Virtua Hospital

Voorhees, NJ

Justin Prior

Mechanical

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VIRTUA WEST JERSEY REPLACEMENT HOSPITAL

Justin Prior Mechanical

Building Info

Location: Voorhees NJ	Start/Finish: March 2008 -2011
Size: 690,000 SF	Delivery: CM at Risk GMP
Levels: 8 above / 9 total	Cost: $450-$500 Million

Owner	Virtua
Architect	HGA
Engineer	HGA
CM	Turner

ARCHITECTURE
- 360 Patient Rooms
- 690,000 SF
- 8 story bed pavillion, 4 story auxiliary space, central utility plant
- Large glass curtain wall along front face
- Aluminum siding and stone veneer along sides

STRUCTURAL
- W14 columns
- Cast in place lightweight concrete floors on 3" steel deck
- Typical bay size 32' x 32' for patient pavillion, 31' x 29' auxilary space
- Steel frame bracing and moment connections for laterial reinforcement

MECHANICAL
- Domestic hot water, heating provided by 4 steam boilers
- 3 1000 ton centrifugal chillers
- 3 sets of VAV AHUs
- 3 cooling towers

LIGHTING/ELECTRICAL
- 12.5 KV service distributed to 6 substations
- 480/277 and 120/208 distributed throughout hospital
- 3 1500 KW backup generators
- 900 KW UPS system

http://www.engr.psu.edu/ae/thesis/portfolios/2011/jcp5065/index.html

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Executive Summary

The Virtua Replacement Hospital is comprised of three areas. The first is the east ancillary which houses most of the operation rooms and other medical rooms. The west ancillary houses the many of the offices and administration areas. The final area is the 8 story patient tower. This houses most of the 365 patient rooms in the hospital.

The building consists of three sets of AHUs. The first set supplies air to the first floor patient tower and the east ancillary. The second set supplies air to the west ancillary area. This set of AHUs has a high amount of outdoor air since it serves many of the medical spaces. The third set of AHUs provides air to the patient tower. A VAV system is used throughout the hospital. Three 1000 ton chillers supply the chilled water to the units, as well as 4 steam boilers providing steam.

Due to the type of building and its size, the energy used is very large. According to energy models performed in this report, the hospital will spend around $4,000,000 annually in utilities (gas, water, electric). For this reason, a Ground Source Heat Pump (GSHP) system was studied to help reduce these loads. Since the entire building loads are too large to put on a GSPH, it was decided to study putting the loads for each AHU set on a GSHP. There are a total of 5 Options studied in this report. The first Option is AHU 1 with a borehole depth of 300 ft. The second Option is also AHU 1, but with a 600 ft borehole depth. Option 3 is AHU 2 with a 600 ft borehole depth. The fourth Option is also AHU 2, but with a depth of 1000 ft. Finally, Option 5 is half the load of AHU 3, at a borehole depth of 1000 ft. It was important to study the effects of the borehole lengths because they can be a very large portion of the cost for installing a GSHP.

Another study for the GSHP was the use of one pump vs. two pumps. While the two pumps are definitely more reliable, the one pump system may save energy. As seen in the report, this was not the case. A two pump system is not only more reliable, but in the case of the designed GSHP, they are also cheaper to operate. A study done on the layout of the heat pumps is also included in this report. A study was done to see if fewer but larger heat pumps was more cost effective than more heat pumps with a smaller capacity. The results for this study varied, and it most likely will depend on the system.

A cost analysis was performed for all 5 options to determine which one was more realistic to install, if any. This was done by comparing first cost, operating costs, simple payback periods, and a simple lifecycle cost. After analyzing the data it was determined that Option 4, AHU 2 at 1000 ft borehole length, was probably the better option of the bunch. However, all 5 options came back with respectable payback periods and lifecycle costs. After studying the results of the GSHP, it seems that they are a serious option to consider when designing a building, as they can really help to reduce the energy consumption of a building.

On top the GSHP study, an Outdoor Air Study was quickly performed. The reason for this was that the airflow design of the zones was calculated using IMC 2003. On top of this, many of the office spaces are ventilated with 100% outdoor air. The reasons for this are not known, but I suspect air quality has a major factor to play in it. While the offices are not located in the operating room areas, the overall theme of the hospitals air system could be have been high air quality as well as comfort. The ASHRAE St 62.1 minimum outdoor air ventilation rates were used in the outdoor air redesign of many of the offices. The results came out to save the hospital a little bit of money, but nothing substantial. For this reason it may be best to leave the designed air flows as they are.

In addition to the mechanical depth items were an electrical and structural depth. The electrical depth was a study of PV Panel Systems. The roof of the hospital is very large, un-obscured, and does not have many objects on it. The solar analysis was done on the panels to determine how much solar energy can be absorbed, and ultimately how much electrical energy is created. The system will require an inverter to switch from DC current to AC, as well as disconnect switches. The voltage and current ratings were found, and the equipment was sized, including the wires.

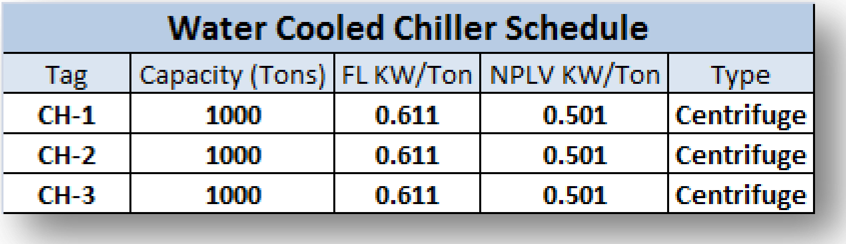
The large amount of panels on the roof could potentially cause structural problems for the current structural system. A study was done to see if the panels forced any changes in the size of the columns. The columns were first designed without the panel loads, since the loads were not known for the actual calculations. The loads were then calculated with the panels. As it turns out, the addition of panels on the roof have very little affect on the loads. None of the columns need to be changed due to the addition of the panels.

System Description

The Virtua West Jersey Replacement Hospital is comprised of three main units. They include the hospital bed tower, the ancillary building comprised of offices and surgery rooms, and a central spine that runs through connecting the bed tower and ancillary building. The mechanical system was separated to condition these spaces separately based on the individual needs. The bedroom tower is mainly patient rooms and offices. These do not require the same indoor air quality as the ancillary building does. The ancillary building requires a much higher overall indoor air quality due to the operating and medical rooms.

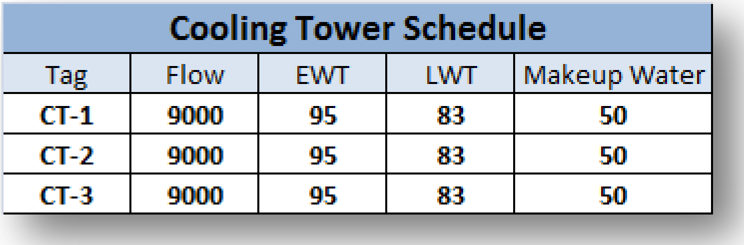
The hospital consists of three 1,000 ton centrifugal chillers located in the central utility plant behind the ancillary portion of the building. The chiller schedule can be seen in Table 1.1. Located on the roof of the building are three 9,000 gpm high efficiency cooling towers. Table 1.2 shows the cooling tower schedule.

The hospital utilizes a VAV (Variable Air Volume) system throughout the building. There are three sets of AHU's located on the 7th floor. The schedules are located in Appendix A. The first set consists of two AHU's at 50,000 cfm each. This will serve dietary areas and labs. The second set of AHU's also consists of two sets of 50,000 cfm AHU's. These will serve emergency and surgery rooms. The last set consists of six 75,000 cfm units that will serve the 8 story patient bedroom tower. For the computer room there are three computer room air conditioning units (CRAC).



Water Cooled Chiller Schedule				
Tag	Capacity (Tons)	FL KW/Ton	NPLV KW/Ton	Type
CH-1	**1000**	**0.611**	**0.501**	**Centrifuge**
CH-2	**1000**	**0.611**	**0.501**	**Centrifuge**
CH-3	**1000**	**0.611**	**0.501**	**Centrifuge**

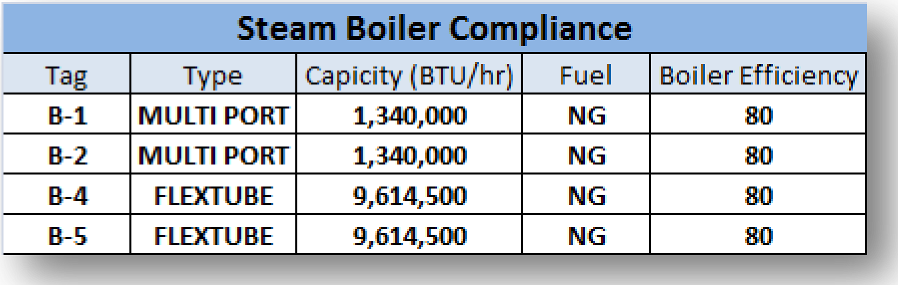
Figure 1.1 Chiller Schedule



Cooling Tower Schedule				
Tag	Flow	EWT	LWT	Makeup Water
CT-1	**9000**	**95**	**83**	**50**
CT-2	**9000**	**95**	**83**	**50**
CT-3	**9000**	**95**	**83**	**50**

