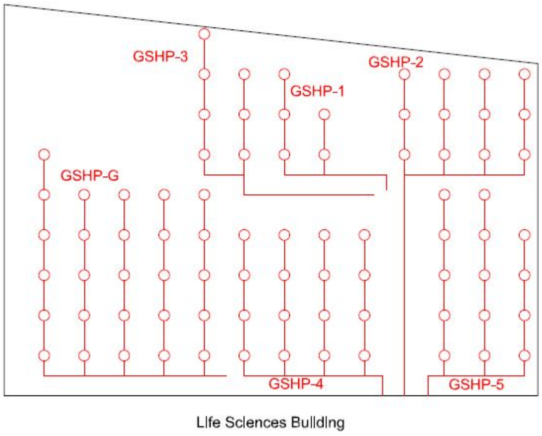
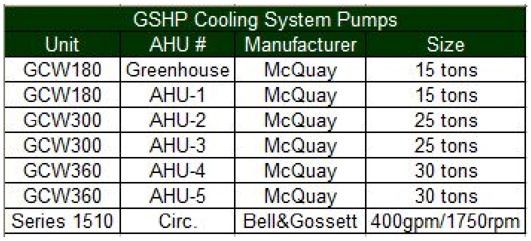


Figure 5: GSHP Heating Layout

Pump Selection

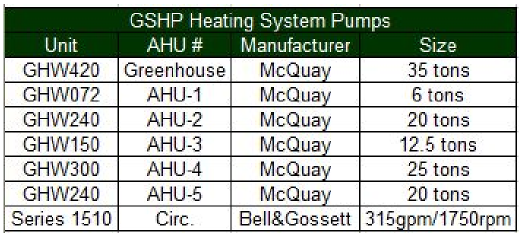
The ground source heat pumps selected for the cooling and heating systems were taken from McQuay. McQuay supplies heat pumps ranging from 3-35 tons. The heat pumps for the ground loops were sized according to the sensible load for each AHU and the greenhouse building. One heat pump was selected per AHU and the greenhouse building. This would make a total of six heat pumps each for the cooling and heating systems. The circulation pumps for each of the systems were sized from the total gpm and headloss from each of the piping configurations. The gpm was taken from McQuay's recommendation of 3gpm/ton. The totals of gpm were 400 gpm for the cooling system and 315 gpm for the heating system. The head loss for the circulation pumps was based off the longest run and factors from fittings and valves. The head loss totals were 55 ft for the cooling system and 50 ft for the heating system. The circulation pumps were than selected from Bell & Gossett pump curves. The pump curves for the circulation pumps can be found in the appendix. Tables 18 and 19 below show the sizes of heat pumps and circulation pumps for each system.

Table 18: GSHP Cooling Pumps



GSHP Cooling System Pumps			
Unit	AHU #	Manufacturer	Size
GCW180	Greenhouse	McQuay	15 tons
GCW180	AHU-1	McQuay	15 tons
GCW300	AHU-2	McQuay	25 tons
GCW300	AHU-3	McQuay	25 tons
GCW360	AHU-4	McQuay	30 tons
GCW360	AHU-5	McQuay	30 tons
Series 1510	Circ.	Bell&Gossett	400gpm/1750rpm

Table 19: GSHP Heating Pumps



GSHP Heating System Pumps			
Unit	AHU #	Manufacturer	Size
GHW420	Greenhouse	McQuay	35 tons
GHW072	AHU-1	McQuay	6 tons
GHW240	AHU-2	McQuay	20 tons
GHW150	AHU-3	McQuay	12.5 tons
GHW300	AHU-4	McQuay	25 tons
GHW240	AHU-5	McQuay	20 tons
Series 1510	Circ.	Bell&Gossett	315gpm/1750rpm

In the tables above the C in GCW stands for cooling unit only and the same for the H in GHW stands for heating only. These designations are taken from McQuay product information. The numbers following them designate the load in load capacity in BTU/h. For instance 180 stands for 180,000 BTU/h in cooling capacity.

System Piping

The piping chosen for the ground loops is 1-1/4" High Density Polyethylene (HDPE) which is the ideal chose for ground loops because it is thermally fused.

Pumping Schematic

The following schematic is for the cooling and heating system pump layouts. Figure 6 below is that schematic.

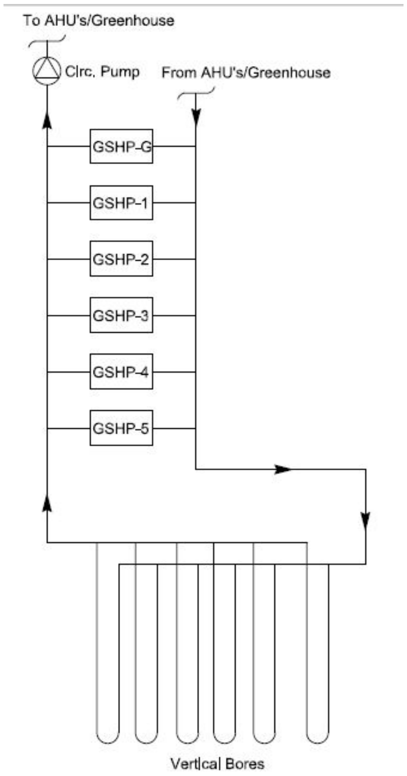


Figure 6: GSHP Pumping Schematic

Construction Breadth

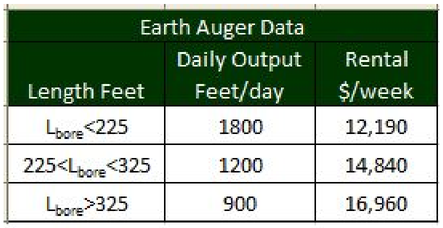
The objective of this study is to analyze the cost and schedule added from the construction of the ground source heat pump system. The construction of a vertical ground source heat pump system can be expensive and time consuming. The cost of drilling, piping, grout, welding and miscellaneous costs were evaluated for this study to optimize the number and depth of boreholes. All costs assumed are from *RS Means Mechanical Cost Data-2011.*

Cost Assumptions

Drilling Costs

Drilling costs rely on the equipment utilized and the crew's capabilities. This study compared three different augers that are capable of drilling different depths. Table 20 below shows the daily output and weekly rental cost of each auger based on the length of borehole it can drill.

Table 20: Auger Data



Earth Auger Data		
Length Feet	Daily Output Feet/day	Rental $/week
$L_{bore}<225$	1800	12,190
$225<L_{bore}<325$	1200	14,840
$L_{bore}>325$	900	16,960

Piping Costs

The pipe used for this study is 1-1/4" High Density Polyethylene (HDPE). The price for this is $0.69/ft and the pipe comes in 40 ft sections. Also a cost for welding the elbows and lengths together is needed. The cost per weld is $4.79 and the machine costs $40.25 a day to rent.

Grouting Costs

The cost for grouting is a constant cost based on the length of borehole. The cost for grouting for the cooling system is $3,256 and the cost of grouting for the heating system is $3,720.

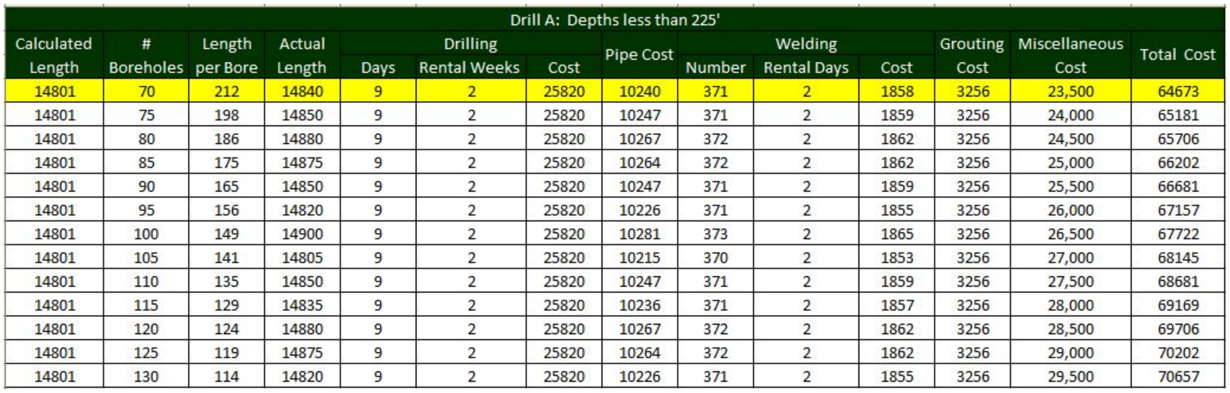
Miscellaneous Costs

Throughout construction miscellaneous costs are inevitable. They can include the purging and testing of the system. These costs are based on the number of boreholes and increase linearly.

Borehole Optimization

The total lengths for boreholes were 14,801 ft for the cooling system and 16,905 ft for the heating system. The number and depth of boreholes was determined for each system by this cost study. Days and weeks for rentals were rounded up to whole periods because no savings will be made to rent equipment shorter than the specified rental times. The following tables, Table 21, 22, 23, 24, 25, and 26, show the calculations for a certain number of boreholes and depths for each earth auger.

Table 21: Borehole Number and Depth for Auger Depths < 225ft (Cooling System)



Drill A: Depths less than 225'

Calculated Length	# Boreholes	Length per Bore	Actual Length	Drilling			Pipe Cost	Welding			Grouting Cost	Miscellaneous Cost	Total Cost
				Days	Rental Weeks	Cost		Number	Rental Days	Cost			
14801	70	212	14840	9	2	25820	10240	371	2	1858	3256	23,500	64673
14801	75	198	14850	9	2	25820	10247	371	2	1859	3256	24,000	65181
14801	80	186	14880	9	2	25820	10267	372	2	1862	3256	24,500	65706
14801	85	175	14875	9	2	25820	10264	372	2	1862	3256	25,000	66202
14801	90	165	14850	9	2	25820	10247	371	2	1859	3256	25,500	66681
14801	95	156	14820	9	2	25820	10226	371	2	1855	3256	26,000	67157
14801	100	149	14900	9	2	25820	10281	373	2	1865	3256	26,500	67722
14801	105	141	14805	9	2	25820	10215	370	2	1853	3256	27,000	68145
14801	110	135	14850	9	2	25820	10247	371	2	1859	3256	27,500	68681
14801	115	129	14835	9	2	25820	10236	371	2	1857	3256	28,000	69169
14801	120	124	14880	9	2	25820	10267	372	2	1862	3256	28,500	69706
14801	125	119	14875	9	2	25820	10264	372	2	1862	3256	29,000	70202
14801	130	114	14820	9	2	25820	10226	371	2	1855	3256	29,500	70657

Table 22: Borehole Number and Depth for Auger Depths Between 225ft & 325ft (Cooling System)

Drill B: Depths greater than 225' and less 325'													
Calculated Length	# Boreholes	Length per Bore	Actual Length	Drilling			Pipe Cost	Welding			Grouting Cost	Miscellaneous Cost	Total Cost
				Days	Rental Weeks	Cost		Number	Rental Days	Cost			
14801	50	297	14850	13	3	38730	10247	371	2	1859	3256	21,500	75591
14801	55	270	14850	13	3	38730	10247	371	2	1859	3256	22,000	76091
14801	60	247	14820	13	3	38730	10226	371	2	1855	3256	22,500	76567
14801	65	228	14820	13	3	38730	10226	371	2	1855	3256	23,000	77067

Table 23: Borehole Number and Depth for Auger Depths > 325ft (Cooling System)

Drill C: Depths greater than 325'													
Calculated Length	# Borehole	Length per Bore	Actual Length	Drilling			Pipe Cost	Welding			Grouting Cost	Miscellaneous Cost	Total Cost
				Days	Rental Weeks	Cost		Number	Rental Days	Cost			
14801	20	741	14820	17	4	51640	10226	371	2	1855	3256	18,500	85477
14801	25	593	14825	17	4	51640	10229	371	2	1856	3256	19,000	85981
14801	30	494	14820	17	4	51640	10226	371	2	1855	3256	19,500	86477
14801	35	423	14805	17	4	51640	10215	370	2	1853	3256	20,000	86965
14801	40	371	14840	17	4	51640	10240	371	2	1858	3256	20,500	87493
14801	45	329	14805	17	4	51640	10215	370	2	1853	3256	21,000	87965

Table 24: Borehole Number and Depth for Auger Depths < 225ft (Heating System)

Drill A: Depths less than 225'													
Calculated Length	# Boreholes	Length per Bore	Actual Length	Drilling			Pipe Cost	Welding			Grouting Cost	Miscellaneous Cost	Total Cost
				Days	Rental Weeks	Cost		Number	Rental Days	Cost			
16905	80	212	16960	10	2	25820	11702	424	2	2111	3720	24,500	67854
16905	85	199	16915	10	2	25820	11671	423	2	2106	3720	25,000	68317
16905	90	188	16920	10	2	25820	11675	423	2	2107	3720	25,500	68821
16905	95	178	16910	10	2	25820	11668	423	2	2105	3720	26,000	69313
16905	100	170	17000	10	2	25820	11730	425	2	2116	3720	26,500	69886
16905	105	161	16905	10	2	25820	11664	423	2	2105	3720	27,000	70309
16905	110	154	16940	10	2	25820	11689	424	2	2109	3720	27,500	70838
16905	115	147	16905	10	2	25820	11664	423	2	2105	3720	28,000	71309
16905	120	141	16920	10	2	25820	11675	423	2	2107	3720	28,500	71821
16905	125	136	17000	10	2	25820	11730	425	2	2116	3720	29,000	72386
16905	130	131	17030	10	2	25820	11751	426	2	2120	3720	29,500	72911

Table 25: Borehole Number and Depth for Auger Depths Between 225ft & 325ft (Heating System)

Drill B: Depths greater than 225' and less 325'													
Calculated Length	# Boreholes	Length per Bore	Actual Length	Drilling			Pipe Cost	Welding			Grouting Cost	Miscellaneous Cost	Total Cost
				Days	Rental Weeks	Cost		Number	Rental Days	Cost			
16905	55	308	16940	15	3	38730	11689	424	2	2109	3720	22,000	78248
16905	60	282	16920	15	3	38730	11675	423	2	2107	3720	22,500	78731
16905	65	261	16965	15	3	38730	11706	424	2	2112	3720	23,000	79268
16905	70	242	16940	15	3	38730	11689	424	2	2109	3720	23,500	79748
16905	75	226	16950	15	3	38730	11696	424	2	2110	3720	24,000	80256

Table 26: Borehole Number and Depth for Auger Depths > 325ft (Heating System)

Drill C: Depths greater than 325'													
Calculated Length	# Borehole	Length per Bore	Actual Length	Drilling			Pipe Cost	Welding			Grouting Cost	Miscellaneous Cost	Total Cost
				Days	Rental Weeks	Cost		Number	Rental Days	Cost			
16905	20	846	16920	19	4	51640	11675	423	2	2107	3720	18,500	87641
16905	25	677	16925	19	4	51640	11678	423	2	2107	3720	19,000	88146
16905	30	564	16920	19	4	51640	11675	423	2	2107	3720	19,500	88641
16905	35	483	16905	19	4	51640	11664	423	2	2105	3720	20,000	89129
16905	40	423	16920	19	4	51640	11675	423	2	2107	3720	20,500	89641
16905	45	376	16920	19	4	51640	11675	423	2	2107	3720	21,000	90141
16905	50	339	16950	19	4	51640	11696	424	2	2110	3720	21,500	90666

Borehole Optimization Results

From the previous tables the best option for the cooling system is 70 boreholes at a depth of 212 ft each. This also was the cheapest cost out of the three drills. The best option for the heating system is 80 boreholes at a depth of 212 ft each, also being the cheapest cost out of the three drills. Charts 3 and 4 below show the number of boreholes per total cost for each auger for the cooling and heating systems, respectively. The charts below show that the main factor in overall cost is the auger selection. The lower an auger can drill the more daily output and less cost per week to rent it is. Also at depths less than 225 feet the ground is softer and therefore easier to drill, making the auger more effective.