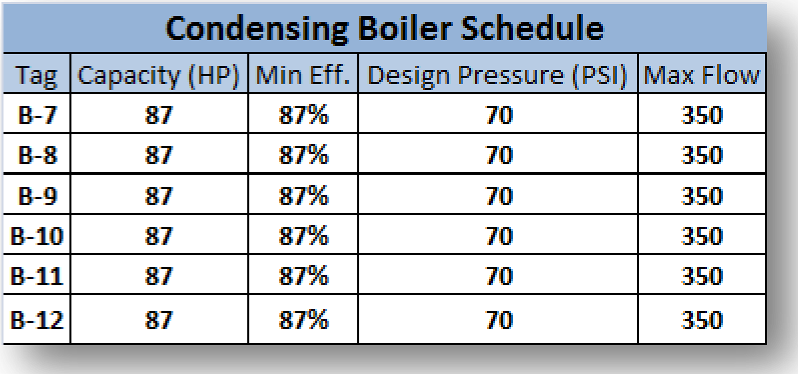
Table 1.2 Cooling Tower Schedule

For heating and humidifying the hospital has four steam boilers and six condensing boilers. The boilers schedules can be seen in Tables 1.3 and 1.4. Two of the steam boilers are 40 BHP, while the other two are 287 BHP. All four are located in the central utility plant. Coupled with the boilers are six shell and tube heat exchangers located in various areas around the building used for hot water heating. Table 1.5 shows the heat exchanger schedule.



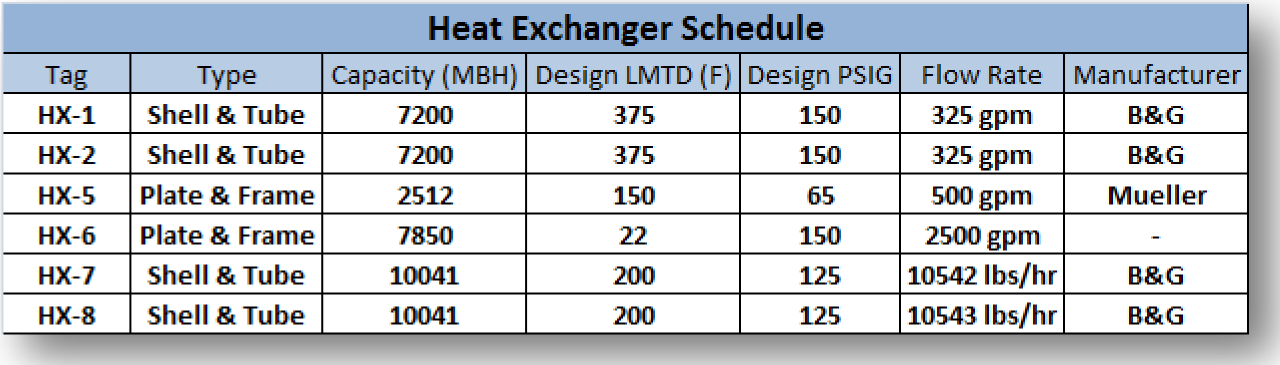
Steam Boiler Compliance				
Tag	Type	Capicity (BTU/hr)	Fuel	Boiler Efficiency
B-1	MULTI PORT	1,340,000	NG	80
B-2	MULTI PORT	1,340,000	NG	80
B-4	FLEXTUBE	9,614,500	NG	80
B-5	FLEXTUBE	9,614,500	NG	80

Table 1.3 Steam Boiler Schedule



Condensing Boiler Schedule				
Tag	Capacity (HP)	Min Eff.	Design Pressure (PSI)	Max Flow
B-7	87	87%	70	350
B-8	87	87%	70	350
B-9	87	87%	70	350
B-10	87	87%	70	350
B-11	87	87%	70	350
B-12	87	87%	70	350

Table 1.4 Condensing Boiler Schedule



Heat Exchanger Schedule						
Tag	Type	Capacity (MBH)	Design LMTD (F)	Design PSIG	Flow Rate	Manufacturer
HX-1	Shell & Tube	7200	375	150	325 gpm	B&G
HX-2	Shell & Tube	7200	375	150	325 gpm	B&G
HX-5	Plate & Frame	2512	150	65	500 gpm	Mueller
HX-6	Plate & Frame	7850	22	150	2500 gpm	-
HX-7	Shell & Tube	10041	200	125	10542 lbs/hr	B&G
HX-8	Shell & Tube	10041	200	125	10543 lbs/hr	B&G

Table 1.5 Heat Exchanger Schedule

Since the occupancy of this building is a hospital the filter selection was also important. Appendix A shows the filter schedule for the various filters used in the building. As can be seen in the table many of the filters have a high MERV rating due to the areas they serve.

Appendix A also shows the supply fan and return fan schedules. Since air is being moved at high rates over high MERV filters the fans had to be larger than normal to overcome the pressure.

AHU Zones

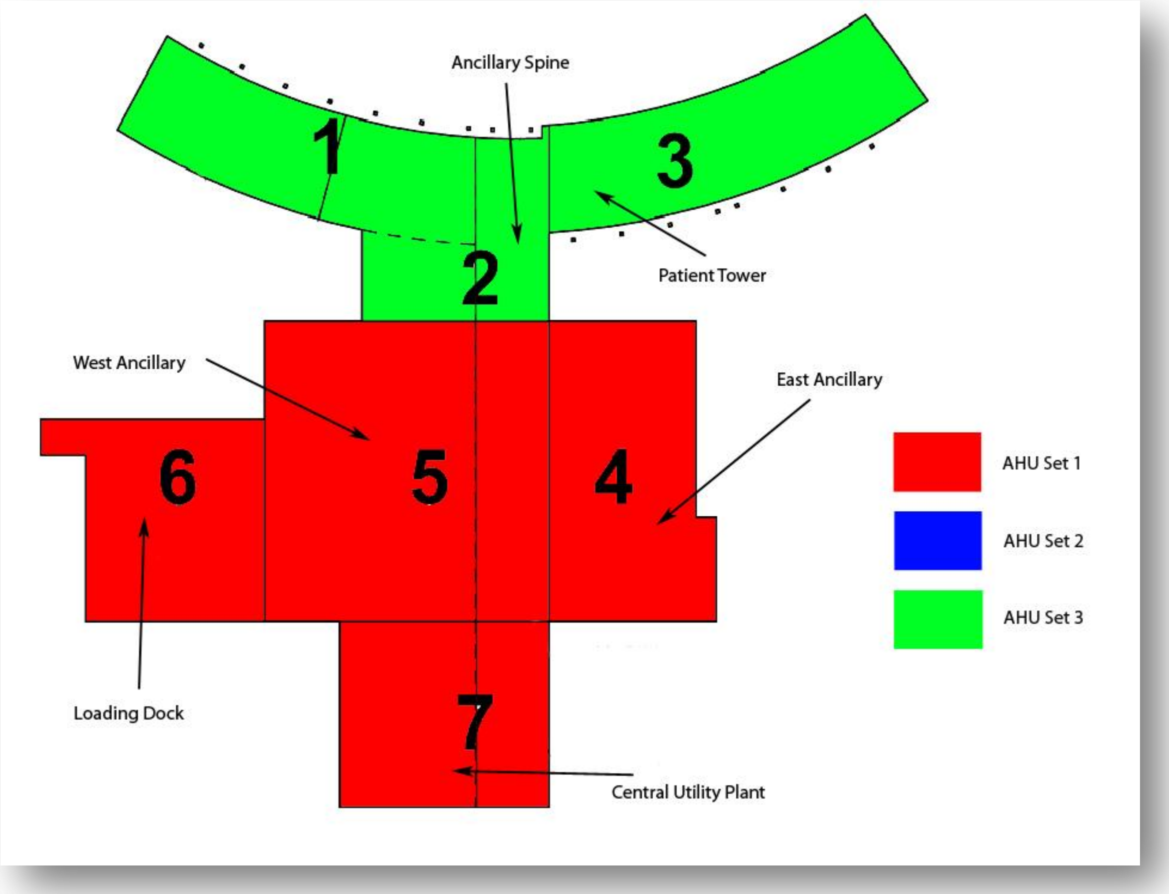


Figure 1.1 AHU Zones Floor Level 1

Figures 1.1, 1.2, and 1.3 show the sections of the building that are being ventilated. AHU Set 1 serves almost all of the first floor lobbies and offices. This extends into the ancillary unit to serve the offices in this space. AHU Set 2 covers all of the west ancillary spaces for all the floors. These rooms consist of mainly operating, recovery, and other types of medical rooms. These are all grouped together under one AHU set since they all require a higher quality of indoor air. AHU Set 3 serves all of the patient rooms in the patient tower, as well as the offices in the east ancillary unit.