Chart 3: Total Borehole Cost Optimization

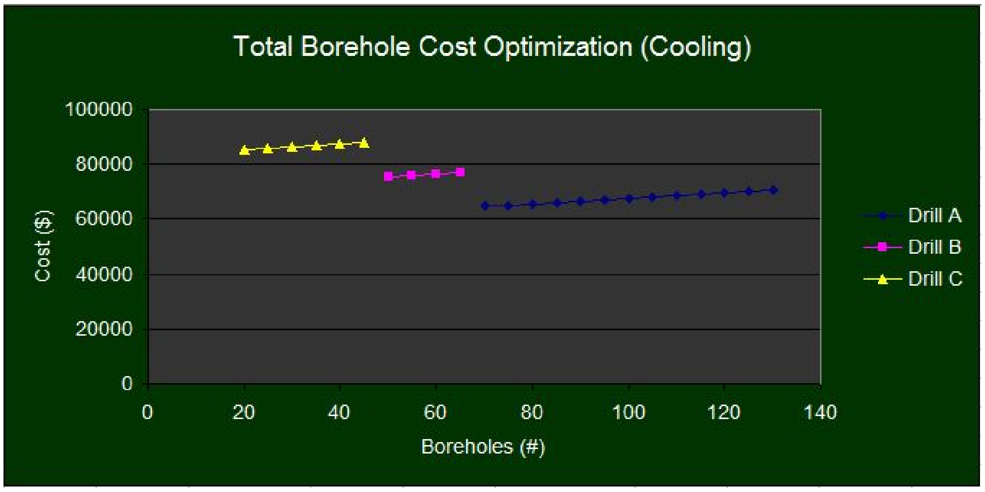
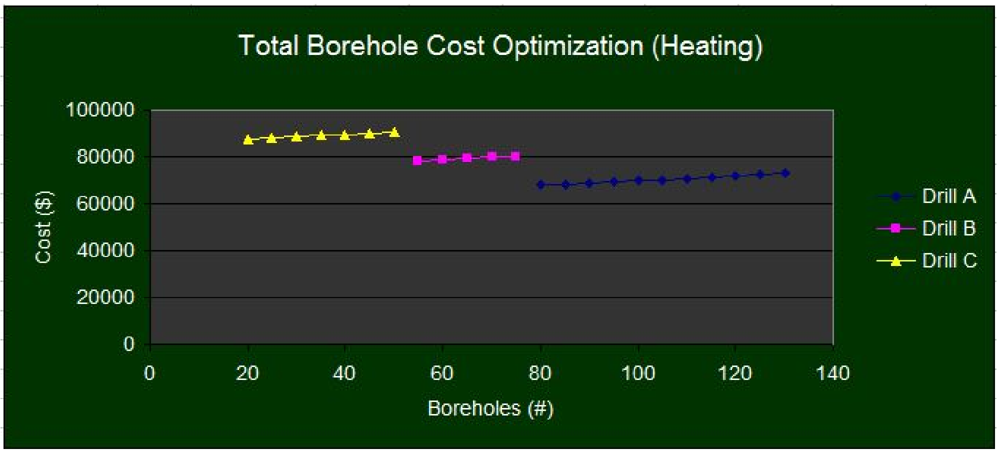
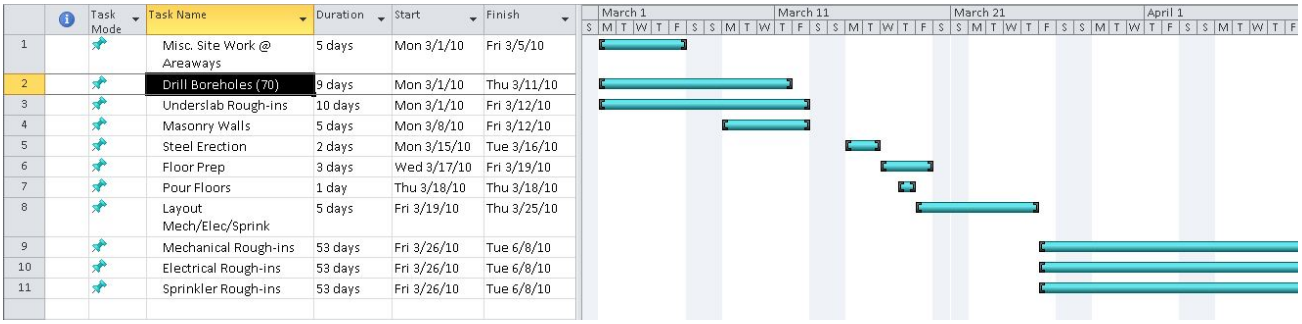


Chart 4: Total Borehole Cost Optimization



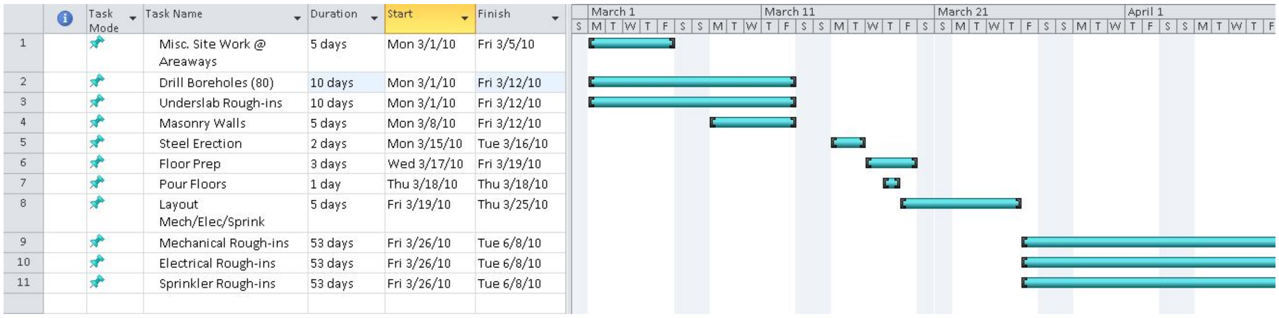
Construction Schedule

With the use of a ground source heat pump system comes more excavation and construction time. This not only adds to the cost but also to the schedule. The time needed to drill boreholes had to be added to the construction schedule. The drilling for boreholes was placed in the schedule to finish before the mechanical system rough-ins. The following figures, Figures 7 and 8, show the schedule changes for the cooling and heating systems respectively.



	ℹ	Task Mode	Task Name	Duration	Start	Finish
1		📌	Misc. Site Work @ Areaways	5 days	Mon 3/1/10	Fri 3/5/10
2		📌	Drill Boreholes (70)	9 days	Mon 3/1/10	Thu 3/11/10
3		📌	Underslab Rough-ins	10 days	Mon 3/1/10	Fri 3/12/10
4		📌	Masonry Walls	5 days	Mon 3/8/10	Fri 3/12/10
5		📌	Steel Erection	2 days	Mon 3/15/10	Tue 3/16/10
6		📌	Floor Prep	3 days	Wed 3/17/10	Fri 3/19/10
7		📌	Pour Floors	1 day	Thu 3/18/10	Thu 3/18/10
8		📌	Layout Mech/Elec/Sprink	5 days	Fri 3/19/10	Thu 3/25/10
9		📌	Mechanical Rough-ins	53 days	Fri 3/26/10	Tue 6/8/10
10		📌	Electrical Rough-ins	53 days	Fri 3/26/10	Tue 6/8/10
11		📌	Sprinkler Rough-ins	53 days	Fri 3/26/10	Tue 6/8/10

Figure 7: Construction Schedule (Cooling System)



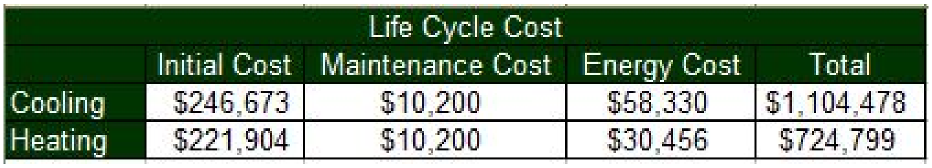
	Task Mode	Task Name	Duration	Start	Finish
1		Misc. Site Work @ Areaways	5 days	Mon 3/1/10	Fri 3/5/10
2		Drill Boreholes (80)	10 days	Mon 3/1/10	Fri 3/12/10
3		Underslab Rough-ins	10 days	Mon 3/1/10	Fri 3/12/10
4		Masonry Walls	5 days	Mon 3/8/10	Fri 3/12/10
5		Steel Erection	2 days	Mon 3/15/10	Tue 3/16/10
6		Floor Prep	3 days	Wed 3/17/10	Fri 3/19/10
7		Pour Floors	1 day	Thu 3/18/10	Thu 3/18/10
8		Layout Mech/Elec/Sprink	5 days	Fri 3/19/10	Thu 3/25/10
9		Mechanical Rough-ins	53 days	Fri 3/26/10	Tue 6/8/10
10		Electrical Rough-ins	53 days	Fri 3/26/10	Tue 6/8/10
11		Sprinkler Rough-ins	53 days	Fri 3/26/10	Tue 6/8/10

Figure 8: Construction Schedule (Heating System)

Life Cycle Cost

A life cycle cost was done for the ground source heat pump systems. Life cycle costs include the initial cost of the system, the maintenance cost, and the energy cost per year of the system. A maintenance figure was used from similar building types to be $0.10/SF. The annual energy cost for the cooling and heating systems was based off the utility rate of $0.0935/kwh. The initial cost for each system was based off the first cost of pumps per ton, $1300/ton, and the cost of drilling and piping. An equipment life of 20 years was assumed. The following table, Table 27, below shows the life cycle cost results for each system.

Table 27: Life Cycle Cost Results



	Life Cycle Cost			
	Initial Cost	Maintenance Cost	Energy Cost	Total
Cooling	$246,673	$10,200	$58,330	$1,104,478
Heating	$221,904	$10,200	$30,456	$724,799

Electrical Breadth

The purpose of this breadth is to resize electrical equipment such as panelboards and the main switchboard because with the addition of ground-source heat pumps. They impose new electrical loads on the building. In this study a panelboard is added for each GSHP system, cooling and heating, as well as feeder sizes and size of the main switchboard.

Electrical Load Calculations

The Full Load Amps, FLA, for the pumps were first found. After this the FLAs were were used to find the watts put out by each pump. The equation used for this is shown below, Equation 9. The KVAs for each pump were than found to help with sizing the panelboards. The power factor, PF, assumed for the pump motors was 0.9 for motors over 5 hp. These values can be seen below in Tables 27 an 28 for each cooling and heating, respectively.

$$W = FLA \times 1.73 \times Voltage \times PF \qquad \text{Equation 9}$$

Table 27: Electrical Loads for Cooling GSHPs

	Electrical Data					
	FLA	PF	Voltage	W_{total}	W_{phase}	KVA_{phase}
GSHP-G	29.6	0.9	480	22122	7374	6.64
GSHP-1	29.6	0.9	480	22122	7374	6.64
GSHP-2	34.4	0.9	480	25709	8570	7.71
GSHP-3	34.4	0.9	480	25709	8570	7.71
GSHP-4	43.6	0.9	480	32585	10862	9.78
GSHP-5	43.6	0.9	480	32585	10862	9.78
Circ. Pump	7.5	0.9	480	5605.2	1868.4	2.07

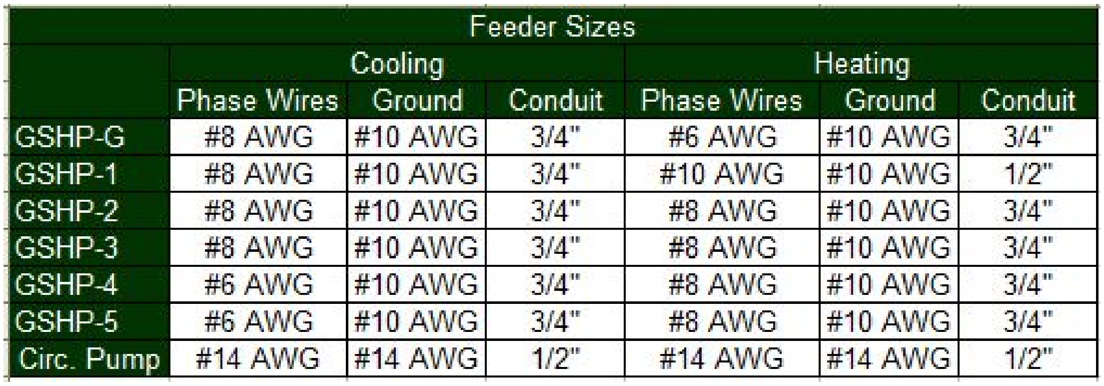
Table 28: Electrical Loads for Heating GSHPs

	Electrical Data					
	FLA	PF	Voltage	Wtotal	Wphase	KVAphase
GSHP-G	47.6	0.9	480	35574	11858	10.67
GSHP-1	20.7	0.9	480	15470	5157	4.64
GSHP-2	31	0.9	480	23168	7723	6.95
GSHP-3	29.6	0.9	480	22122	7374	6.64
GSHP-4	34.4	0.9	480	25709	8570	7.71
GSHP-5	31	0.9	480	23168	7723	6.95
Circ. Pump	7.5	0.9	480	5605.2	1868.4	2.07

Feeder Sizing

To size the feeders for the pumps and panelboards *Table 310.16 from NEC 2008* was used. Feeder sizes are based off the FLA multiplied by a sizing factor of 1.25. Ground wires were sized using Table *250.122 from NEC 2008*. Conduit sizes were found using *Table C.1 for EMT, (electrical metallic tubing), from NEC 2008*. Table 29 below shows the feeder sizes for the GSHPs used for cooling and heating systems.

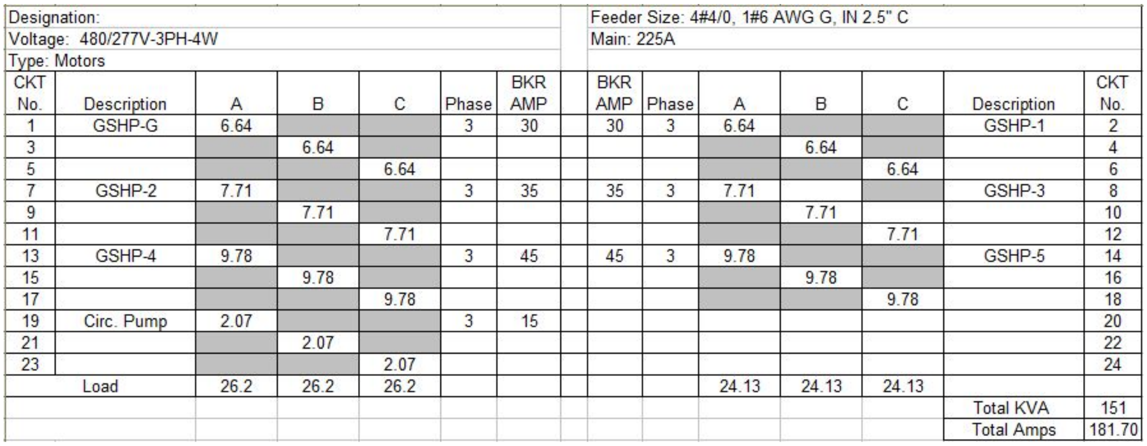
Table 29: Feeder Sizes for GSHPs



	Feeder Sizes					
	Cooling			Heating		
	Phase Wires	Ground	Conduit	Phase Wires	Ground	Conduit
GSHP-G	#8 AWG	#10 AWG	3/4"	#6 AWG	#10 AWG	3/4"
GSHP-1	#8 AWG	#10 AWG	3/4"	#10 AWG	#10 AWG	1/2"
GSHP-2	#8 AWG	#10 AWG	3/4"	#8 AWG	#10 AWG	3/4"
GSHP-3	#8 AWG	#10 AWG	3/4"	#8 AWG	#10 AWG	3/4"
GSHP-4	#6 AWG	#10 AWG	3/4"	#8 AWG	#10 AWG	3/4"
GSHP-5	#6 AWG	#10 AWG	3/4"	#8 AWG	#10 AWG	3/4"
Circ. Pump	#14 AWG	#14 AWG	1/2"	#14 AWG	#14 AWG	1/2"

Panelboards

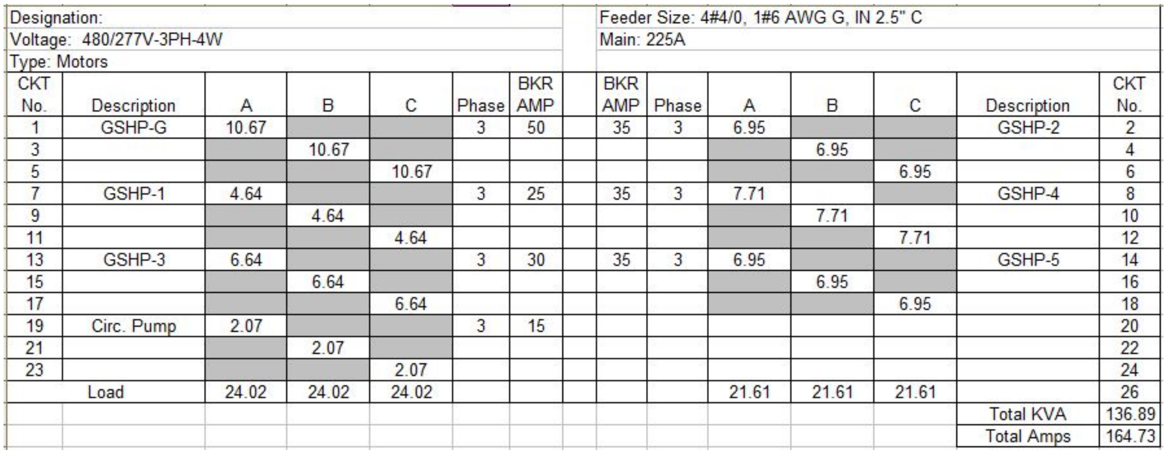
One panelboard each was added for the cooling and heating GSHPs. The panelboards were sized using the KVA from each pump to find the total amps. These total amps were than used to size overcurrent protection devices, circuit breakers, for the panelboards and the GSHPs. The circuit breaker sizes can be found on the panelboards. The feeder sizes for the panelboards from the main switchboard are also found on the panelboards. Figures 9 and 10 below are the panelboards for cooling and heating systems, respectively.



Designation:
Voltage: 480/277V-3PH-4W
Type: Motors
Feeder Size: 4#4/0, 1#6 AWG G, IN 2.5" C
Main: 225A

CKT No.	Description	A	B	C	Phase	BKR AMP	BKR AMP	Phase	A	B	C	Description	CKT No.
1	GSHP-G	6.64			3	30	30	3	6.64			GSHP-1	2
3			6.64							6.64			4
5				6.64							6.64		6
7	GSHP-2	7.71			3	35	35	3	7.71			GSHP-3	8
9			7.71							7.71			10
11				7.71							7.71		12
13	GSHP-4	9.78			3	45	45	3	9.78			GSHP-5	14
15			9.78							9.78			16
17				9.78							9.78		18
19	Circ. Pump	2.07			3	15							20
21			2.07										22
23				2.07									24
Load		26.2	26.2	26.2					24.13	24.13	24.13		
												Total KVA	151
												Total Amps	181.70

Figure 9: Cooling GSHPs Panelboard



Designation:
Voltage: 480/277V-3PH-4W
Type: Motors
Feeder Size: 4#4/0, 1#6 AWG G, IN 2.5" C
Main: 225A

CKT No.	Description	A	B	C	Phase	BKR AMP	BKR AMP	Phase	A	B	C	Description	CKT No.
1	GSHP-G	10.67			3	50	35	3	6.95			GSHP-2	2
3			10.67							6.95			4
5				10.67							6.95		6
7	GSHP-1	4.64			3	25	35	3	7.71			GSHP-4	8
9			4.64							7.71			10
11				4.64							7.71		12
13	GSHP-3	6.64			3	30	35	3	6.95			GSHP-5	14
15			6.64							6.95			16
17				6.64							6.95		18
19	Circ. Pump	2.07			3	15							20
21			2.07										22
23				2.07									24
Load		24.02	24.02	24.02					21.61	21.61	21.61		26
												Total KVA	136.89
												Total Amps	164.73

Figure 10: Heating GSHPs Panelboard

Switchboard

The main switchboard was sized according to the total FLAs that are in the electrical loads from the life sciences building and greenhouse building. The FLAs from all the panelboards were added together to get the total amps. For both the cooling and heating GSHP systems the main switchboard has a size of 4000A. The total amps were 3101A for cooling and 3529A for heating. 4000A is the next size that will meet both of these amp totals.