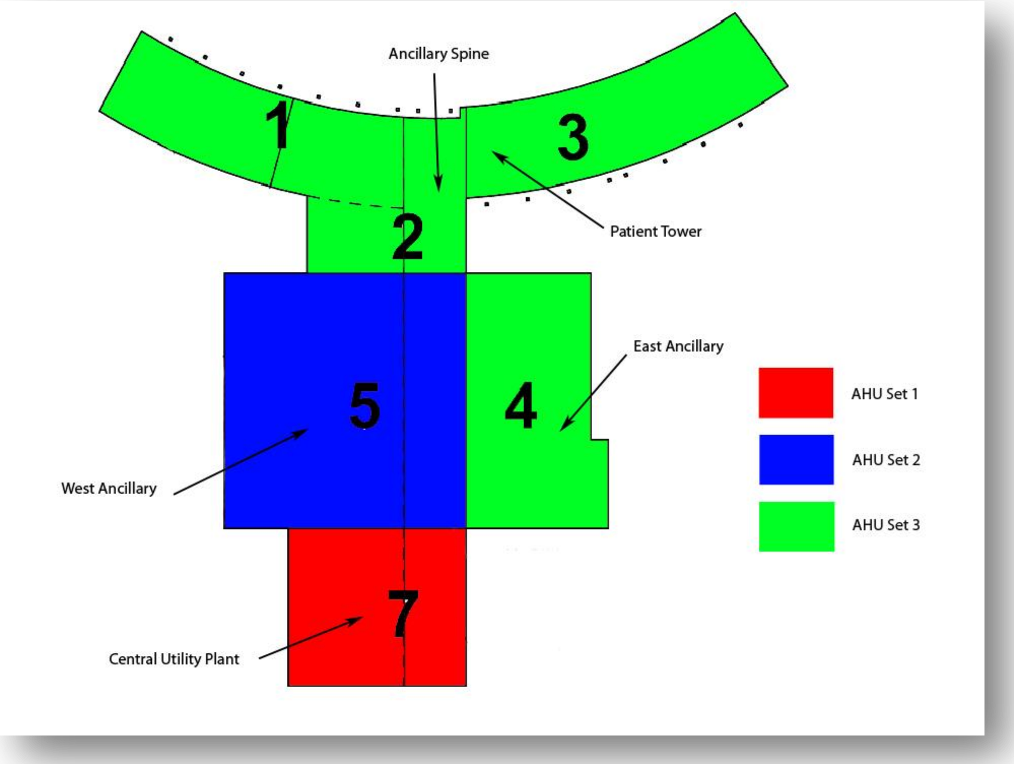


Figure 1.2 AHU Zones Floor Levels 2-6

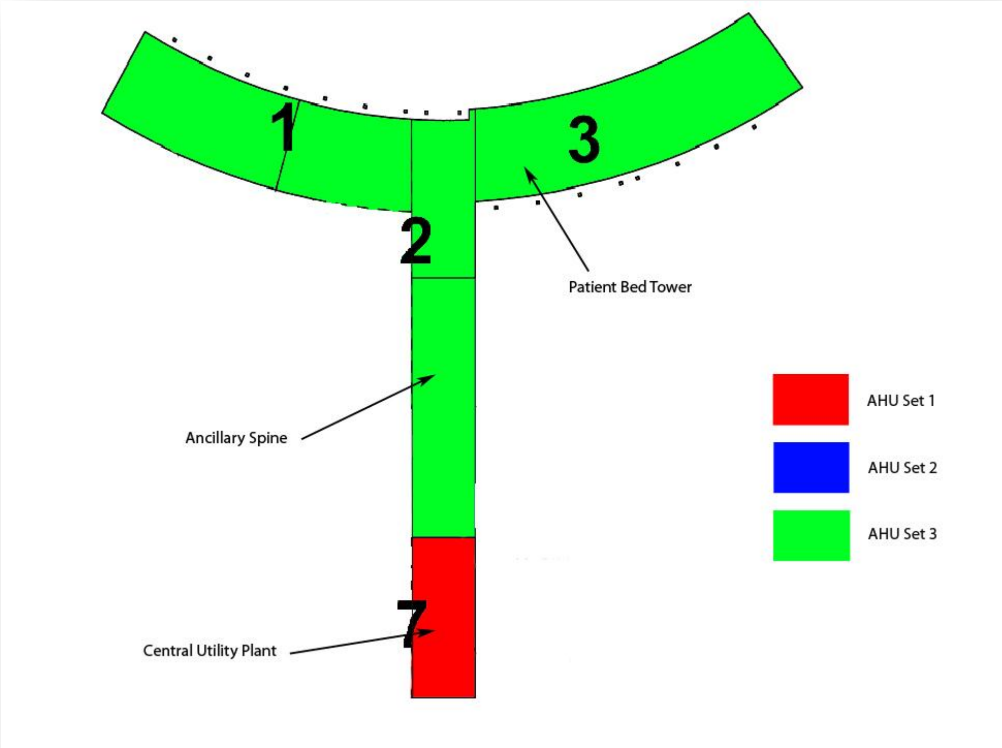


Figure 1.3 AHU Zones Floor Levels 7-8

ASHRAE Std 62. 1

Section 5

Section 5.1Natural Ventilation

There is no natural ventilation being used in the building, and there are no operable windows as well so section 5.1 does not apply.

Section 5.2 Ventilation Air Distribution

All the spaces in the building meet the ventilation requirements. Since a VAV system is utilized throughout the building the dampers are set not to go past a certain angle as to allow no less than minimum ventilation.

Section 5.3Exhaust Duct Location

All exhaust fans from surgery, patient rooms, kitchens, and other exhausted areas are ducted directly to the roof. They are all negatively pressured as to not allow any contaminants to spread throughout occupied spaces. Figure 2.1 shows a typical assembly for the exhaust located on the roof. This particular exhaust is for a kitchen hood, and contains a drip pan to catch any grease or contaminants.

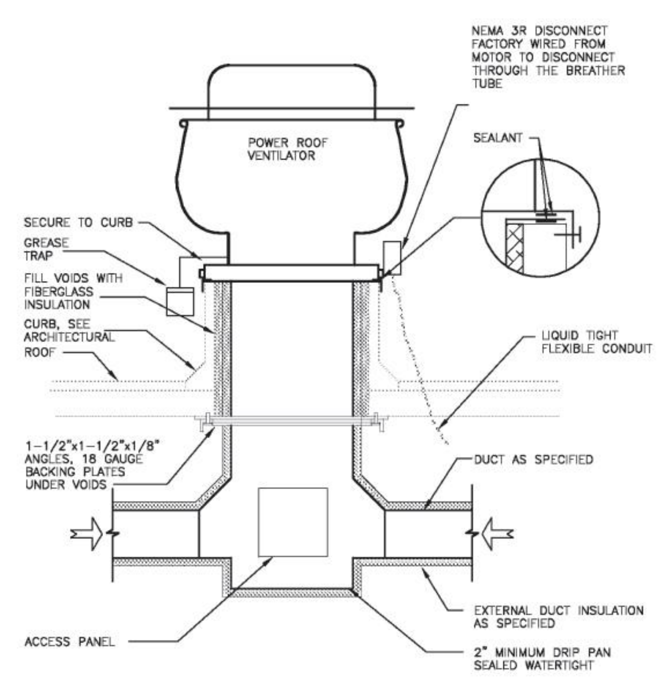


Figure 2.1Typical Exhaust

Section 5.4Ventilation System Controls

All boilers are controlled by a BAS (Building Automation System) that provides header pressure control. The BAS system is also integrated into the chillers. They are programmed to always be on, but can be adjusted by the user for a certain time table for the mechanical room. The return and exhaust ducts shall be controlled to maintain a constant negative shaft pressure. All 3 AHU sets will be controlled by a separate dedicated direct digital controller.

Section 5.5Airstream Surfaces

All surfaces and materials in the ducts and mechanical equipment have been tested under ASTM C1338 and UL 181, among other ASTM tests. All materials in contact with the airstream are resistant to mold growth and erosion.

Section 5.6 Outdoor Air Intakes

All outdoor air intakes are well over the minimum distance from any contaminated exhaust, loading area, or garbage area. However, the boiler exhaust flues are directly next to the cooling towers allowing possible contamination of the chilled water, which can be seen in Figure 2.2. There are two boiler exhaust flues within a couple feet of a cooling tower, which is not compliant.