Conclusion and Discussion of Results

The ground source heat pump system employed to replace the chiller and boiler systems separately saved a good amount of energy used each year. The reduction in energy cost from using the chiller system to using GSHPs and chilled beams to replace it was a savings of $137,495/year. This is a significant savings in energy cost because of the amount of equipment taken out from the mechanical system. That includes the chiller, the cooling towers, the condenser pumps, chilled water pumps, and a reduction in supply air from chilled beams. The reduction in energy cost with replacing the boiler system with GSHPs and chilled beams results in a savings of $78,436/year. This is also a significant reduction in energy because of losing mechanical equipment such as the heat pumps, boilers, and reduction in supply air from the chilled beams. The following charts, Charts 5, 6, 7, and 8 show the energy consumption and cost per month for the cooling system employed with GSHPs. Charts 9 and 10 below show the energy consumption and cost per month for the heating system employed with GSHPs. Tables 30 and 31 below breakdown the energy consumption from each system per year.

Chart 5: Natural Gas Consumption per Month

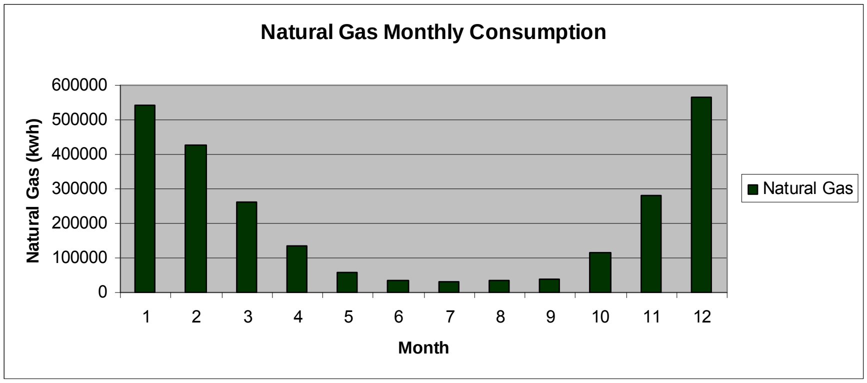


Chart 6: Natural Gas Cost per Month

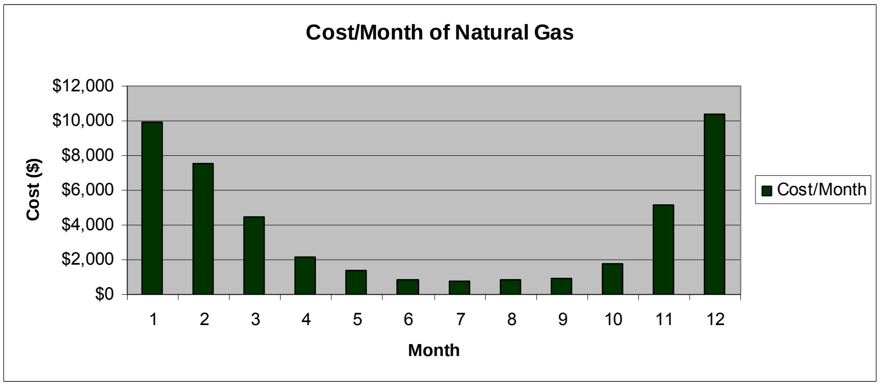


Chart 7: Electrical Consumption per Month (GSHP Cooling)

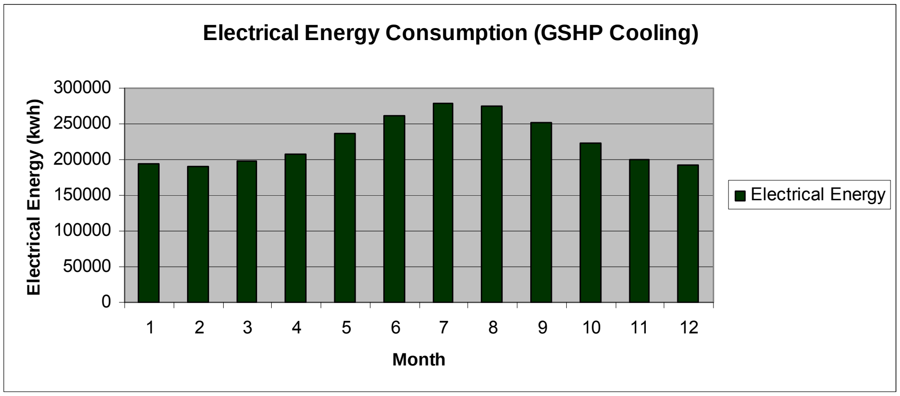


Chart 8: Electrical Consumption Cost per Month (GSHP Cooling)

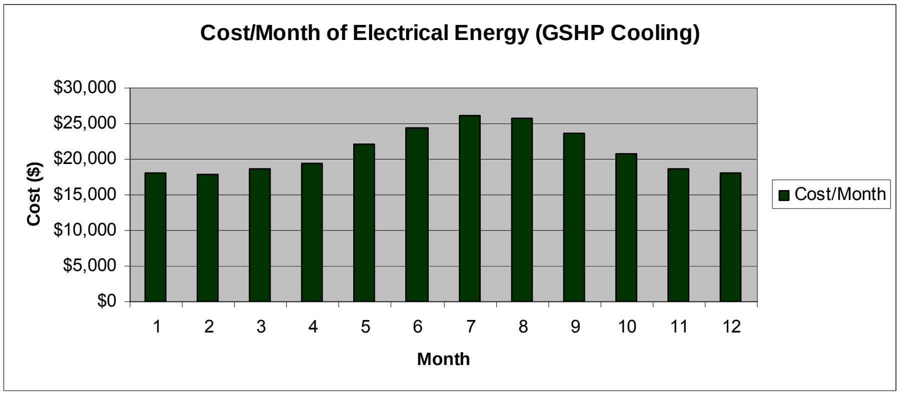


Chart 9: Electrical Consumption per Month (GSHP Heating)

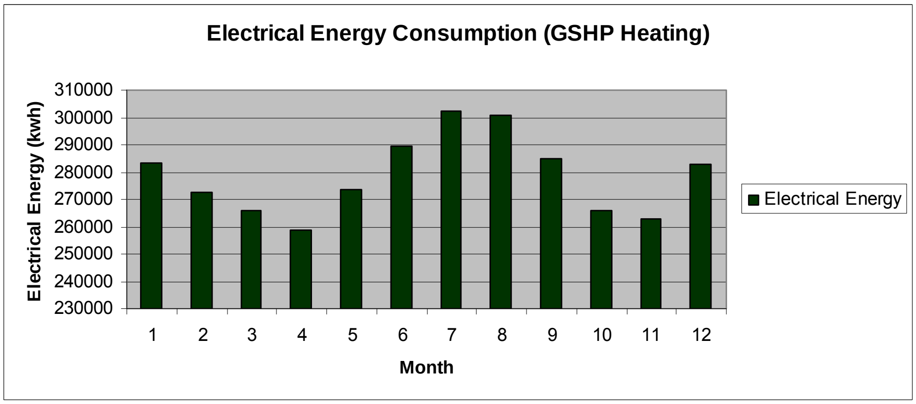


Chart 10: Electrical Consumption Cost per Month (GSHP Heating)

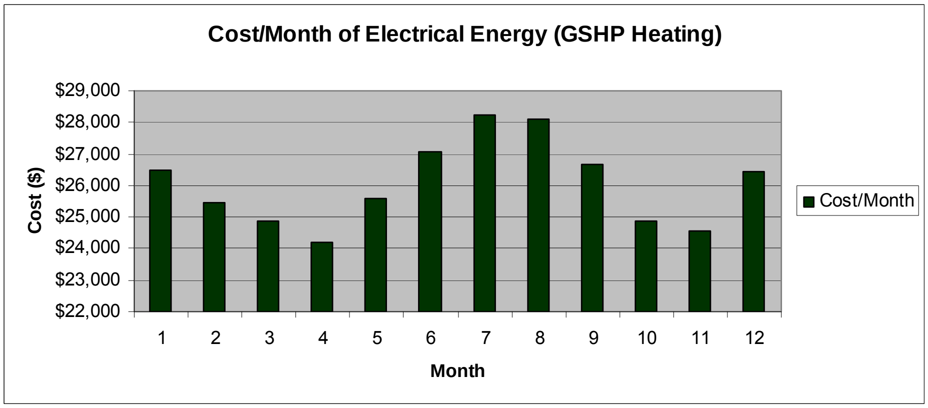
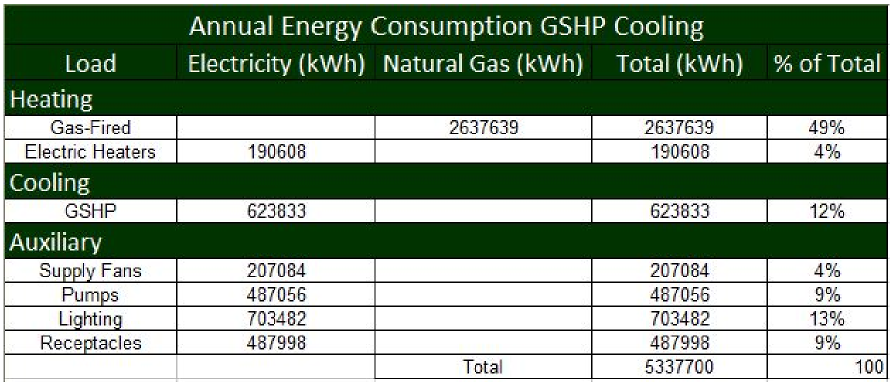
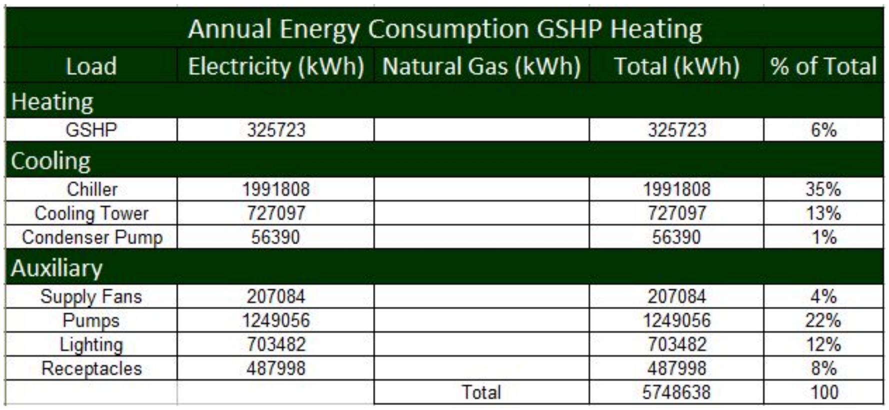


Table 30: Annual Energy Consumption (GSHP Cooling)



Annual Energy Consumption GSHP Cooling				
Load	Electricity (kWh)	Natural Gas (kWh)	Total (kWh)	% of Total
Heating				
Gas-Fired		2637639	2637639	49%
Electric Heaters	190608		190608	4%
Cooling				
GSHP	623833		623833	12%
Auxiliary				
Supply Fans	207084		207084	4%
Pumps	487056		487056	9%
Lighting	703482		703482	13%
Receptacles	487998		487998	9%
		Total	5337700	100

Table 31: Annual Energy Consumption (GSHP Heating)



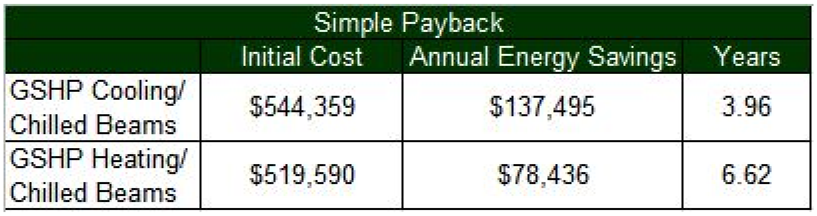
Annual Energy Consumption GSHP Heating				
Load	Electricity (kWh)	Natural Gas (kWh)	Total (kWh)	% of Total
Heating				
GSHP	325723		325723	6%
Cooling				
Chiller	1991808		1991808	35%
Cooling Tower	727097		727097	13%
Condenser Pump	56390		56390	1%
Auxiliary				
Supply Fans	207084		207084	4%
Pumps	1249056		1249056	22%
Lighting	703482		703482	12%
Receptacles	487998		487998	8%
		Total	5748638	100

From the previous charts and tables it shows that it is more feasible to replace the chiller system with GSHPs than the boiler system. This is because the annual energy savings are much more significant using cooling than heating GSHPs.

Simple Payback

The simple payback for the ground source heat pumps and chilled beams combined are calculated below. The initial cost is taken over the annual cost savings to find a payback period. Table 32 below shows the payback periods for each the cooling and heating systems.

Table 32: Simple Payback

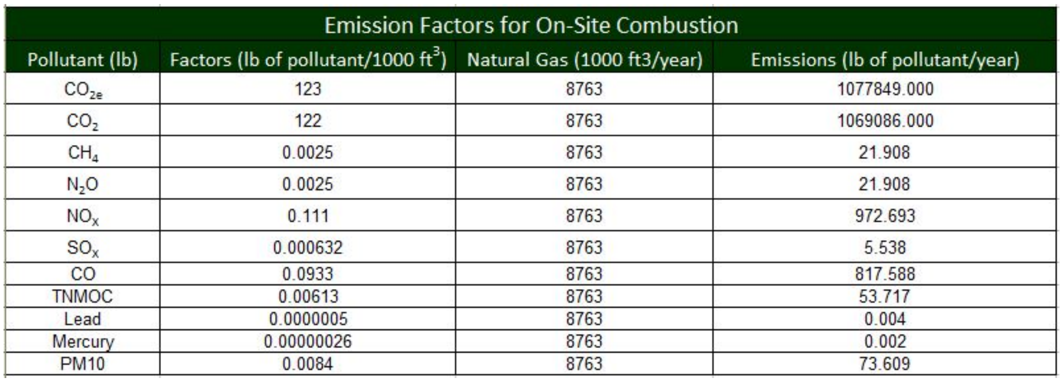


Simple Payback			
	Initial Cost	Annual Energy Savings	Years
GSHP Cooling/ Chilled Beams	$544,359	$137,495	3.96
GSHP Heating/ Chilled Beams	$519,590	$78,436	6.62

Emissions

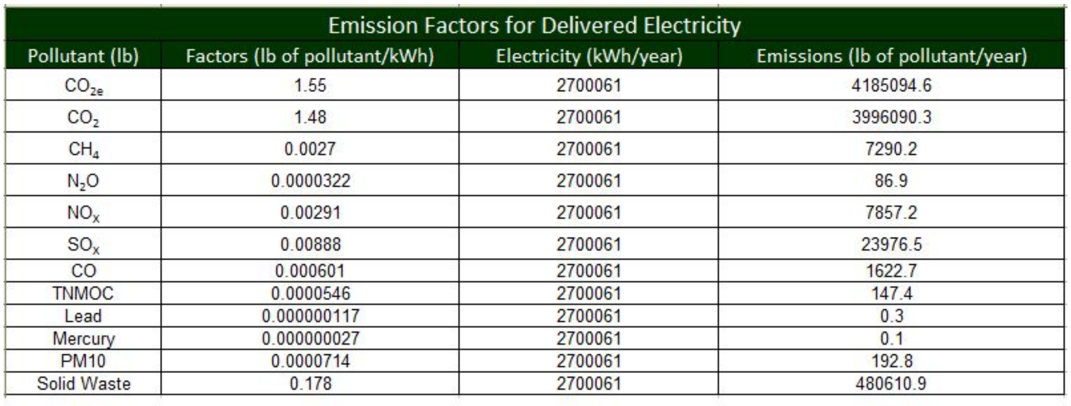
Because the electrical energy consumption reduced for each the cooling and heating systems the emissions will reduce for each of the systems. If the GSHP heating system were to be used there would be no emissions from the natural gas boilers. However since it is more feasible to replace the chiller system there will still be emissions from the natural gas boilers. Tables 33 and 34 below show the emissions from the GSHP cooling system that is replacing the chiller system.

Table 33: Annual Natural Gas Emissions



Emission Factors for On-Site Combustion			
Pollutant (lb)	Factors (lb of pollutant/1000 ft^3)	Natural Gas (1000 ft3/year)	Emissions (lb of pollutant/year)
CO_{2e}	123	8763	1077849.000
CO_2	122	8763	1069086.000
CH_4	0.0025	8763	21.908
N_2O	0.0025	8763	21.908
NO_X	0.111	8763	972.693
SO_X	0.000632	8763	5.538
CO	0.0933	8763	817.588
TNMOC	0.00613	8763	53.717
Lead	0.0000005	8763	0.004
Mercury	0.00000026	8763	0.002
PM10	0.0084	8763	73.609

Table 34: Annual Electricity Emissions



Emission Factors for Delivered Electricity			
Pollutant (lb)	Factors (lb of pollutant/kWh)	Electricity (kWh/year)	Emissions (lb of pollutant/year)
CO_{2e}	1.55	2700061	4185094.6
CO_2	1.48	2700061	3996090.3
CH_4	0.0027	2700061	7290.2
N_2O	0.0000322	2700061	86.9
NO_X	0.00291	2700061	7857.2
SO_X	0.00888	2700061	23976.5
CO	0.000601	2700061	1622.7
TNMOC	0.0000546	2700061	147.4
Lead	0.000000117	2700061	0.3
Mercury	0.000000027	2700061	0.1
PM10	0.0000714	2700061	192.8
Solid Waste	0.178	2700061	480610.9

References

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“Chilled Beams in Laboratories: Key Strategies to Ensure Effective Design, Construction, and Operation”. Laboratories for the 21st Century: Best Practice Guide. June 2009.

McQuay. Geothermal Heat Pump Design Manual. 2002.