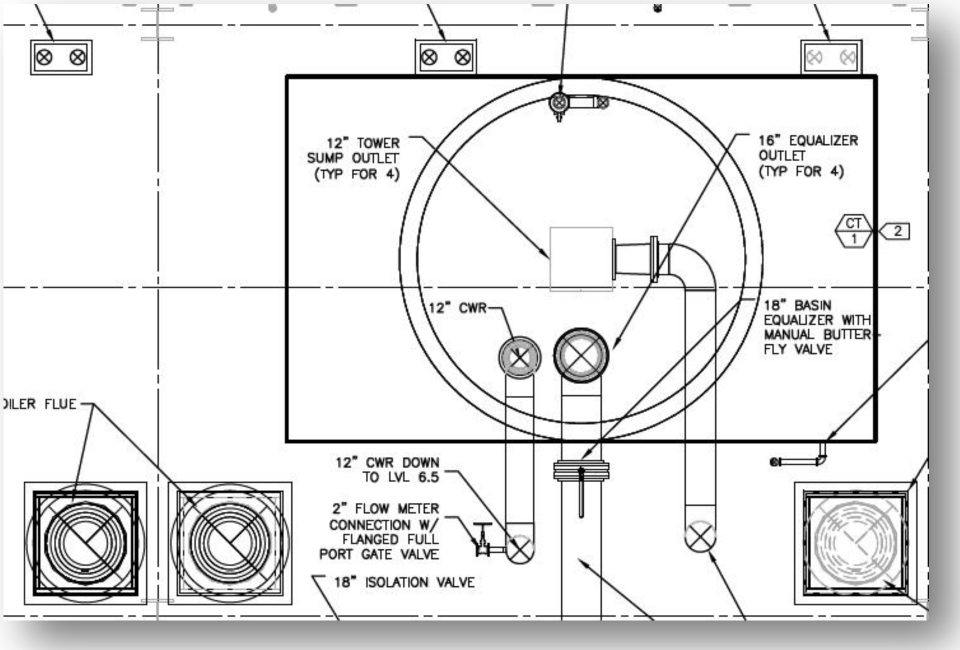


Figure 2.2 Cooling Tower/Exhaust Relation

Section 5.7 Load Capture of Contaminants

All exhaust systems exit directly to the roof of the building, allowing no contaminants back inside of the building or mechanical system. Figure 2.3 shows the two direct exhaust ducts that are connected directly to the generators that go directly to the roof for immediate extraction. Figure 2.4

shows the exhaust ducts for the mechanical room. Seen here is the exhaust ducts for the chillers and boilers. It also shows the location of exhaust ducts for future additions.

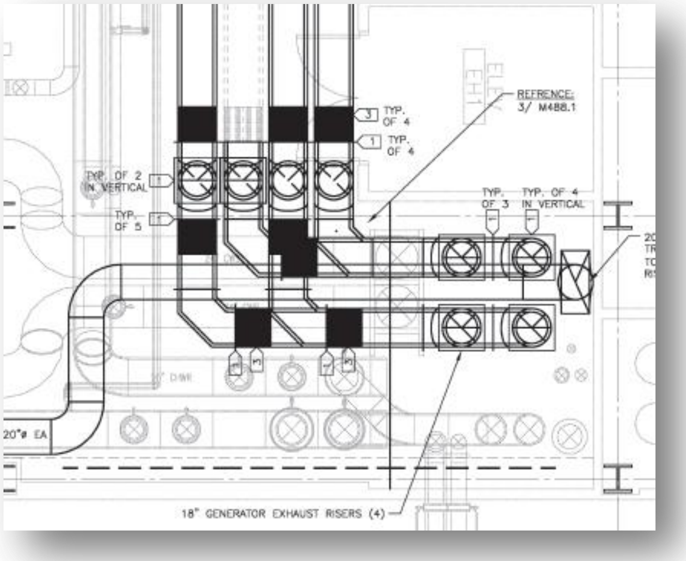


Figure 2.3 Generators Direct Exhaust

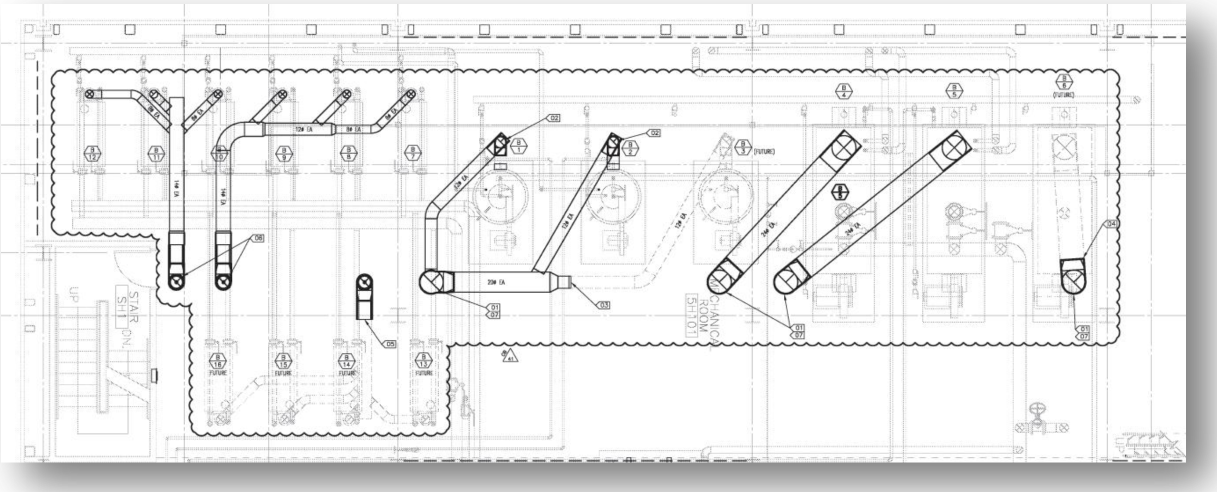


Figure 2.4 Mechanical Room Direct Exhaust

Section 5.8 Combustion Air

Combustion air from the generators, boilers, and heaters are all directly exhausted outdoors allowing no contamination inside the building.

Section 5.9 Particulate Matter Removal

The minimum rating in the building is an 8 MERV rating for public places and corridors. 13 to 17 MERV filters are used for surgery, patient, and lab rooms. Appendix A shows the types of filters that are used in the AHU units. AHU sets 1 and 2 both serve areas where the supply air needs to be cleaner, which is why they have the 13 MERV and 17 MERV filters.

Section 5.10 Dehumidification Systems

No space inside the building exceeds the 65% relative humidity. The overall pressure of the building is positive except for certain spaces such as surgery rooms, and toilets which constantly maintain a negative pressure.

Section 5.11Drain Pans

Drain pans are sloped stainless steel pans located directly under the cooling coils in order to collect condensation. A drain is located on the bottom end of the pan for proper drainage to prevent mold growth around the coil. Figure 2.5 shows the location of the drain pan directly underneath the cooling coil in a typical AHU unit.

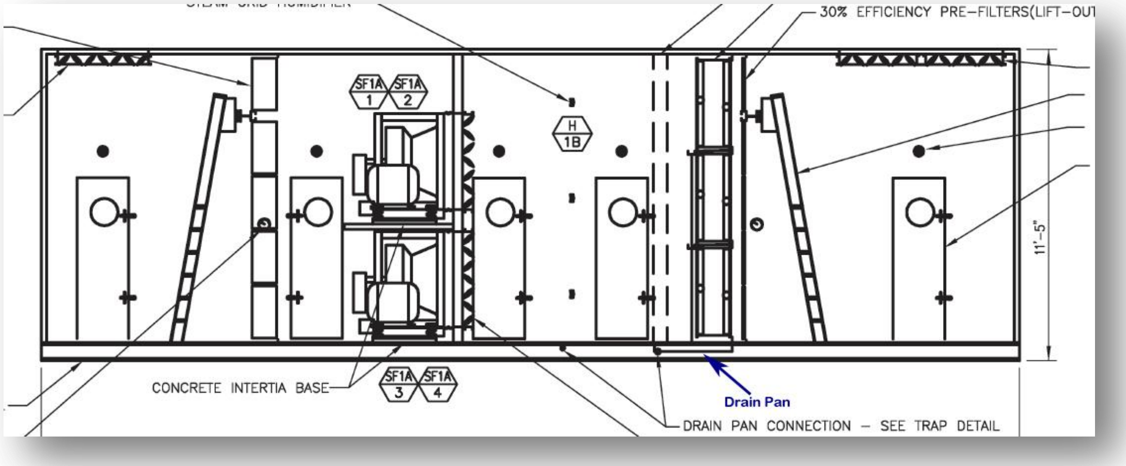


Figure 2.5 Drain Pan Location

Section 5.12 Finned-tube Coils and Heat Exchangers

There are no finned tube coil heat exchangers located in the building located in the building so this section does not apply. The ones used in this building are shell and tube, and plate and frame.

Section 5.13 Humidifiers and Water-Spray Systems

All water originates from an offsite source and goes through a filtration process within the hospital.

Section 5.14 Access for Inspection, Cleaning, and Maintenance

Boilers and chillers located in large open floors for ease of access all around the equipment and pipes. AHU's are located on an accessible floor, and have 2 rolling maintenance ladders leading into each end for easy maintenance. Figure 2.6 shows the two rolling ladders that are located on each end. These allow for maintenance to the unit as well as the ability to easily change the filters.

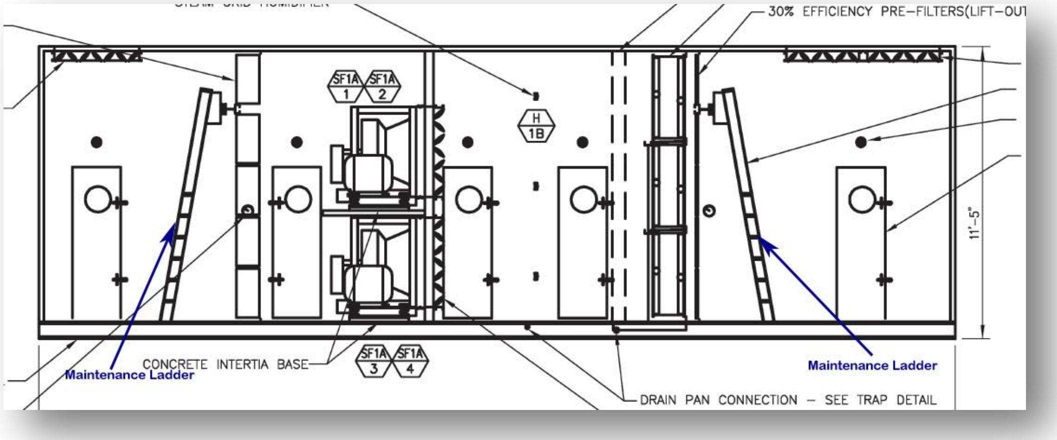


Figure 2.6 Maintenance Ladder Locations

Section 5.15 Building Envelope and Interior Surfaces

Elastomeric sheet water proofing is used on walls located below grade for water protection. Hot fluid applied rubberized asphalt waterproofing is used on concrete horizontal surfaces such as slabs on grade. Interior walls of the building have a polyethylene vapor retarder with a max .13 perm. Elastomeric wall membrane moisture barriers are used on the exterior walls as well as the joints for moisture protection.

Section 5.16 Buildings with Attached Parking Garages

There is no attached parking garage so this section does not apply.

Section 5.17Air Classification and Recirculation

The buildings return air is classified as class 1 for public areas such as the lobby and corridor spaces. Exhaust air from the kitchens and surgery rooms are at least class 3 and are exhausted directly to the roof. Toilets are class 2 and are also directed to the roof.

Section 5.18 Requirements for Buildings Containing ETS Areas and ETS-Free Areas

The building is a non-smoking building and smoking areas are located away from any entrance so indoor air quality is not affected by this.

Section 6

An analysis of all three sets of AHU's was done using the ASHRAE Std 62.1 Section 6 guidelines.

Ventilation Rate Procedure

Breathing Zone Outdoor Airflow (V_{bz})

$V_{bz} = R_p \times P_z + R_a \times A_z$ (Eq. 6-1)

A_z = zone floor area (ft^2)
P_z = zone population
R_p = outdoor airflow rate per person (cfm/person)
R_a = Outdoor airflow rate per unit area (cfm/ft^2)

Zone Outdoor Airflow (V_{oz})

$Z_p = V_{oz}/V_{pz}$ (Eq. 6-5)

- For VAV Systems, V_{pz} is the minimum expected primary airflow for design purposes.

System Ventilation Efficiency (E_v)

E_v is found by using the Maximum Z_p value (Table 6-3)

Uncorrected Outdoor Air Intake (V_{ou})

$V_{ou} = D\sum allzones(R_p \times P_z) + \sum allzones(R_a \times A_z)$ (Eq. 6-6)

D = Diversity = $P_s/\sum allzones(P_z)$ (Eq. 6-7)
P_s = system population, total population in the area served by the system

Outdoor Air Intake (V_{ot})

$V_{ot} = V_{out}/E_v$ (Eq. 6-8)

Outdoor Air Flow Calculation Assumptions

While analyzing the different spaces for Section 6, it was necessary to make certain assumptions for many of the areas listed. I considered all passages and alcoves as corridors when calculating outdoor air requirements. All spaces labeled HSKG are essentially storage spaces for gloves and lab coats, so these were treated as normal storage units.

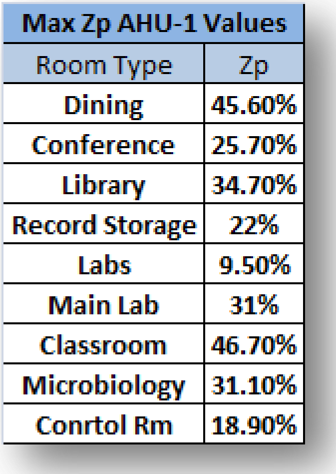
Since the building is a hospital, there are many specialized rooms used for different types of surgeries and procedures. ASHRAE does not have values for these types of spaces, so values for R_p were based on the International Mechanical Code (IMC) 2003. Both IMC 2003 and AIA 2001 were the codes that were used on the design of the HVAC system in this hospital. Many of the surgery and clean procedure rooms required a minimum of 15 cfm/person based on these codes.

Std 62.1 Findings

The HVAC design of the hospital meets all of the requirements in Section 5 of Std 62.1, except for location of the cooling towers relative to the exhaust flues for the boilers. This is odd because there is a major effort to not let any contaminants in the air into the indoor spaces. This is done through making sure the outdoor air intakes are located well away from any exhaust ducts. Since the building is located in the middle of a 120 acre site, any pollutants from an exterior source will not reach the intakes. A minimum of 8MERV filters are used, with a minimum of 13 MERV used for spaces requiring very clean air. However, due to the location of the boiler exhausts, it is possible that contamination can still happen through the cooling towers.

Calculations were performed for each room in Section 6 to determine the minimum outdoor airflow requirements based on ASHRAE standards. The outdoor air fraction (Z_p) for each space was calculated based on the calculated outdoor airflow requirements and the design supply air. Next the overall system Z_p was calculated along with the total amount of airflow that the systems will need to produce. These values for each space in the hospital can be seen in the spreadsheet in Appendix A.

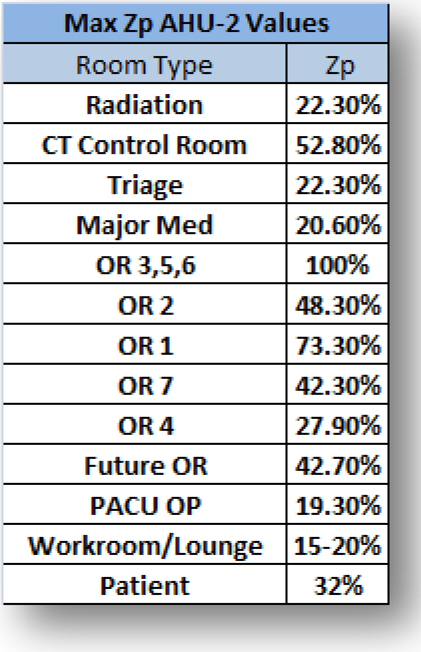
The AHU systems for the hospital are broken down into 3 main sets of AHU's. AHU Set 1 consists of two AHU units, manufactured by Haakon, that each produces 50,000 cfm. Table 2.1 below shows the larger Z_p values for the spaces served by AHU 1A and 1B.



Max Zp AHU-1 Values	
Room Type	Zp
Dining	45.60%
Conference	25.70%
Library	34.70%
Record Storage	22%
Labs	9.50%
Main Lab	31%
Classroom	46.70%
Microbiology	31.10%
Conrtol Rm	18.90%

Table 2.1 Max Z_p Values for Spaces in AHU Set 1

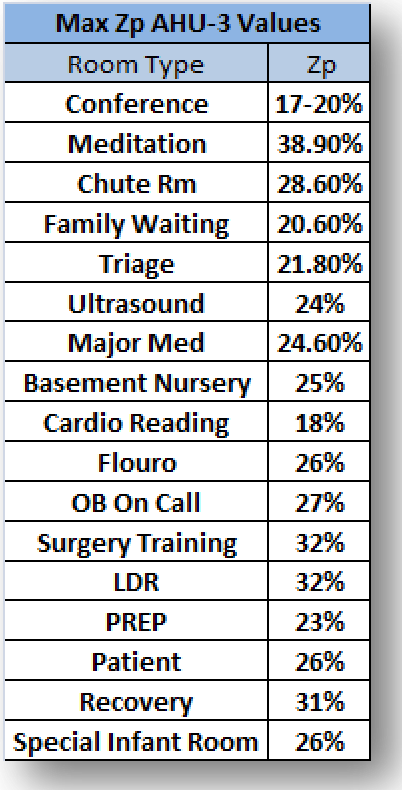
The max Z_p for AHU Set 1 is the classroom and dining area. The dining area has a large Z_p due to its function, as well as the large amount of people that will be in the space. The classrooms high Z_p can be attributed to the fact that the required rates for a classroom are high, and the design supply airflow is low compared to the calculated outdoor air flow. The library has a large fraction of outdoor air as well; this can be attributed to the fact that libraries require more outdoor air so that mold does not collect on the books. The same could be said for the record storage room, since this houses many of the patient records. The main lab and the microbiology room both have a large Z_p, but this is expected since they are labs and a large outdoor air intake is a must.



Max Zp AHU-2 Values	
Room Type	Zp
Radiation	22.30%
CT Control Room	52.80%
Triage	22.30%
Major Med	20.60%
OR 3,5,6	100%
OR 2	48.30%
OR 1	73.30%
OR 7	42.30%
OR 4	27.90%
Future OR	42.70%
PACU OP	19.30%
Workroom/Lounge	15-20%
Patient	32%

Table 2.2 Max Z_p Values for Spaces in AHU Set 2

Table 2.2 shows the max Z_p values for AHU Set 2. This set is the same as AHU Set 1, it contains two Haakon units that each produce 50,000 cfm. The rooms with the highest Z_p are the operating rooms. They each differ in Z_p due to the difference in size, and design supply air. Three of the operating rooms are 100% outdoor air. The four remaining operating rooms do have a mix of return air in the supply air. However, there is still a very high Z_p for these rooms, with 73% being the next highest. The triage, major med, and radiation rooms also have a high Z_p since they also require a lot of outdoor air. The workrooms and lounges also have a higher Z_p due to the fact that each space has a high occupant density.