Carrier HAP eHelp

RS Means 2011 Mechanical Cost Data

Appendix

Ground Source Heat Pump Bore Length Calculations

Cooling Length:

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

Heating Length:

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

$F_{of} = 4{*}\alpha{*}\tau_f/d_b^2$

$F_{o1} = 4{*}\alpha{*}(\tau_f - \tau_1)/d_b^2$

$F_{o2} = 4{*}\alpha{*}(\tau_f - \tau_2)/d_b^2$

$R_{ga} = (G_f - G_1)/k_g$

$R_{gm} = (G_1 - G_2)/k_g$

$R_{gd} = G_2/k_g$

Cooling Parameters:
F_{sc}= 1.02
q_a= 1,594,800 Btu/h
q_{lc}= 1,594,800 Btu/h
R_{ga}= 0.112 h-ft-°F/Btu
R_{gd}= 0.202 h-ft-°F/Btu
R_{gm}= 0.191 h-ft-°F/Btu
R_b= 0.09 h-ft-°F/Btu
t_g= 53 °F
t_p= -4.7 °F
t_{wi}= 75 °F
t_{wo}=85 °F
W_c = 16,499 W
PLF_m= 1
F_{of} = 39,859
F_{o1} = 3058
F_{o2} = 33
α = 1.22 ft^2/day
d_b= 0.22 ft
k_g= 1.78 Btu /h-ft-°F
τ_1= 365
τ_2= 395
τ_f= 395.33
G_1= 0.7
G_2= 0.36
G_f= 0.9

Heating Parameters:
F_{sc}= 1.02
q_a= 1,260,563 Btu/h
q_{lh}= 1,260,563 Btu/h
R_{ga}= 0.112 h-ft-°F/Btu
R_{gd}= 0.202 h-ft-°F/Btu
R_{gm}= 0.191 h-ft-°F/Btu
R_b= 0.09 h-ft-°F/Btu
t_g= 53 °F
t_p= 4.7 °F
t_{wi}= 50 °F
t_{wo}= 40 °F
W_h = 14,061 W
PLF_m= 1
F_{of} = 39,859
F_{o1} = 3058
F_{o2} = 33
α = 1.22 ft^2/day
d_b= 0.22 ft
k_g= 1.78 Btu /h-ft-°F
τ_1= 365
τ_2= 395
τ_f= 395.33
G_1= 0.7
G_2= 0.36
G_f= 0.9

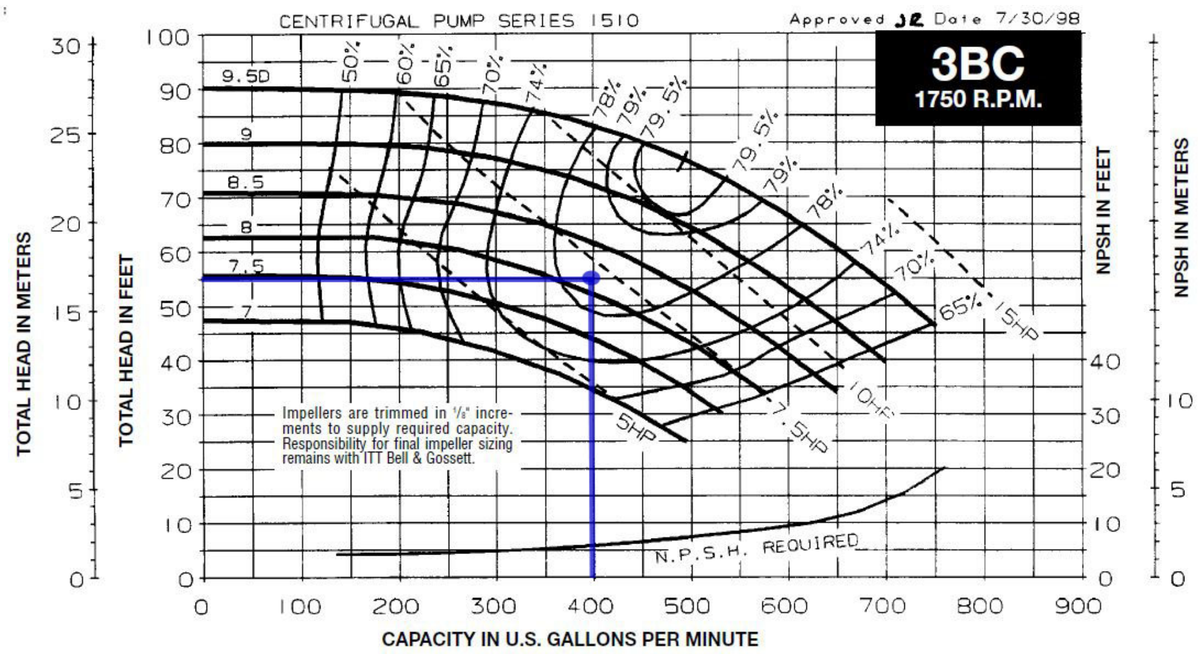
Solutions:

L_c= 14,801 ft

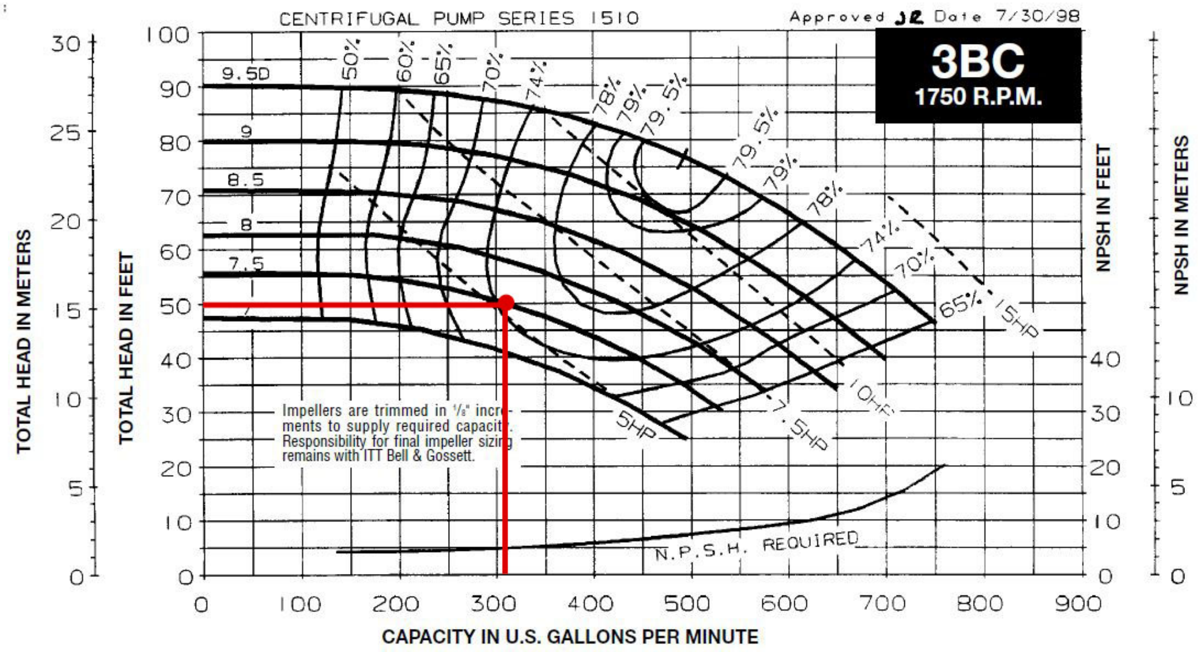
L_h= 16,905 ft

Pump Curves

Cooling Circulation Pump Curve

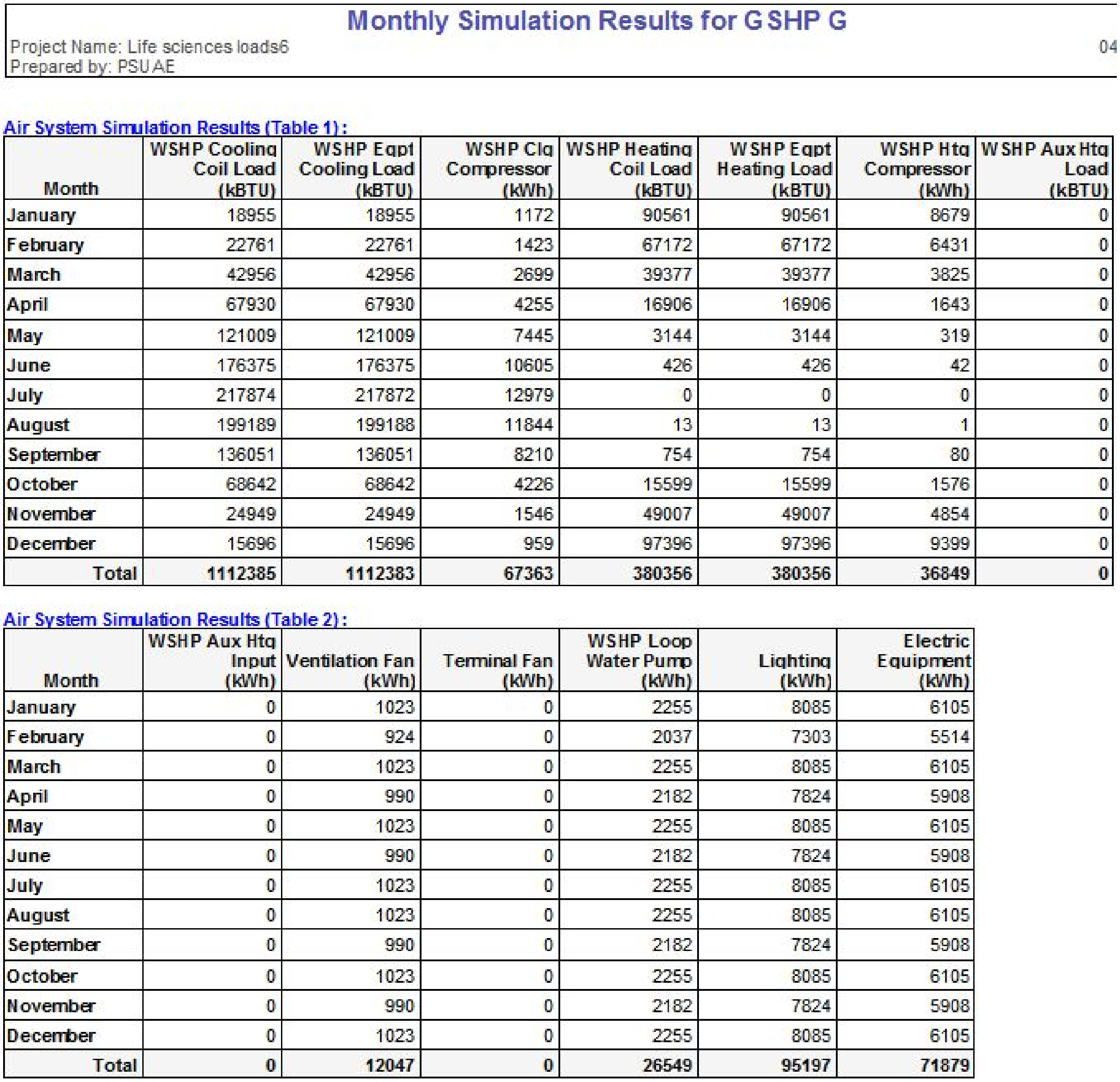


Heating Circulation Pump Curve



Ground Source Heat Pump Calculations

Greenhouse GSHP



Monthly Simulation Results for GSHP G

Project Name: Life sciences loads6 04
Prepared by: PSU AE

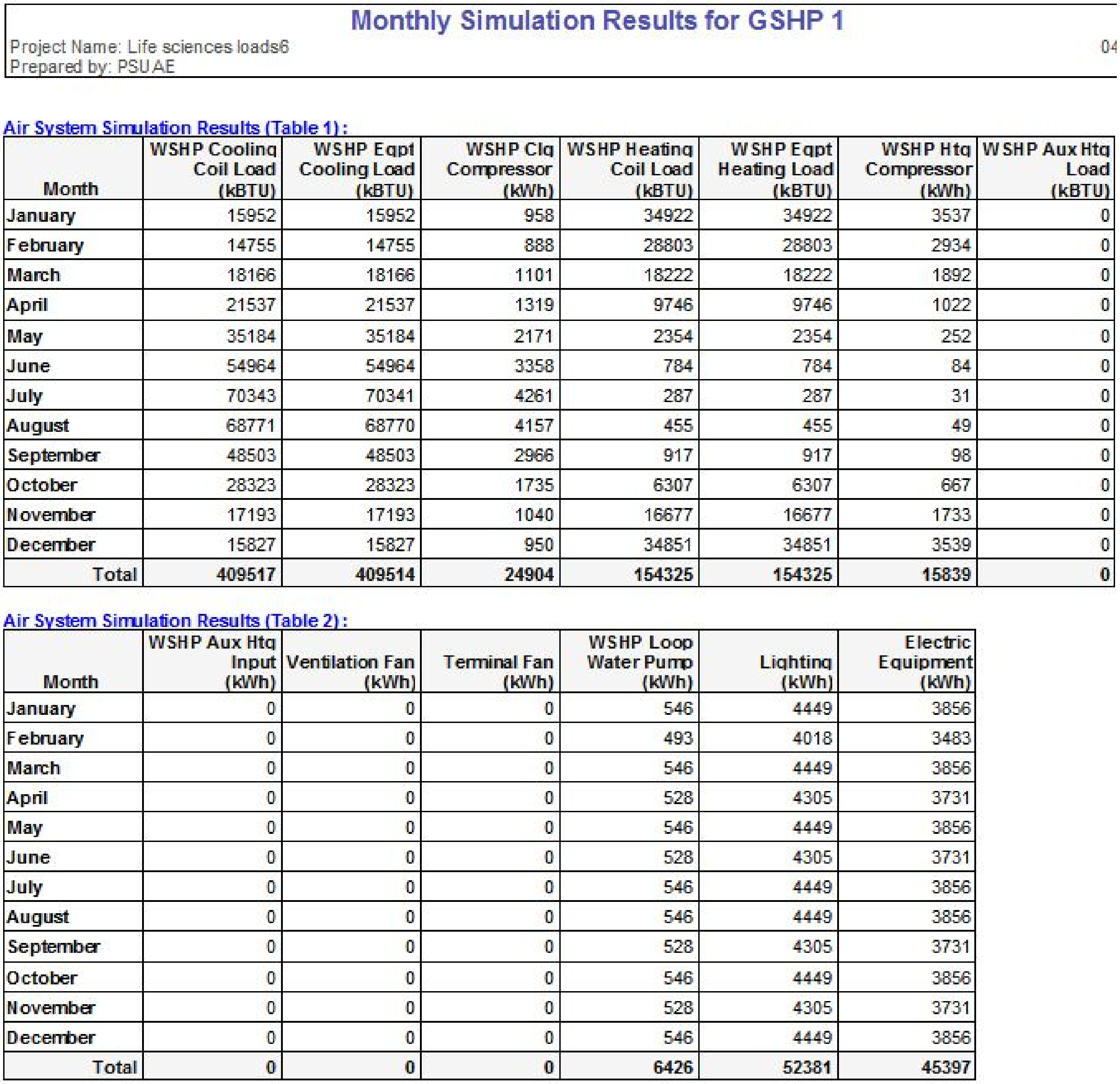
Air System Simulation Results (Table 1):

Month	WSHP Cooling Coil Load (kBTU)	WSHP Eqpt Cooling Load (kBTU)	WSHP Clg Compressor (kWh)	WSHP Heating Coil Load (kBTU)	WSHP Eqpt Heating Load (kBTU)	WSHP Htg Compressor (kWh)	WSHP Aux Htg Load (kBTU)
January	18955	18955	1172	90561	90561	8679	0
February	22761	22761	1423	67172	67172	6431	0
March	42956	42956	2699	39377	39377	3825	0
April	67930	67930	4255	16906	16906	1643	0
May	121009	121009	7445	3144	3144	319	0
June	176375	176375	10605	426	426	42	0
July	217874	217872	12979	0	0	0	0
August	199189	199188	11844	13	13	1	0
September	136051	136051	8210	754	754	80	0
October	68642	68642	4226	15599	15599	1576	0
November	24949	24949	1546	49007	49007	4854	0
December	15696	15696	959	97396	97396	9399	0
Total	**1112385**	**1112383**	**67363**	**380356**	**380356**	**36849**	**0**

Air System Simulation Results (Table 2):

Month	WSHP Aux Htg Input (kWh)	Ventilation Fan (kWh)	Terminal Fan (kWh)	WSHP Loop Water Pump (kWh)	Lighting (kWh)	Electric Equipment (kWh)
January	0	1023	0	2255	8085	6105
February	0	924	0	2037	7303	5514
March	0	1023	0	2255	8085	6105
April	0	990	0	2182	7824	5908
May	0	1023	0	2255	8085	6105
June	0	990	0	2182	7824	5908
July	0	1023	0	2255	8085	6105
August	0	1023	0	2255	8085	6105
September	0	990	0	2182	7824	5908
October	0	1023	0	2255	8085	6105
November	0	990	0	2182	7824	5908
December	0	1023	0	2255	8085	6105
Total	**0**	**12047**	**0**	**26549**	**95197**	**71879**

AHU-1 GSHP



Monthly Simulation Results for GSHP 1

Project Name: Life sciences loads6 04
Prepared by: PSU AE

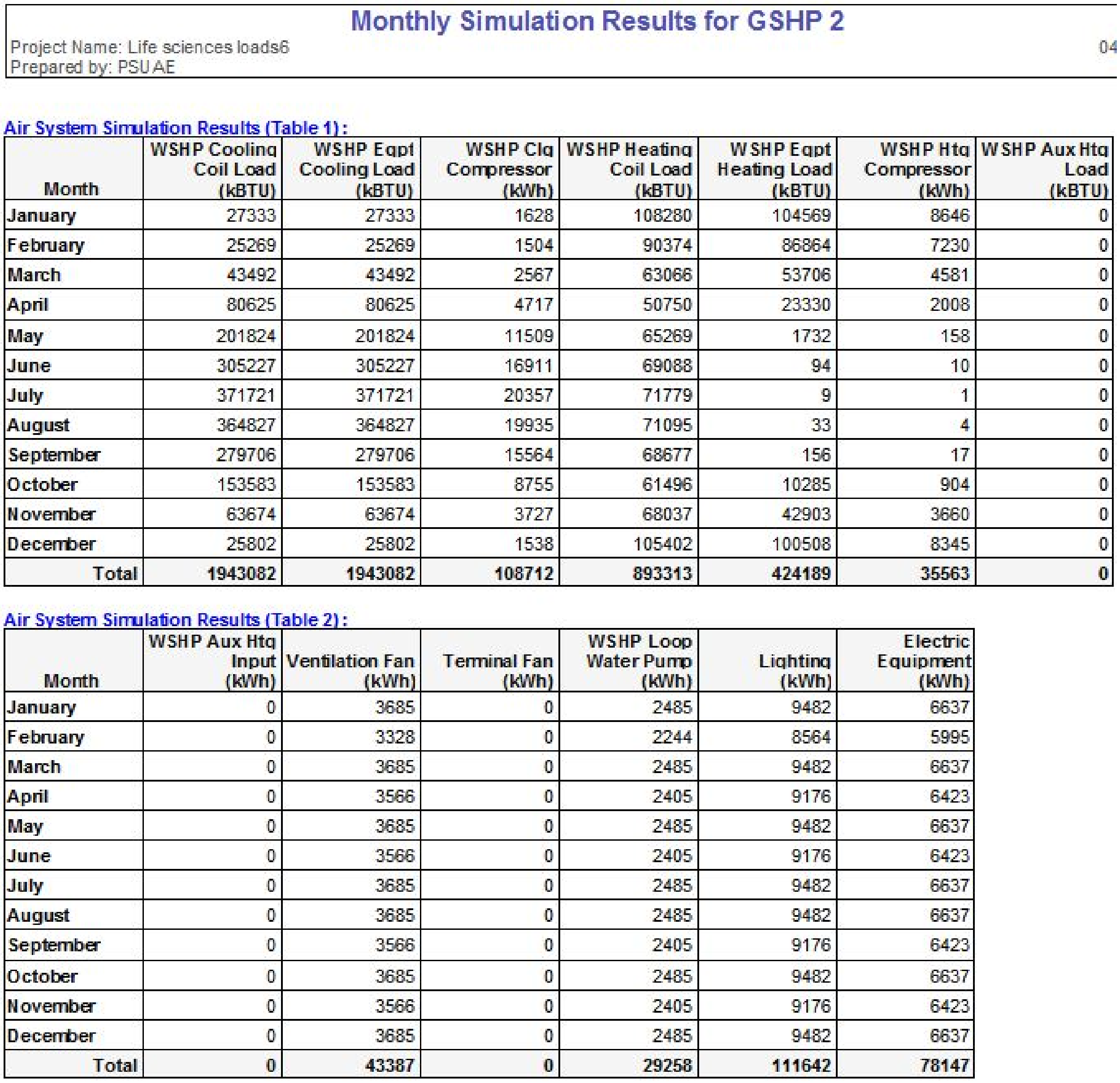
Air System Simulation Results (Table 1):

Month	WSHP Cooling Coil Load (kBTU)	WSHP Eqpt Cooling Load (kBTU)	WSHP Clg Compressor (kWh)	WSHP Heating Coil Load (kBTU)	WSHP Eqpt Heating Load (kBTU)	WSHP Htg Compressor (kWh)	WSHP Aux Htg Load (kBTU)
January	15952	15952	958	34922	34922	3537	0
February	14755	14755	888	28803	28803	2934	0
March	18166	18166	1101	18222	18222	1892	0
April	21537	21537	1319	9746	9746	1022	0
May	35184	35184	2171	2354	2354	252	0
June	54964	54964	3358	784	784	84	0
July	70343	70341	4261	287	287	31	0
August	68771	68770	4157	455	455	49	0
September	48503	48503	2966	917	917	98	0
October	28323	28323	1735	6307	6307	667	0
November	17193	17193	1040	16677	16677	1733	0
December	15827	15827	950	34851	34851	3539	0
Total	**409517**	**409514**	**24904**	**154325**	**154325**	**15839**	**0**

Air System Simulation Results (Table 2):

Month	WSHP Aux Htg Input (kWh)	Ventilation Fan (kWh)	Terminal Fan (kWh)	WSHP Loop Water Pump (kWh)	Lighting (kWh)	Electric Equipment (kWh)
January	0	0	0	546	4449	3856
February	0	0	0	493	4018	3483
March	0	0	0	546	4449	3856
April	0	0	0	528	4305	3731
May	0	0	0	546	4449	3856
June	0	0	0	528	4305	3731
July	0	0	0	546	4449	3856
August	0	0	0	546	4449	3856
September	0	0	0	528	4305	3731
October	0	0	0	546	4449	3856
November	0	0	0	528	4305	3731
December	0	0	0	546	4449	3856
Total	**0**	**0**	**0**	**6426**	**52381**	**45397**

AHU-2 GSHP



Monthly Simulation Results for GSHP 2

Project Name: Life sciences loads6
Prepared by: PSU AE

04

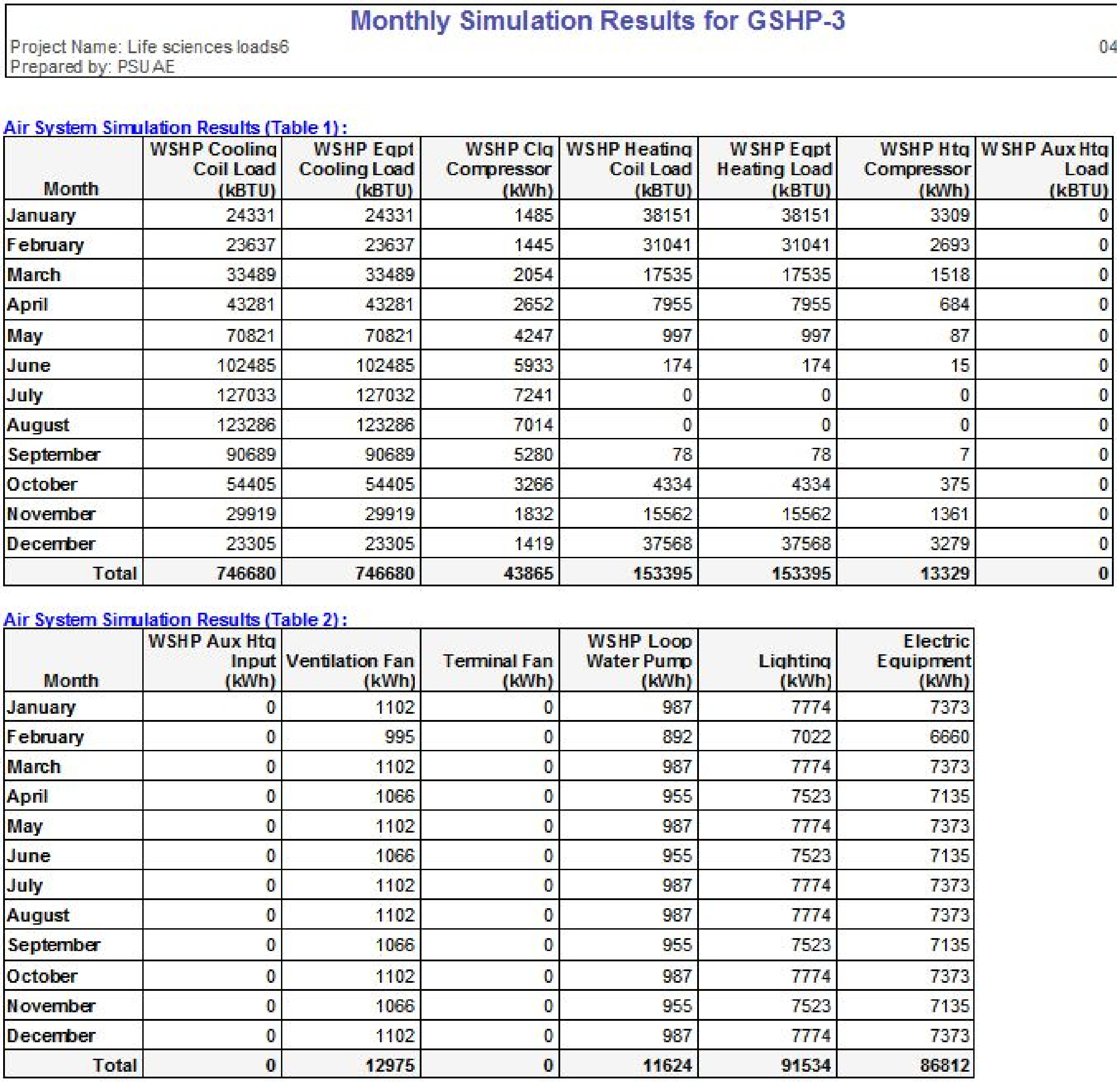
Air System Simulation Results (Table 1):

Month	WSHP Cooling Coil Load (kBTU)	WSHP Eqpt Cooling Load (kBTU)	WSHP Clg Compressor (kWh)	WSHP Heating Coil Load (kBTU)	WSHP Eqpt Heating Load (kBTU)	WSHP Htg Compressor (kWh)	WSHP Aux Htg Load (kBTU)
January	27333	27333	1628	108280	104569	8646	0
February	25269	25269	1504	90374	86864	7230	0
March	43492	43492	2567	63066	53706	4581	0
April	80625	80625	4717	50750	23330	2008	0
May	201824	201824	11509	65269	1732	158	0
June	305227	305227	16911	69088	94	10	0
July	371721	371721	20357	71779	9	1	0
August	364827	364827	19935	71095	33	4	0
September	279706	279706	15564	68677	156	17	0
October	153583	153583	8755	61496	10285	904	0
November	63674	63674	3727	68037	42903	3660	0
December	25802	25802	1538	105402	100508	8345	0
Total	**1943082**	**1943082**	**108712**	**893313**	**424189**	**35563**	**0**

Air System Simulation Results (Table 2):

Month	WSHP Aux Htg Input (kWh)	Ventilation Fan (kWh)	Terminal Fan (kWh)	WSHP Loop Water Pump (kWh)	Lighting (kWh)	Electric Equipment (kWh)
January	0	3685	0	2485	9482	6637
February	0	3328	0	2244	8564	5995
March	0	3685	0	2485	9482	6637
April	0	3566	0	2405	9176	6423
May	0	3685	0	2485	9482	6637
June	0	3566	0	2405	9176	6423
July	0	3685	0	2485	9482	6637
August	0	3685	0	2485	9482	6637
September	0	3566	0	2405	9176	6423
October	0	3685	0	2485	9482	6637
November	0	3566	0	2405	9176	6423
December	0	3685	0	2485	9482	6637
Total	**0**	**43387**	**0**	**29258**	**111642**	**78147**

AHU-3 GSHP



Monthly Simulation Results for GSHP-3

Project Name: Life sciences loads6 04
Prepared by: PSU AE

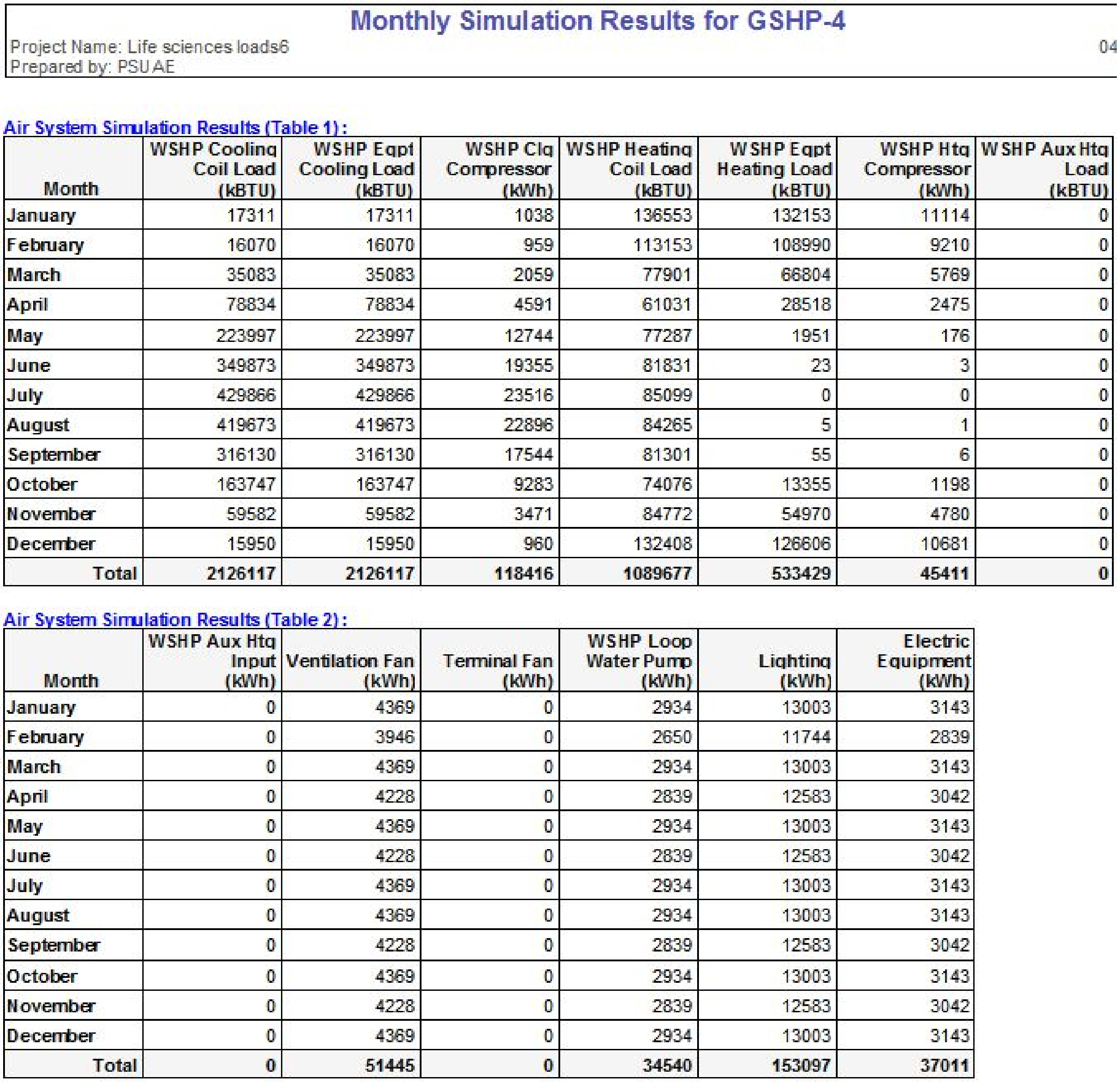
Air System Simulation Results (Table 1):

Month	WSHP Cooling Coil Load (kBTU)	WSHP Eqpt Cooling Load (kBTU)	WSHP Clg Compressor (kWh)	WSHP Heating Coil Load (kBTU)	WSHP Eqpt Heating Load (kBTU)	WSHP Htg Compressor (kWh)	WSHP Aux Htg Load (kBTU)
January	24331	24331	1485	38151	38151	3309	0
February	23637	23637	1445	31041	31041	2693	0
March	33489	33489	2054	17535	17535	1518	0
April	43281	43281	2652	7955	7955	684	0
May	70821	70821	4247	997	997	87	0
June	102485	102485	5933	174	174	15	0
July	127033	127032	7241	0	0	0	0
August	123286	123286	7014	0	0	0	0
September	90689	90689	5280	78	78	7	0
October	54405	54405	3266	4334	4334	375	0
November	29919	29919	1832	15562	15562	1361	0
December	23305	23305	1419	37568	37568	3279	0
Total	**746680**	**746680**	**43865**	**153395**	**153395**	**13329**	**0**

Air System Simulation Results (Table 2):

Month	WSHP Aux Htg Input (kWh)	Ventilation Fan (kWh)	Terminal Fan (kWh)	WSHP Loop Water Pump (kWh)	Lighting (kWh)	Electric Equipment (kWh)
January	0	1102	0	987	7774	7373
February	0	995	0	892	7022	6660
March	0	1102	0	987	7774	7373
April	0	1066	0	955	7523	7135
May	0	1102	0	987	7774	7373
June	0	1066	0	955	7523	7135
July	0	1102	0	987	7774	7373
August	0	1102	0	987	7774	7373
September	0	1066	0	955	7523	7135
October	0	1102	0	987	7774	7373
November	0	1066	0	955	7523	7135
December	0	1102	0	987	7774	7373
Total	**0**	**12975**	**0**	**11624**	**91534**	**86812**

AHU-4 GSHP



Monthly Simulation Results for GSHP-4

Project Name: Life sciences loads6

Prepared by: PSU AE

04

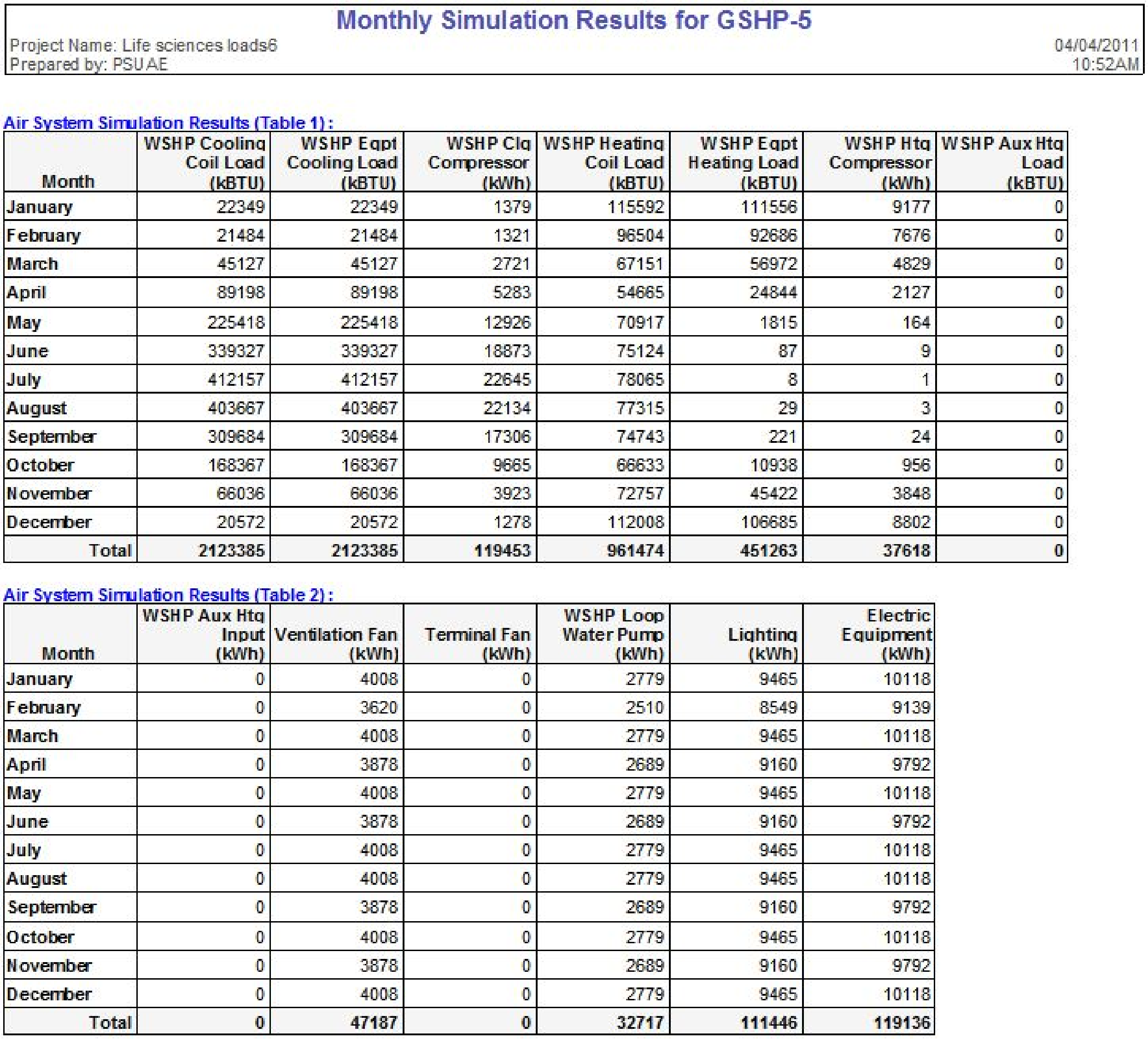
Air System Simulation Results (Table 1):