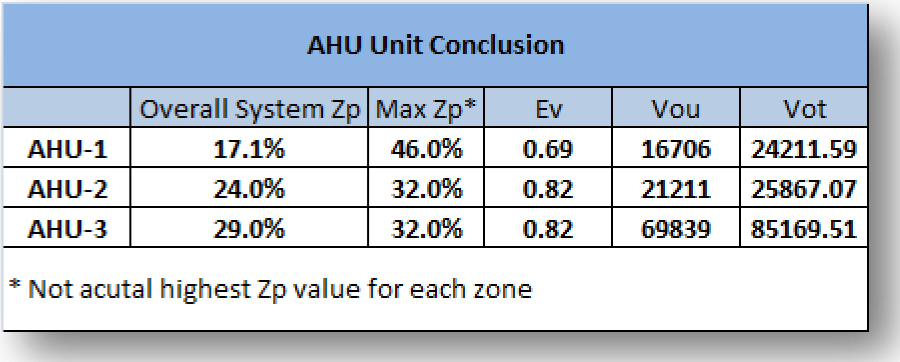


Max Zp AHU-3 Values	
Room Type	Zp
Conference	17-20%
Meditation	38.90%
Chute Rm	28.60%
Family Waiting	20.60%
Triage	21.80%
Ultrasound	24%
Major Med	24.60%
Basement Nursery	25%
Cardio Reading	18%
Flouro	26%
OB On Call	27%
Surgery Training	32%
LDR	32%
PREP	23%
Patient	26%
Recovery	31%
Special Infant Room	26%

Table 2.3 Max Z_p Values for Spaces in AHU Set 3

Table 2.3 shows the max Z_p values for AHU Set 3. This particular set supplies a much larger area than the previous two. This set contains six AHU units that provide 75,000 cfm each. The max Z_p level for this set is the meditation room. This is because it numerous people and was modeled after an aerobics room in the ASHRAE Table 6-1 table. Much like AHU Set 2, there are a couple spaces that require more outdoor air than normal since they are surgery/clean rooms. These include the triage, major med, ultrasound, and the prep room. All of these values are around 25%. Like the family waiting rooms, the conference rooms also require a larger fraction of outdoor air due to the large population that it is designed for. The Z_p of the patient rooms is also important to note. There are 313 patient rooms on this AHU set, and each patient room has a Z_p of 25-31%, depending on the size and function. These are high because patient comfort and health are a major factor for the design of the hospital. An increase in outdoor air will make the air cleaner and fresher for the patients.

Std 62.1 Conclusion



AHU Unit Conclusion					
	Overall System Zp	Max Zp*	Ev	Vou	Vot
AHU-1	**17.1%**	**46.0%**	**0.69**	**16706**	**24211.59**
AHU-2	**24.0%**	**32.0%**	**0.82**	**21211**	**25867.07**
AHU-3	**29.0%**	**32.0%**	**0.82**	**69839**	**85169.51**

* Not acutal highest Zp value for each zone

Table 2.4 AHU System Values

Table 2.4 above shows the final values for all three AHU sets. It is important to note that the actual highest value of Z_p was not chosen. This is due to the fact that the hospital has specialty rooms that require a large amount of outdoor air. Choosing the absolute highest Z_p would be misleading in terms of figuring out the overall system efficiency. For example, AHU Set 2 has operating rooms that have a 100% Z_p and a 73% Z_p. These are only a couple rooms out of 500, and once again are specialty rooms. The E_v of AHU Set 2 and 3 are both high due to the lower max Z_p values. Both these values were for the patient rooms. Finally the final V_{ot} was calculated for each system.

The design supply air does not include the design outdoor air in the room schedules. When adding the V_{ot} to the supply air for AHU Set 1, the total value was 122,091 cfm. This is important to note because AHU Set 1 can only produce 100,000 cfms, meaning that by AHSRAE standards this system is undersized. This could be because ASHRAE codes were not used in the analysis in this building. Instead IMC 2003 and AIA 2001 were used to determine ventilation rates. AHU Set 2 has the same problem; it is undersized by about 16000 cfm when using ASHRAE standards. AHU Set 3 is actually oversized. It can produce a total of 450,000 cfms; meanwhile only 325,749 cfms are required. There is a reason for this however. Almost all of the hospitals mechanical equipment is designed to have additions in the future. There are plans to add an additional chiller and boilers. The same is being done for additional spaces in the building. AHU Set 3 was designed to be able to handle the additional cooling and heating loads that will occur when new additions are put in place.

ASHRAE Std 90.1

Section 5

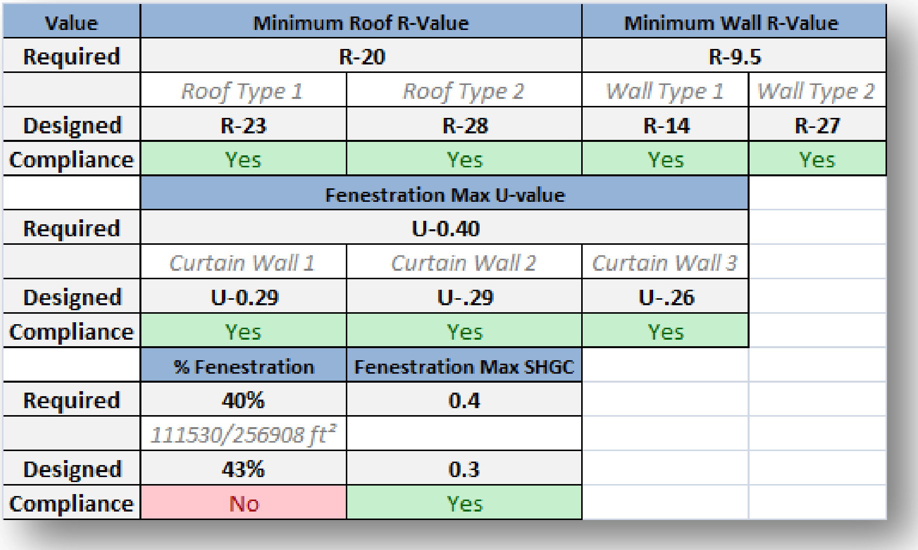
The Virtua Replacement Hospital is located in Voorhees NJ, which is in climate zone 4A as seen in the ASHRAE Table B1.

As seen in Table 3.1 the vertical fenestration is over the limit set by ASHRAE. However, it is only over by 3%, and the type of glass used has a U-Value that is well below the max. For this reason it was decided that the Prescriptive Building Envelope Compliance Path was an acceptable path to follow.

As seen in Table 3.1 the building envelope complies with all of the standards of Section 5.4. Roof type 1 is the standard roof used on the hospital and it does meet the minimum R-Value. Roof type 2 is a green roof. The construction is the same as Roof Type 1, except it has an additional soil barrier and 4” of soil, thus giving it a higher overall R-Value.

Figure 3.1(Wall Type 1) and 3.2 (Wall Type 2) show the two main exterior wall constructions used in the building. Wall Type 1 consists of stone veneer panels, while Wall Type 2 consists of composite metal panels. As seen in Table 3.1 below, both comply with code.

The exterior envelope of the hospital consists of a large amount of glass as seen by the fenestration percentage. Many types of glass are used throughout the building, but there are three main types that were analyzed. Curtain Wall 1 consists of a clear Low e glass ¼” panel, followed by a ½” air space, and then another ¼” Low e panel for a total U-Value of 0.29. Curtain Wall 2 is a clear heat strengthened ¼” panel, with a ½” air space, followed by another ¼” heat strengthened panel for a total U-Value of 0.29. Wall Type 3 consists of a silk screened Low e ¼” panel, ½” airspace, followed by another ¼” Low e panel for a total U-Value of 0.26. All of these values are well below the max U-Value, so the large amount of glass shouldn’t be a problem.