Month	WSHP Cooling Coil Load (kBTU)	WSHP Eqpt Cooling Load (kBTU)	WSHP Clg Compressor (kWh)	WSHP Heating Coil Load (kBTU)	WSHP Eqpt Heating Load (kBTU)	WSHP Htg Compressor (kWh)	WSHP Aux Htg Load (kBTU)
January	17311	17311	1038	136553	132153	11114	0
February	16070	16070	959	113153	108990	9210	0
March	35083	35083	2059	77901	66804	5769	0
April	78834	78834	4591	61031	28518	2475	0
May	223997	223997	12744	77287	1951	176	0
June	349873	349873	19355	81831	23	3	0
July	429866	429866	23516	85099	0	0	0
August	419673	419673	22896	84265	5	1	0
September	316130	316130	17544	81301	55	6	0
October	163747	163747	9283	74076	13355	1198	0
November	59582	59582	3471	84772	54970	4780	0
December	15950	15950	960	132408	126606	10681	0
Total	**2126117**	**2126117**	**118416**	**1089677**	**533429**	**45411**	**0**

Air System Simulation Results (Table 2):

Month	WSHP Aux Htg Input (kWh)	Ventilation Fan (kWh)	Terminal Fan (kWh)	WSHP Loop Water Pump (kWh)	Lighting (kWh)	Electric Equipment (kWh)
January	0	4369	0	2934	13003	3143
February	0	3946	0	2650	11744	2839
March	0	4369	0	2934	13003	3143
April	0	4228	0	2839	12583	3042
May	0	4369	0	2934	13003	3143
June	0	4228	0	2839	12583	3042
July	0	4369	0	2934	13003	3143
August	0	4369	0	2934	13003	3143
September	0	4228	0	2839	12583	3042
October	0	4369	0	2934	13003	3143
November	0	4228	0	2839	12583	3042
December	0	4369	0	2934	13003	3143
Total	**0**	**51445**	**0**	**34540**	**153097**	**37011**

AHU-5 GSHP



Monthly Simulation Results for GSHP-5

Project Name: Life sciences loads6
Prepared by: PSU AE

04/04/2011
10:52AM

Air System Simulation Results (Table 1) :

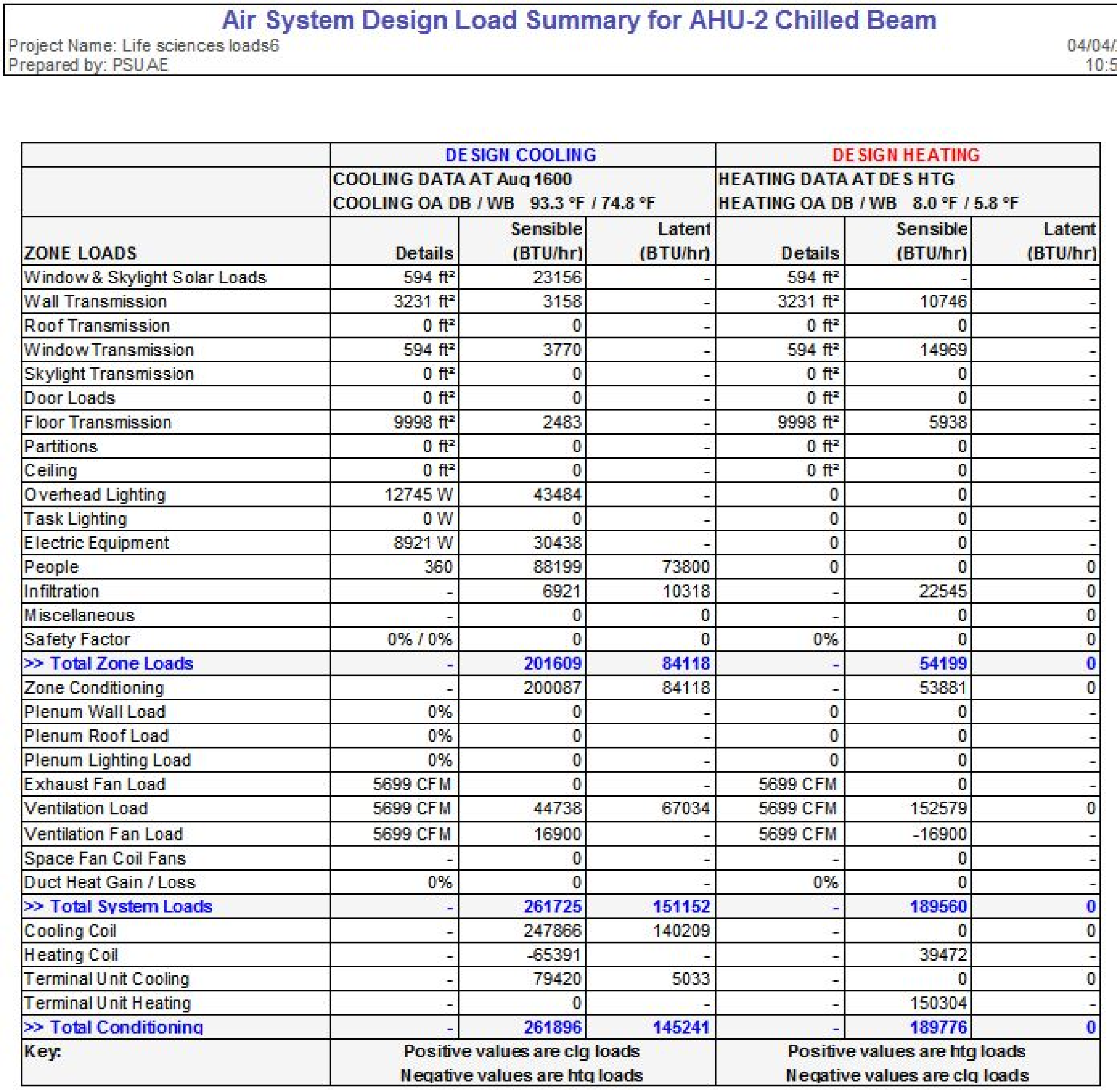
Month	WSHP Cooling Coil Load (kBTU)	WSHP Eqpt Cooling Load (kBTU)	WSHP Clg Compressor (kWh)	WSHP Heating Coil Load (kBTU)	WSHP Eqpt Heating Load (kBTU)	WSHP Htg Compressor (kWh)	WSHP Aux Htg Load (kBTU)
January	22349	22349	1379	115592	111556	9177	0
February	21484	21484	1321	96504	92686	7676	0
March	45127	45127	2721	67151	56972	4829	0
April	89198	89198	5283	54665	24844	2127	0
May	225418	225418	12926	70917	1815	164	0
June	339327	339327	18873	75124	87	9	0
July	412157	412157	22645	78065	8	1	0
August	403667	403667	22134	77315	29	3	0
September	309684	309684	17306	74743	221	24	0
October	168367	168367	9665	66633	10938	956	0
November	66036	66036	3923	72757	45422	3848	0
December	20572	20572	1278	112008	106685	8802	0
Total	**2123385**	**2123385**	**119453**	**961474**	**451263**	**37618**	**0**

Air System Simulation Results (Table 2) :

Month	WSHP Aux Htg Input (kWh)	Ventilation Fan (kWh)	Terminal Fan (kWh)	WSHP Loop Water Pump (kWh)	Lighting (kWh)	Electric Equipment (kWh)
January	0	4008	0	2779	9465	10118
February	0	3620	0	2510	8549	9139
March	0	4008	0	2779	9465	10118
April	0	3878	0	2689	9160	9792
May	0	4008	0	2779	9465	10118
June	0	3878	0	2689	9160	9792
July	0	4008	0	2779	9465	10118
August	0	4008	0	2779	9465	10118
September	0	3878	0	2689	9160	9792
October	0	4008	0	2779	9465	10118
November	0	3878	0	2689	9160	9792
December	0	4008	0	2779	9465	10118
Total	**0**	**47187**	**0**	**32717**	**111446**	**119136**

Chilled Beam Calculations

AHU-2 Chilled Beam

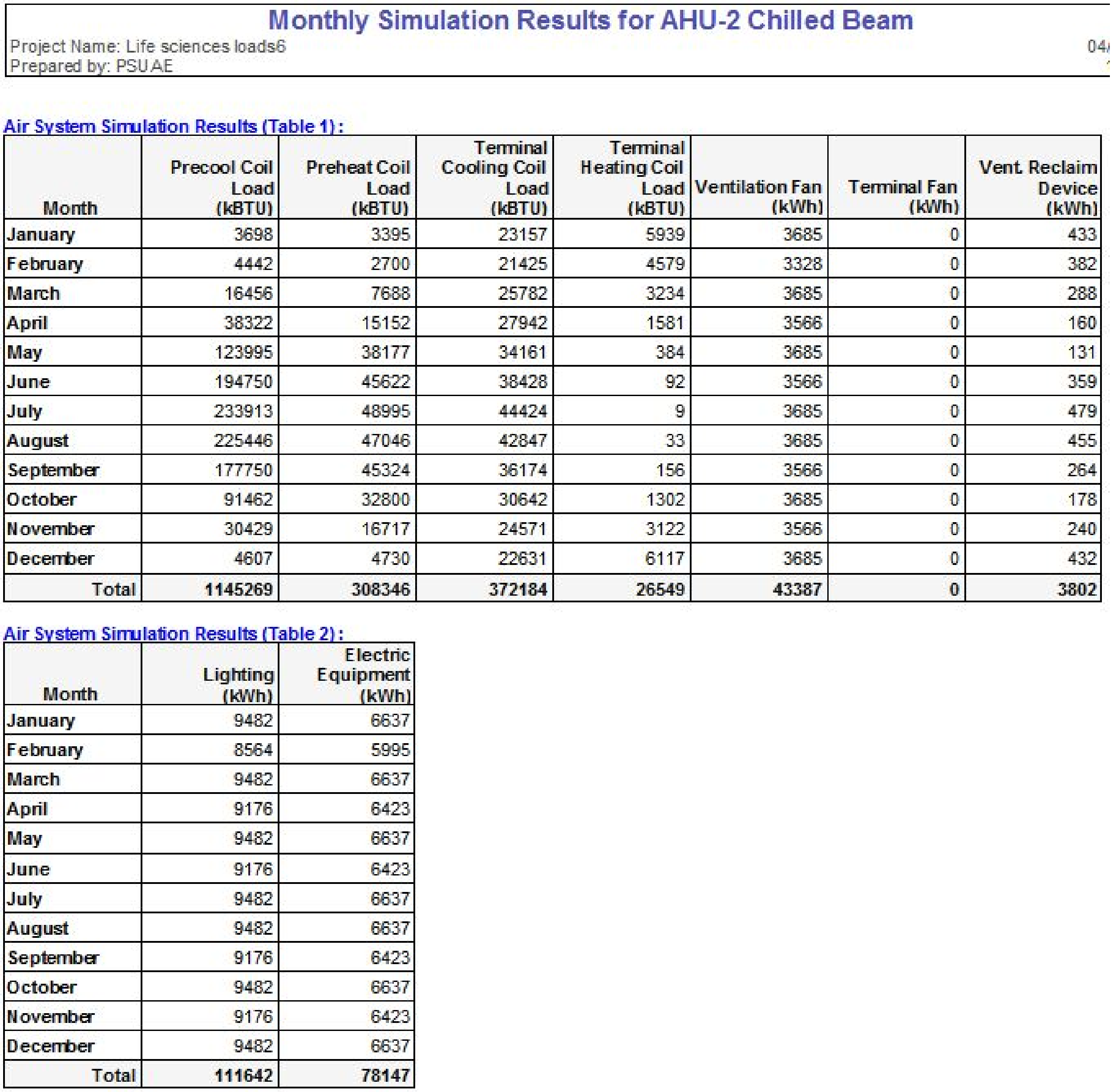


Air System Design Load Summary for AHU-2 Chilled Beam

Project Name: Life sciences loads6 04/04/

Prepared by: PSU AE 10:5

	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Aug 1600 COOLING OA DB / WB 93.3 °F / 74.8 °F			HEATING DATA AT DES HTG HEATING OA DB / WB 8.0 °F / 5.8 °F		
ZONE LOADS	Details	Sensible (BTU/hr)	Latent (BTU/hr)	Details	Sensible (BTU/hr)	Latent (BTU/hr)
Window & Skylight Solar Loads	594 ft²	23156	-	594 ft²	-	-
Wall Transmission	3231 ft²	3158	-	3231 ft²	10746	-
Roof Transmission	0 ft²	0	-	0 ft²	0	-
Window Transmission	594 ft²	3770	-	594 ft²	14969	-
Skylight Transmission	0 ft²	0	-	0 ft²	0	-
Door Loads	0 ft²	0	-	0 ft²	0	-
Floor Transmission	9998 ft²	2483	-	9998 ft²	5938	-
Partitions	0 ft²	0	-	0 ft²	0	-
Ceiling	0 ft²	0	-	0 ft²	0	-
Overhead Lighting	12745 W	43484	-	0	0	-
Task Lighting	0 W	0	-	0	0	-
Electric Equipment	8921 W	30438	-	0	0	-
People	360	88199	73800	0	0	0
Infiltration	-	6921	10318	-	22545	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	**201609**	**84118**	-	**54199**	**0**
Zone Conditioning	-	200087	84118	-	53881	0
Plenum Wall Load	0%	0	-	0	0	-
Plenum Roof Load	0%	0	-	0	0	-
Plenum Lighting Load	0%	0	-	0	0	-
Exhaust Fan Load	5699 CFM	0	-	5699 CFM	0	-
Ventilation Load	5699 CFM	44738	67034	5699 CFM	152579	0
Ventilation Fan Load	5699 CFM	16900	-	5699 CFM	-16900	-
Space Fan Coil Fans	-	0	-	-	0	-
Duct Heat Gain / Loss	0%	0	-	0%	0	-
>> Total System Loads	-	**261725**	**151152**	-	**189560**	**0**
Cooling Coil	-	247866	140209	-	0	0
Heating Coil	-	-65391	-	-	39472	-
Terminal Unit Cooling	-	79420	5033	-	0	0
Terminal Unit Heating	-	0	-	-	150304	-
>> Total Conditioning	-	**261896**	**145241**	-	**189776**	**0**
Key:	Positive values are clg loads Negative values are htg loads			Positive values are htg loads Negative values are clg loads		



Monthly Simulation Results for AHU-2 Chilled Beam

Project Name: Life sciences loads6 04/
Prepared by: PSU AE

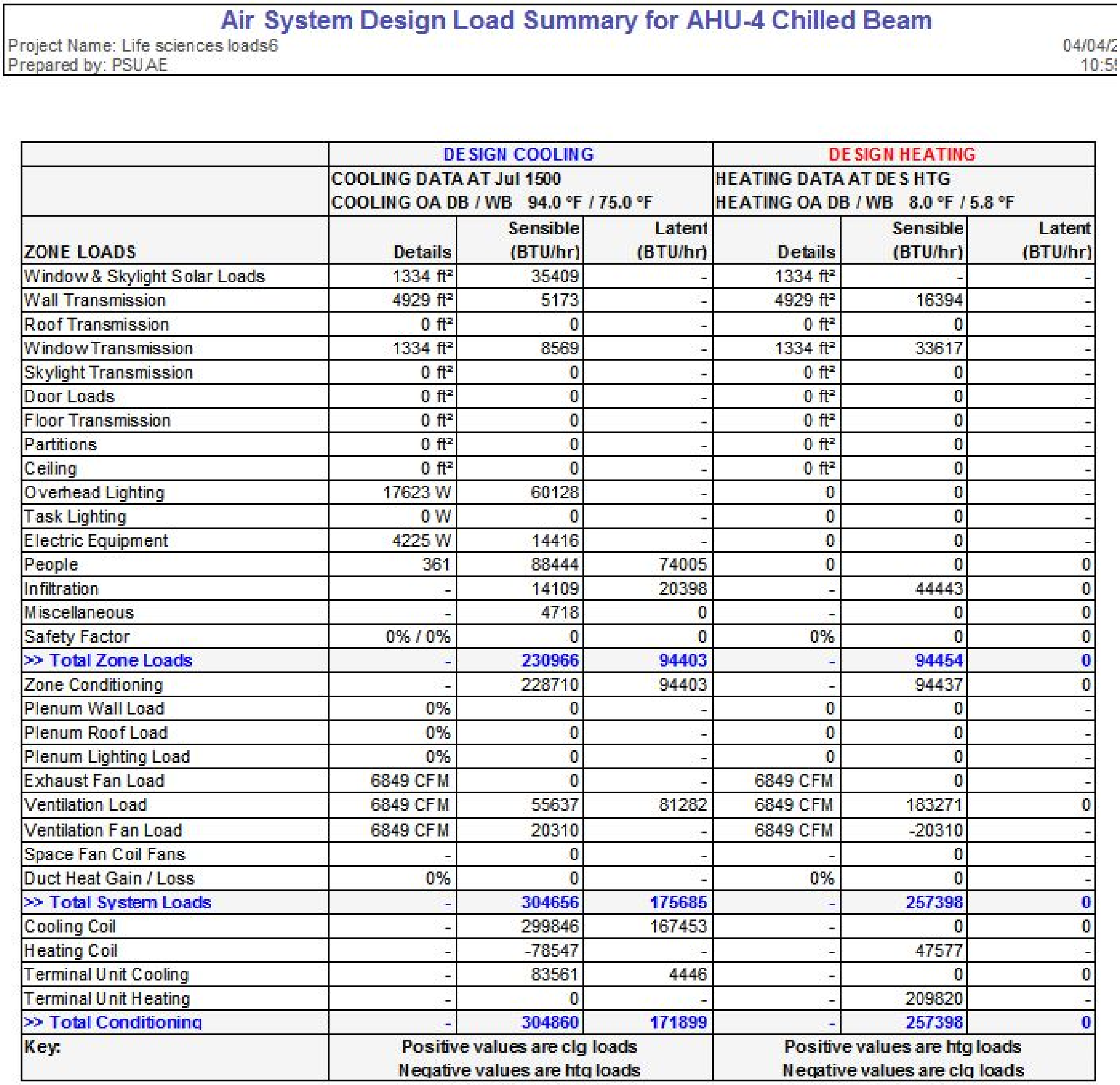
Air System Simulation Results (Table 1) :