Value	Minimum Roof R-Value		Minimum Wall R-Value	
Required	R-20		R-9.5	
	Roof Type 1	*Roof Type 2*	*Wall Type 1*	*Wall Type 2*
Designed	R-23	R-28	R-14	R-27
Compliance	Yes	Yes	Yes	Yes
	Fenestration Max U-value			
Required	U-0.40			
	Curtain Wall 1	*Curtain Wall 2*	*Curtain Wall 3*	
Designed	U-0.29	U-.29	U-.26	
Compliance	Yes	Yes	Yes	
	% Fenestration	Fenestration Max SHGC		
Required	40%	0.4		
	111530/256908 ft^2			
Designed	43%	0.3		
Compliance	No	Yes		

Table 3.1 Exterior Envelope Analysis

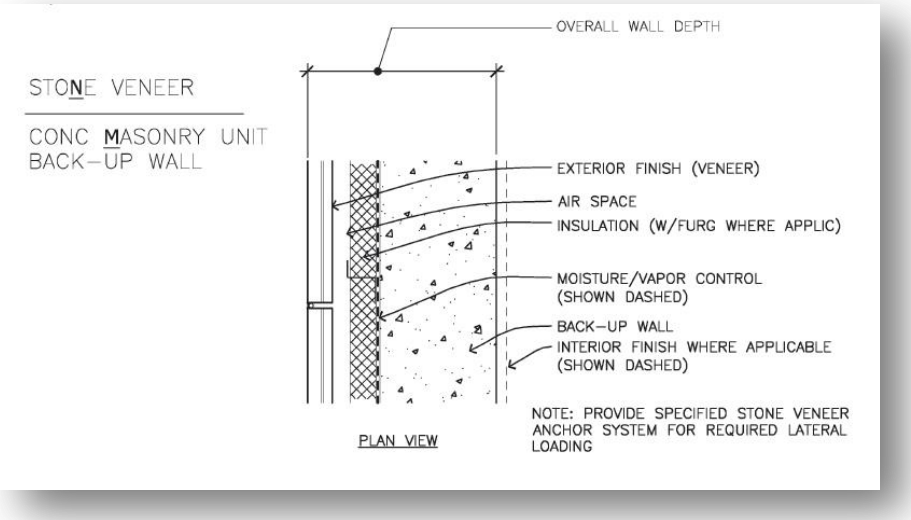


Figure 3.1 Wall Type 1

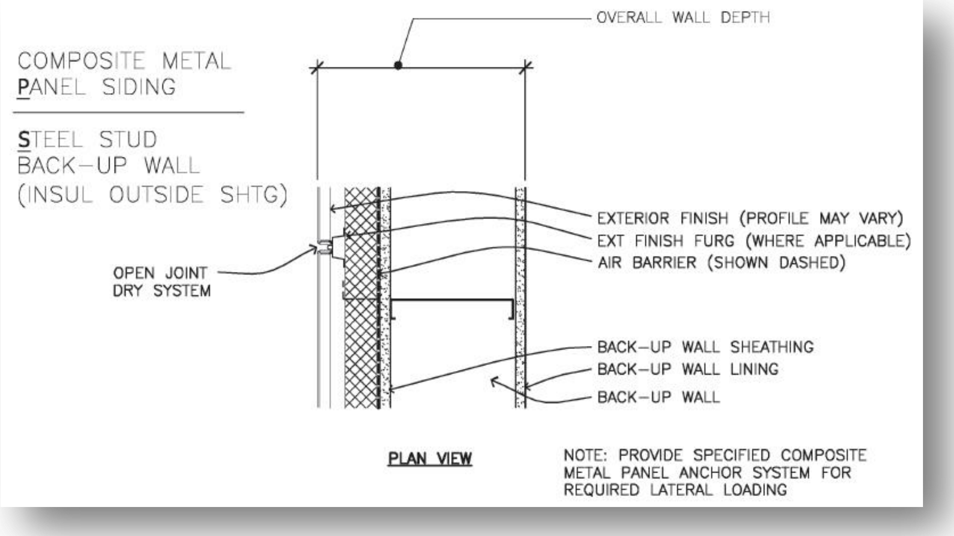


Figure 3.2 Wall Type 2

Section 6

Section 6.2 Compliance Path

The Mandatory Provisions and Prescriptive Path shall be used for this analysis due to the large size of the building.

Section 6.4 Mandatory Provisions

Thermostatic controls will control the supply of heating and cooling energy that reaches each zone. The thermostats used will be very accurate with an accuracy of ±1º F. Since this is a hospital and many spaces are used 24/7 there is not a scheduled stop and start time for the system. For spaces that do run 24/7, there are occupancy sensors that are capable of shutting the supply air of when no one is in the room for a certain amount of time. The heating controls will have the option to automatically restart and operate the system to maintain zone temperatures above a heating set point down to 55ºF.

All exhaust ducts are equipped with dampers that will allow them to be shut when not in use. The maximum damper leakage is 1 cfm/ft² which is well below the maximum damper leakage.

Section 6.5 Prescriptive Path

Appendix B shows the Fan Power Limitation for the supply air fans. None of the supply fans comply with this standard. This is likely due to the extra pressure drops due to the higher rated filters. Many of the filters are 13, 14, and 17 MERV filters so the supply fan motors must be more powerful to accommodate the increase in pressure.

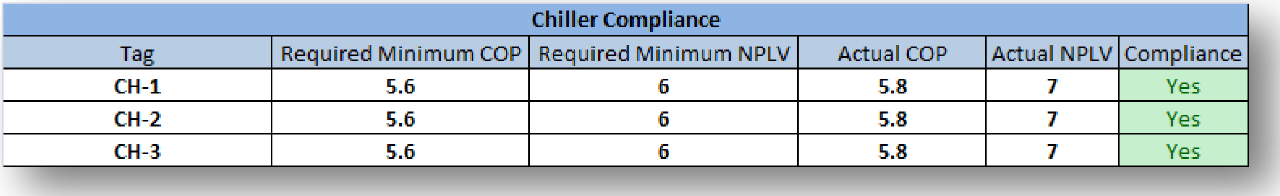
Appendix B shows the Fan Power Limitation for the return and exhaust fans. All but one of the exhaust fans comply with the standard, meanwhile all of the return fans comply.

Section 6.7 Submittals

All systems are to be tested to ensure that the controls are calibrated and are in working order.

Section 6.8 Minimum Equipment Efficiency Tables

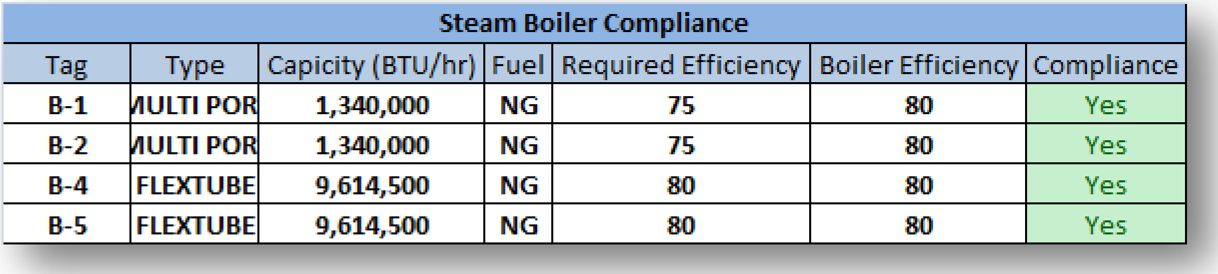
All systems were analyzed based on the tables in Section 6.8. As seen in Table 3.2, all three centrifugal chillers are compliant. The COP and NPLV were calculated based on the full load and part load KW/Ton values.



Chiller Compliance					
Tag	Required Minimum COP	Required Minimum NPLV	Actual COP	Actual NPLV	Compliance
CH-1	5.6	6	5.8	7	Yes
CH-2	5.6	6	5.8	7	Yes
CH-3	5.6	6	5.8	7	Yes

Table 3.2 Chiller Compliance

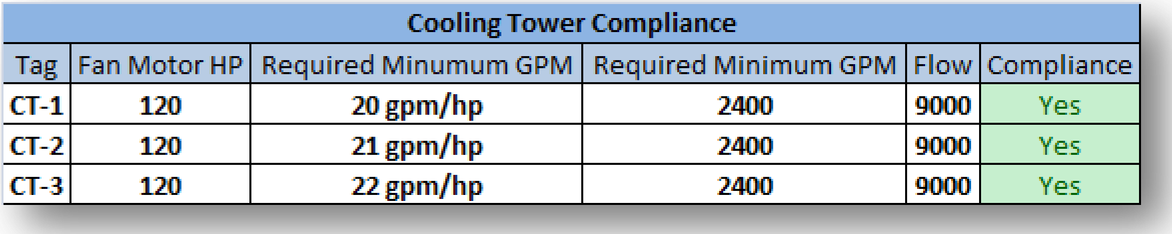
Table 3.3 shows that all four steam boilers are compliant with the standards. The multi port boilers surpass the minimum efficiency; meanwhile the flex tube boilers just meet the requirements. All four boilers run on natural gas.