Month	Precool Coil Load (kBTU)	Preheat Coil Load (kBTU)	Terminal Cooling Coil Load (kBTU)	Terminal Heating Coil Load (kBTU)	Ventilation Fan (kWh)	Terminal Fan (kWh)	Vent. Reclaim Device (kWh)
January	3698	3395	23157	5939	3685	0	433
February	4442	2700	21425	4579	3328	0	382
March	16456	7688	25782	3234	3685	0	288
April	38322	15152	27942	1581	3566	0	160
May	123995	38177	34161	384	3685	0	131
June	194750	45622	38428	92	3566	0	359
July	233913	48995	44424	9	3685	0	479
August	225446	47046	42847	33	3685	0	455
September	177750	45324	36174	156	3566	0	264
October	91462	32800	30642	1302	3685	0	178
November	30429	16717	24571	3122	3566	0	240
December	4607	4730	22631	6117	3685	0	432
Total	**1145269**	**308346**	**372184**	**26549**	**43387**	**0**	**3802**

Air System Simulation Results (Table 2) :

Month	Lighting (kWh)	Electric Equipment (kWh)
January	9482	6637
February	8564	5995
March	9482	6637
April	9176	6423
May	9482	6637
June	9176	6423
July	9482	6637
August	9482	6637
September	9176	6423
October	9482	6637
November	9176	6423
December	9482	6637
Total	**111642**	**78147**

AHU-4 Chilled Beam

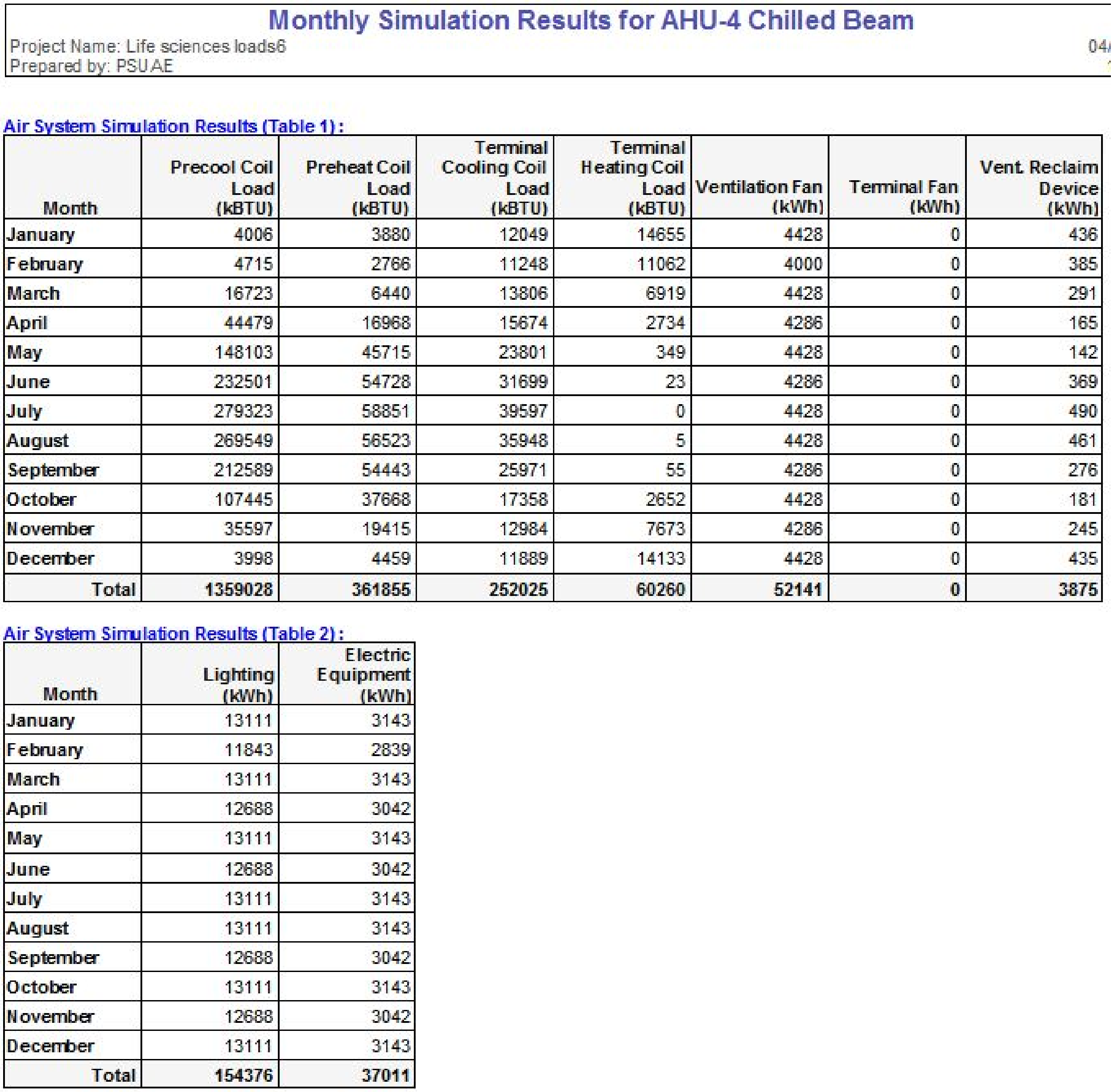


Air System Design Load Summary for AHU-4 Chilled Beam

Project Name: Life sciences loads6
Prepared by: PSU AE

04/04/2
10:5

	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1500 COOLING OA DB / WB 94.0 °F / 75.0 °F			HEATING DATA AT DES HTG HEATING OA DB / WB 8.0 °F / 5.8 °F		
ZONE LOADS	Details	Sensible (BTU/hr)	Latent (BTU/hr)	Details	Sensible (BTU/hr)	Latent (BTU/hr)
Window & Skylight Solar Loads	1334 ft²	35409	-	1334 ft²	-	-
Wall Transmission	4929 ft²	5173	-	4929 ft²	16394	-
Roof Transmission	0 ft²	0	-	0 ft²	0	-
Window Transmission	1334 ft²	8569	-	1334 ft²	33617	-
Skylight Transmission	0 ft²	0	-	0 ft²	0	-
Door Loads	0 ft²	0	-	0 ft²	0	-
Floor Transmission	0 ft²	0	-	0 ft²	0	-
Partitions	0 ft²	0	-	0 ft²	0	-
Ceiling	0 ft²	0	-	0 ft²	0	-
Overhead Lighting	17623 W	60128	-	0	0	-
Task Lighting	0 W	0	-	0	0	-
Electric Equipment	4225 W	14416	-	0	0	-
People	361	88444	74005	0	0	0
Infiltration	-	14109	20398	-	44443	0
Miscellaneous	-	4718	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	230966	94403	-	94454	0
Zone Conditioning	-	228710	94403	-	94437	0
Plenum Wall Load	0%	0	-	0	0	-
Plenum Roof Load	0%	0	-	0	0	-
Plenum Lighting Load	0%	0	-	0	0	-
Exhaust Fan Load	6849 CFM	0	-	6849 CFM	0	-
Ventilation Load	6849 CFM	55637	81282	6849 CFM	183271	0
Ventilation Fan Load	6849 CFM	20310	-	6849 CFM	-20310	-
Space Fan Coil Fans	-	0	-	-	0	-
Duct Heat Gain / Loss	0%	0	-	0%	0	-
>> Total System Loads	-	304656	175685	-	257398	0
Cooling Coil	-	299846	167453	-	0	0
Heating Coil	-	-78547	-	-	47577	-
Terminal Unit Cooling	-	83561	4446	-	0	0
Terminal Unit Heating	-	0	-	-	209820	-
>> Total Conditioning	-	304860	171899	-	257398	0
Key:	Positive values are clg loads Negative values are htg loads			Positive values are htg loads Negative values are clg loads		



Monthly Simulation Results for AHU-4 Chilled Beam

Project Name: Life sciences loads6 04/
Prepared by: PSU AE

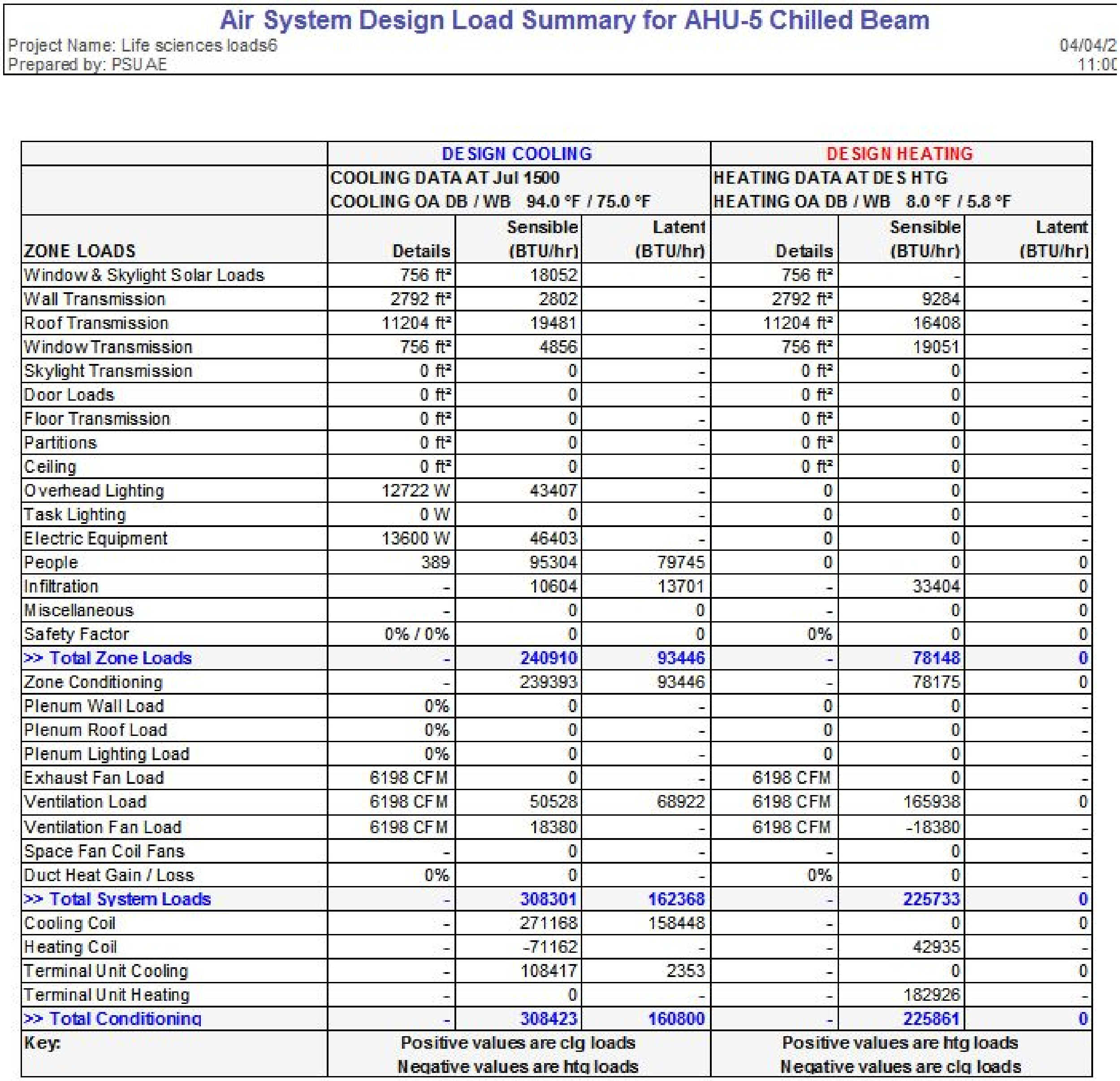
Air System Simulation Results (Table 1) :

Month	Precool Coil Load (kBTU)	Preheat Coil Load (kBTU)	Terminal Cooling Coil Load (kBTU)	Terminal Heating Coil Load (kBTU)	Ventilation Fan (kWh)	Terminal Fan (kWh)	Vent. Reclaim Device (kWh)
January	4006	3880	12049	14655	4428	0	436
February	4715	2766	11248	11062	4000	0	385
March	16723	6440	13806	6919	4428	0	291
April	44479	16968	15674	2734	4286	0	165
May	148103	45715	23801	349	4428	0	142
June	232501	54728	31699	23	4286	0	369
July	279323	58851	39597	0	4428	0	490
August	269549	56523	35948	5	4428	0	461
September	212589	54443	25971	55	4286	0	276
October	107445	37668	17358	2652	4428	0	181
November	35597	19415	12984	7673	4286	0	245
December	3998	4459	11889	14133	4428	0	435
Total	**1359028**	**361855**	**252025**	**60260**	**52141**	**0**	**3875**

Air System Simulation Results (Table 2) :

Month	Lighting (kWh)	Electric Equipment (kWh)
January	13111	3143
February	11843	2839
March	13111	3143
April	12688	3042
May	13111	3143
June	12688	3042
July	13111	3143
August	13111	3143
September	12688	3042
October	13111	3143
November	12688	3042
December	13111	3143
Total	**154376**	**37011**

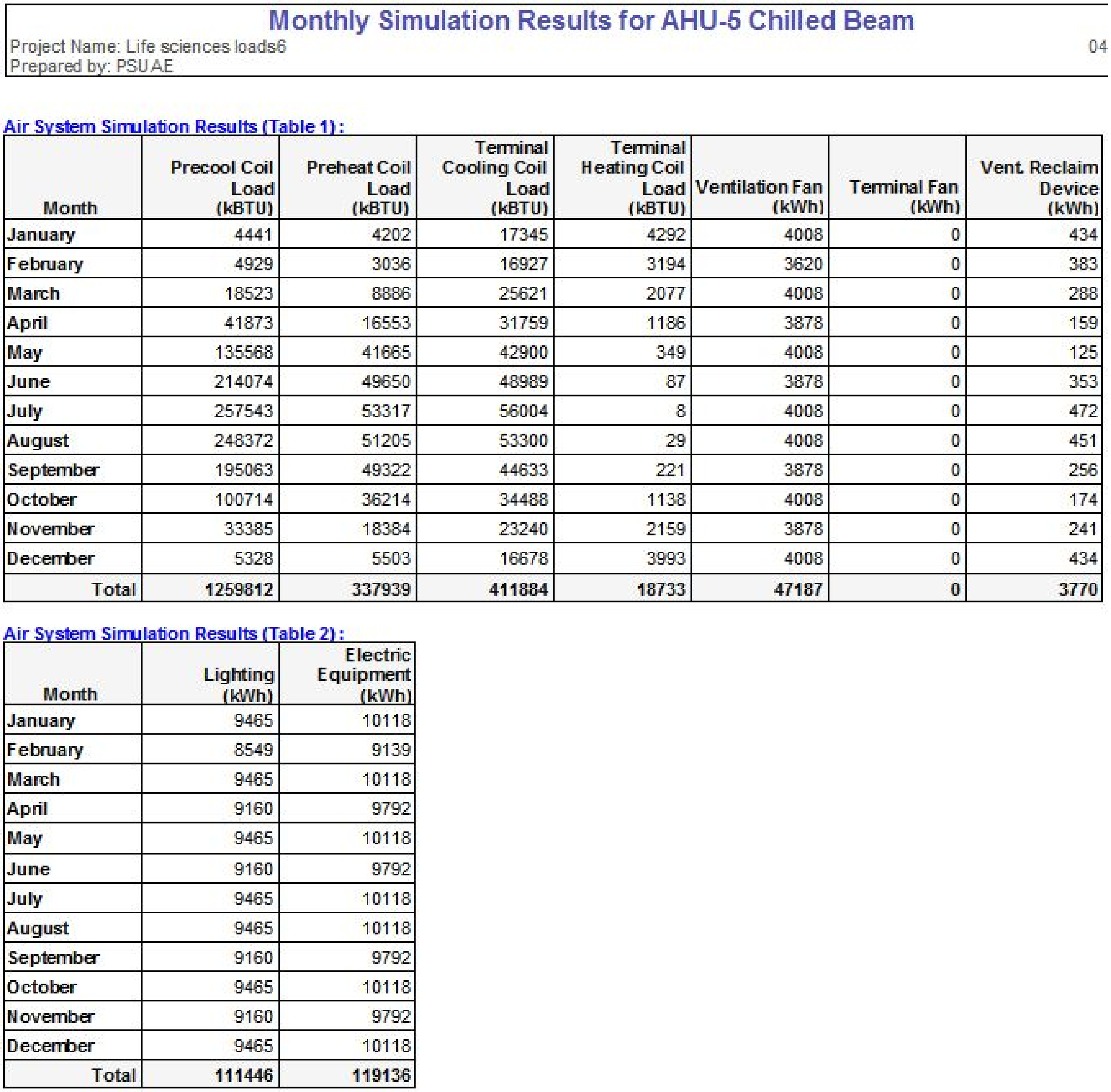
AHU-5 Chilled Beam



Air System Design Load Summary for AHU-5 Chilled Beam

Project Name: Life sciences loads6 04/04/2
Prepared by: PSU AE 11:0

	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1500 COOLING OA DB / WB 94.0 °F / 75.0 °F			HEATING DATA AT DES HTG HEATING OA DB / WB 8.0 °F / 5.8 °F		
ZONE LOADS	Details	Sensible (BTU/hr)	Latent (BTU/hr)	Details	Sensible (BTU/hr)	Latent (BTU/hr)
Window & Skylight Solar Loads	756 ft²	18052	-	756 ft²	-	-
Wall Transmission	2792 ft²	2802	-	2792 ft²	9284	-
Roof Transmission	11204 ft²	19481	-	11204 ft²	16408	-
Window Transmission	756 ft²	4856	-	756 ft²	19051	-
Skylight Transmission	0 ft²	0	-	0 ft²	0	-
Door Loads	0 ft²	0	-	0 ft²	0	-
Floor Transmission	0 ft²	0	-	0 ft²	0	-
Partitions	0 ft²	0	-	0 ft²	0	-
Ceiling	0 ft²	0	-	0 ft²	0	-
Overhead Lighting	12722 W	43407	-	0	0	-
Task Lighting	0 W	0	-	0	0	-
Electric Equipment	13600 W	46403	-	0	0	-
People	389	95304	79745	0	0	0
Infiltration	-	10604	13701	-	33404	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	240910	93446	-	78148	0
Zone Conditioning	-	239393	93446	-	78175	0
Plenum Wall Load	0%	0	-	0	0	-
Plenum Roof Load	0%	0	-	0	0	-
Plenum Lighting Load	0%	0	-	0	0	-
Exhaust Fan Load	6198 CFM	0	-	6198 CFM	0	-
Ventilation Load	6198 CFM	50528	68922	6198 CFM	165938	0
Ventilation Fan Load	6198 CFM	18380	-	6198 CFM	-18380	-
Space Fan Coil Fans	-	0	-	-	0	-
Duct Heat Gain / Loss	0%	0	-	0%	0	-
>> Total System Loads	-	308301	162368	-	225733	0
Cooling Coil	-	271168	158448	-	0	0
Heating Coil	-	-71162	-	-	42935	-
Terminal Unit Cooling	-	108417	2353	-	0	0
Terminal Unit Heating	-	0	-	-	182926	-
>> Total Conditioning	-	308423	160800	-	225861	0
Key:	Positive values are clg loads Negative values are htg loads			Positive values are htg loads Negative values are clg loads		



Monthly Simulation Results for AHU-5 Chilled Beam

Project Name: Life sciences loads6 04
Prepared by: PSU AE

Air System Simulation Results (Table 1) :

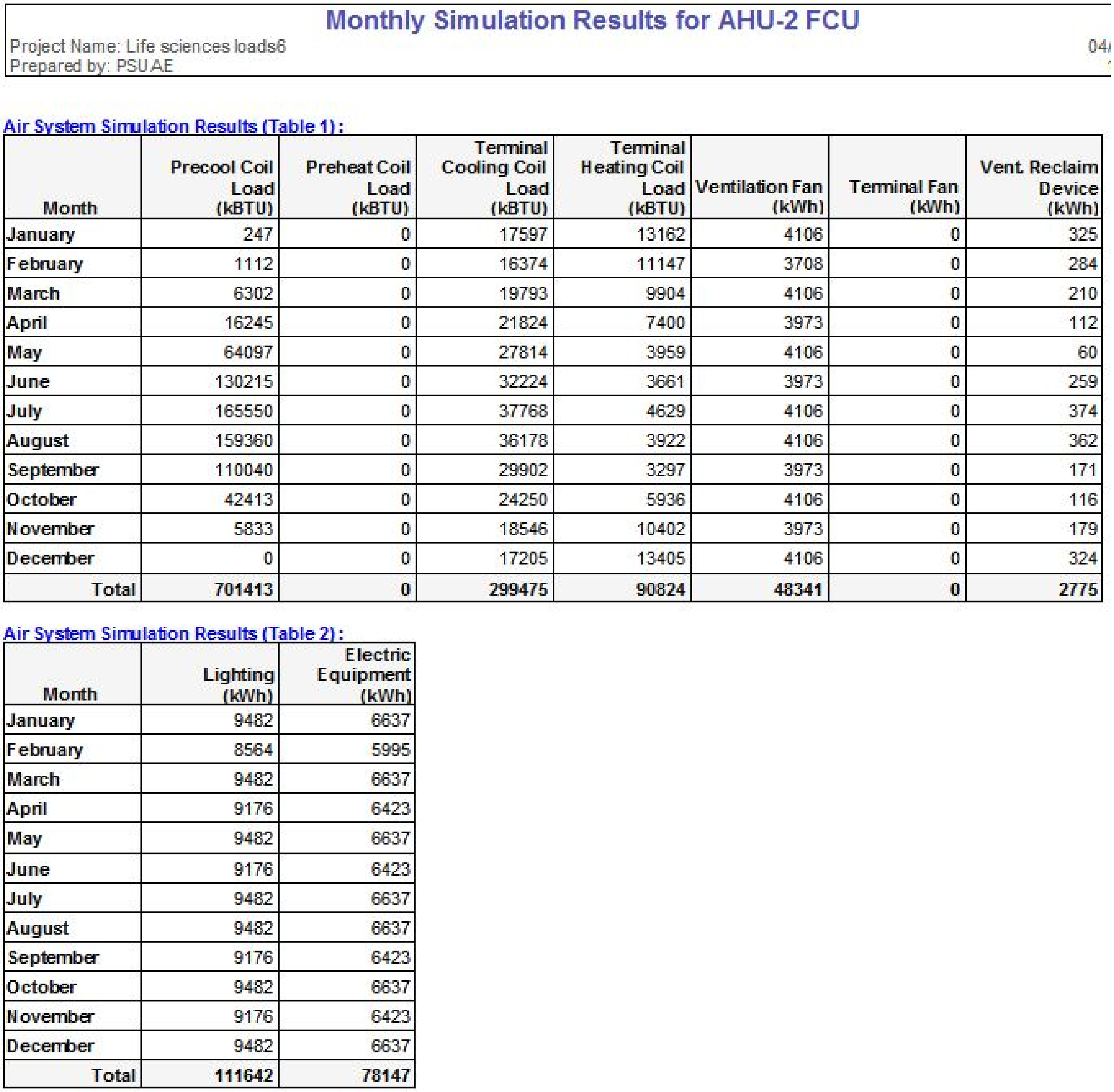
Month	Precool Coil Load (kBTU)	Preheat Coil Load (kBTU)	Terminal Cooling Coil Load (kBTU)	Terminal Heating Coil Load (kBTU)	Ventilation Fan (kWh)	Terminal Fan (kWh)	Vent. Reclaim Device (kWh)
January	4441	4202	17345	4292	4008	0	434
February	4929	3036	16927	3194	3620	0	383
March	18523	8886	25621	2077	4008	0	288
April	41873	16553	31759	1186	3878	0	159
May	135568	41665	42900	349	4008	0	125
June	214074	49650	48989	87	3878	0	353
July	257543	53317	56004	8	4008	0	472
August	248372	51205	53300	29	4008	0	451
September	195063	49322	44633	221	3878	0	256
October	100714	36214	34488	1138	4008	0	174
November	33385	18384	23240	2159	3878	0	241
December	5328	5503	16678	3993	4008	0	434
Total	**1259812**	**337939**	**411884**	**18733**	**47187**	**0**	**3770**

Air System Simulation Results (Table 2) :

Month	Lighting (kWh)	Electric Equipment (kWh)
January	9465	10118
February	8549	9139
March	9465	10118
April	9160	9792
May	9465	10118
June	9160	9792
July	9465	10118
August	9465	10118
September	9160	9792
October	9465	10118
November	9160	9792
December	9465	10118
Total	**111446**	**119136**

Fan Coil Unit Calculations (For Comparison with Chilled Beams)

AHU-2 FCUs



Monthly Simulation Results for AHU-2 FCU

Project Name: Life sciences loads6
Prepared by: PSU AE
04/

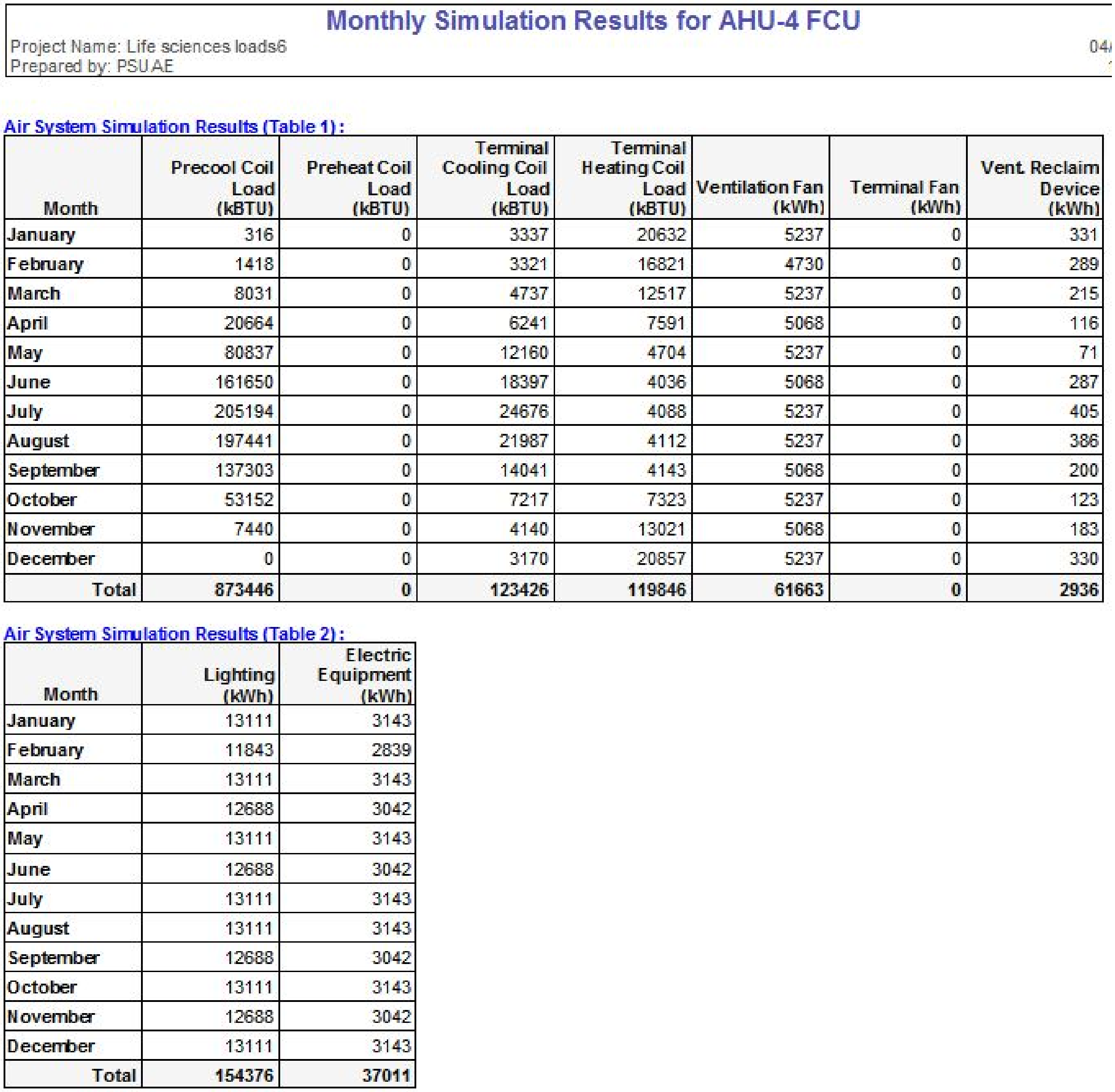
Air System Simulation Results (Table 1) :

Month	Precool Coil Load (kBTU)	Preheat Coil Load (kBTU)	Terminal Cooling Coil Load (kBTU)	Terminal Heating Coil Load (kBTU)	Ventilation Fan (kWh)	Terminal Fan (kWh)	Vent. Reclaim Device (kWh)
January	247	0	17597	13162	4106	0	325
February	1112	0	16374	11147	3708	0	284
March	6302	0	19793	9904	4106	0	210
April	16245	0	21824	7400	3973	0	112
May	64097	0	27814	3959	4106	0	60
June	130215	0	32224	3661	3973	0	259
July	165550	0	37768	4629	4106	0	374
August	159360	0	36178	3922	4106	0	362
September	110040	0	29902	3297	3973	0	171
October	42413	0	24250	5936	4106	0	116
November	5833	0	18546	10402	3973	0	179
December	0	0	17205	13405	4106	0	324
Total	**701413**	**0**	**299475**	**90824**	**48341**	**0**	**2775**

Air System Simulation Results (Table 2) :

Month	Lighting (kWh)	Electric Equipment (kWh)
January	9482	6637
February	8564	5995
March	9482	6637
April	9176	6423
May	9482	6637
June	9176	6423
July	9482	6637
August	9482	6637
September	9176	6423
October	9482	6637
November	9176	6423
December	9482	6637
Total	**111642**	**78147**

AHU-4 FCUs



Monthly Simulation Results for AHU-4 FCU

Project Name: Life sciences loads6 04/
Prepared by: PSU AE

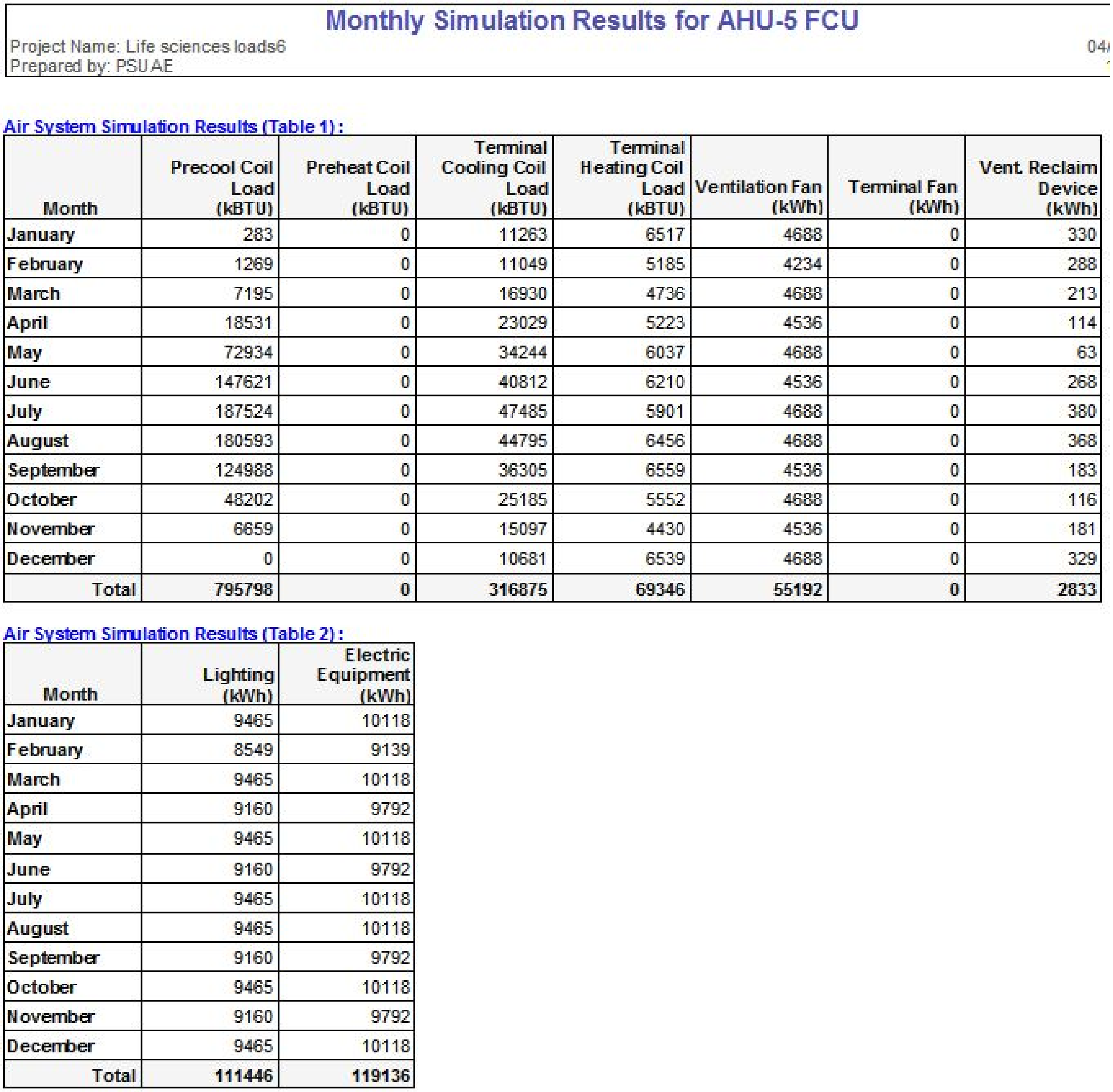
Air System Simulation Results (Table 1) :

Month	Precool Coil Load (kBTU)	Preheat Coil Load (kBTU)	Terminal Cooling Coil Load (kBTU)	Terminal Heating Coil Load (kBTU)	Ventilation Fan (kWh)	Terminal Fan (kWh)	Vent. Reclaim Device (kWh)
January	316	0	3337	20632	5237	0	331
February	1418	0	3321	16821	4730	0	289
March	8031	0	4737	12517	5237	0	215
April	20664	0	6241	7591	5068	0	116
May	80837	0	12160	4704	5237	0	71
June	161650	0	18397	4036	5068	0	287
July	205194	0	24676	4088	5237	0	405
August	197441	0	21987	4112	5237	0	386
September	137303	0	14041	4143	5068	0	200
October	53152	0	7217	7323	5237	0	123
November	7440	0	4140	13021	5068	0	183
December	0	0	3170	20857	5237	0	330
Total	**873446**	**0**	**123426**	**119846**	**61663**	**0**	**2936**

Air System Simulation Results (Table 2) :

Month	Lighting (kWh)	Electric Equipment (kWh)
January	13111	3143
February	11843	2839
March	13111	3143
April	12688	3042
May	13111	3143
June	12688	3042
July	13111	3143
August	13111	3143
September	12688	3042
October	13111	3143
November	12688	3042
December	13111	3143
Total	**154376**	**37011**

AHU-5 FCUs



Monthly Simulation Results for AHU-5 FCU

Project Name: Life sciences loads6 04/
Prepared by: PSU AE

Air System Simulation Results (Table 1) :

Month	Precool Coil Load (kBTU)	Preheat Coil Load (kBTU)	Terminal Cooling Coil Load (kBTU)	Terminal Heating Coil Load (kBTU)	Ventilation Fan (kWh)	Terminal Fan (kWh)	Vent. Reclaim Device (kWh)
January	283	0	11263	6517	4688	0	330
February	1269	0	11049	5185	4234	0	288
March	7195	0	16930	4736	4688	0	213
April	18531	0	23029	5223	4536	0	114
May	72934	0	34244	6037	4688	0	63
June	147621	0	40812	6210	4536	0	268
July	187524	0	47485	5901	4688	0	380
August	180593	0	44795	6456	4688	0	368
September	124988	0	36305	6559	4536	0	183
October	48202	0	25185	5552	4688	0	116
November	6659	0	15097	4430	4536	0	181
December	0	0	10681	6539	4688	0	329
Total	**795798**	**0**	**316875**	**69346**	**55192**	**0**	**2833**

Air System Simulation Results (Table 2) :

Month	Lighting (kWh)	Electric Equipment (kWh)
January	9465	10118
February	8549	9139
March	9465	10118
April	9160	9792
May	9465	10118
June	9160	9792
July	9465	10118
August	9465	10118
September	9160	9792
October	9465	10118
November	9160	9792
December	9465	10118
Total	**111446**	**119136**