Steam Boiler Compliance						
Tag	Type	Capicity (BTU/hr)	Fuel	Required Efficiency	Boiler Efficiency	Compliance
B-1	MULTI POR	1,340,000	NG	75	80	Yes
B-2	MULTI POR	1,340,000	NG	75	80	Yes
B-4	FLEXTUBE	9,614,500	NG	80	80	Yes
B-5	FLEXTUBE	9,614,500	NG	80	80	Yes

Table 3.3 Boiler Compliance

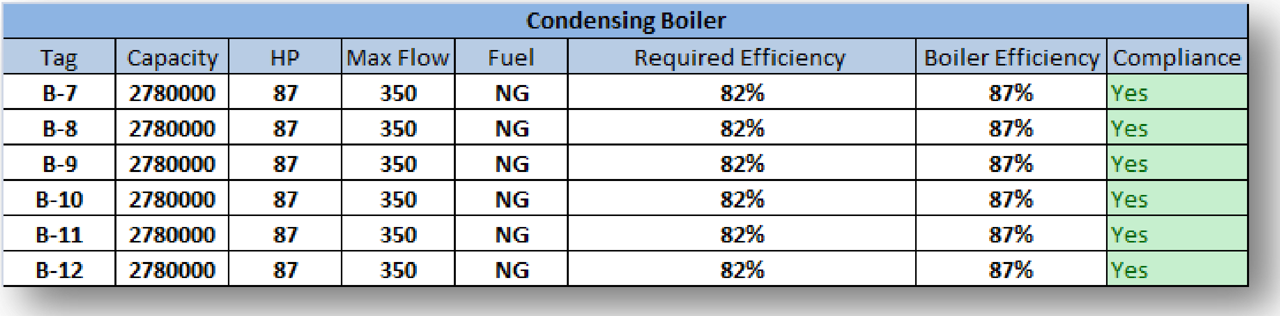
Table 3.4 shows that the cooling towers are also well above the required minimum requirements specified in Section 6.8.



Cooling Tower Compliance					
Tag	Fan Motor HP	Required Minumum GPM	Required Minimum GPM	Flow	Compliance
CT-1	120	20 gpm/hp	2400	9000	Yes
CT-2	120	21 gpm/hp	2400	9000	Yes
CT-3	120	22 gpm/hp	2400	9000	Yes

Table 3.4 Cooling Tower Compliance

The final system analyzed was the condensing boilers. As seen in Table 3.5 they all comply with the standard.



Condensing Boiler							
Tag	Capacity	HP	Max Flow	Fuel	Required Efficiency	Boiler Efficiency	Compliance
B-7	2780000	87	350	NG	82%	87%	Yes
B-8	2780000	87	350	NG	82%	87%	Yes
B-9	2780000	87	350	NG	82%	87%	Yes
B-10	2780000	87	350	NG	82%	87%	Yes
B-11	2780000	87	350	NG	82%	87%	Yes
B-12	2780000	87	350	NG	82%	87%	Yes

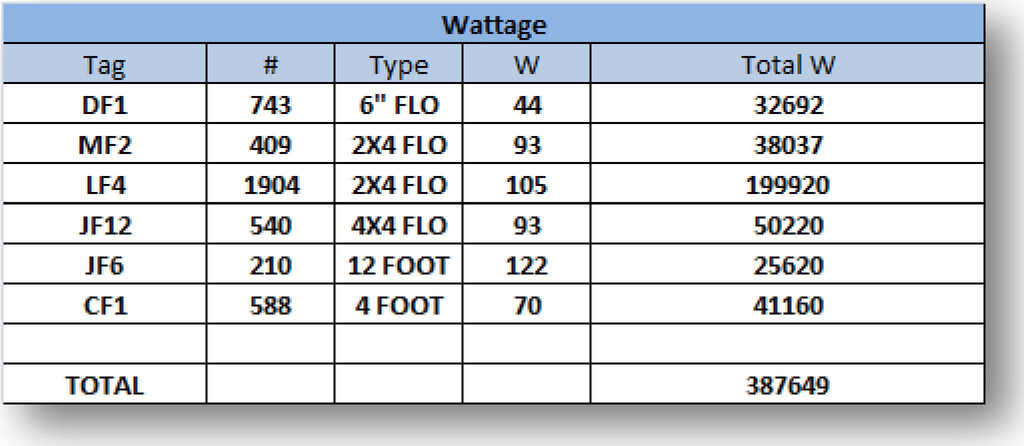
Table 3.5 Condensing Boiler Compliance

Section 7

Domestic Hot Water is supplied by three shell and tube 10,041 MBH heat exchangers, as well as the steam boilers. Each heat exchanger has an efficiency of 88%, which is well above the 80% required.

Section 9

The method used to calculate the lighting density was to find the total wattage serving the lights and then divide it by the square footage. Table 3.6 shows the fixtures used in the building along with the wattage of each one. According to Section 9 Table 9.5.1 there should be no more than 1.2 W/ft^2 for a hospital. This hospital has a .6 W/ft^2 for lighting. This is well below the limit for hospital. The reason for this is not only the use of energy efficient lights, but because of the significant use of daylight. The patient rooms all utilize a significant amount of daylight and because of this the amount of light needed is greatly diminished.



Wattage				
Tag	#	Type	W	Total W
DF1	743	6" FLO	44	32692
MF2	409	2X4 FLO	93	38037
LF4	1904	2X4 FLO	105	199920
JF12	540	4X4 FLO	93	50220
JF6	210	12 FOOT	122	25620
CF1	588	4 FOOT	70	41160
TOTAL				387649

Table 3.6 Lighting Power Density

Std 90.1 Conclusion

The building complies with Std 90.1 for the most part. The chillers, boilers, and cooling towers are all above the required efficiencies. All of the supply fans did not comply, however this is most likely due to the increase in pressure due to the filters being used. The remaining exhaust and return fans all did comply with code except for one exhaust fan.

The building does an exceptional job with its exterior envelope, especially considering the amount of glass that is being used. The glass U-Values were well below the max, and the R-Values were all much higher than required. The lighting density was also very good. It was well below the max value for a hospital. This is definitely due to the fact that the hospital makes great use of natural day lighting.

Design Load Estimation

Load Sources and Modeling Information

The main load sources in the hospital are the occupants, electrical and mechanical equipment, lighting, and the solar gain due to the large amount of glass that is being used.

Design Occupancy and Ventilation

The ventilation rates used for each space were taken from the design documents as well as the occupancy. These include the Max OA at Max SA, Max SA, Min SA, and Min OA at Min SA. Exhaust rates were also taken directly from the design documents.

Infiltration

The Virtua Hospital was assumed to have tight construction with positive pressure. This yielded .3 air changes per hour, which was used for all the spaces with an exterior wall.

Electrical Loads

All of the lighting loads were entered on a Watt/square foot basis. Lighting loads for different spaces varied greatly. Corridors for example, had a value of .9 Watts per square foot. Offices and other similar spaces had a higher value at around 1.2 Watts per square foot. This is because more light is needed in this space since work is being done. Operating rooms were given a particularly high value at 1.6 Watts per square foot since a lot of light is needed during the surgeries. Some of these spaces will not operate 100% of the time however, so the lighting load will not be as significant as if the lights were on 100% of the time. Patient rooms were given a 1 Watt per square foot value. There is less lighting in these rooms on purpose, since the idea for the patient rooms was to make it darker so patients could sleep during daylight hours. All of these values are estimated for each space.

Loads for the electrical equipment in each space were entered by Watts. This is because equipment plans were made available, which showed the exact equipment being used in each space. Using 2005 ASHRAE Handbook of Fundamentals, wattages were determined for each space. Using this method made for a more accurate energy model.

Weather Data

The outdoor and indoor air conditions for Philadelphia, PA were used. This is because there was no available data for the buildings location in Voorhees NJ. However, Philadelphia is very close, making the weather data an accurate representation for the weather in Voorhees. Values were taken from the 2005 ASHRAE Handbook of Fundamentals. Values used were the .4% and 99.6%. The OA Dry Bulb for the summer is 92.7º F, while the OA Wet Bulb is 75.6º F. The OA Dry Bulb for the winter is 11.6º F. The clearness number was .98 as well. The weather data information can be seen in Appendix C.

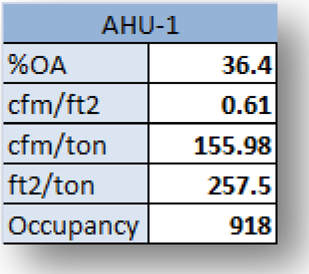
Energy Model Foreword

The building model was first constructed in REVIT Architecture. This was done to accurately represent the square footages, volumes, and wall types for each of the spaces. The model was then imported into Trace 700 for energy analysis. Trace 700 was used due to the author's familiarity with the program, as well as its history of showing accurate results when used by the author.

While comparing the results to the actual building energy model results from the actual design engineers would be ideal in confirming an accurate energy analysis, HGA Architects and Engineers preferred not to make the information available. The results of the energy model will be compared to industry standards and rules of thumb. Comparing the different systems of the hospital will to each will also help determine if the results are indeed accurate.

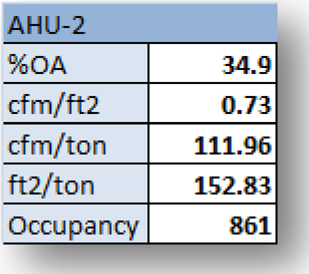
Energy Model Results

The first section analyzed after the modeling was complete was the three main AHU sets. Tables 4.1, 4.2, and 4.3 show the basic analysis for each AHU set.



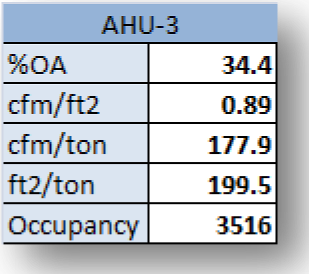
AHU-1	
%OA	36.4
cfm/ft2	0.61
cfm/ton	155.98
ft2/ton	257.5
Occupancy	918

Table4.1AHU Set 1 Analysis



AHU-2	
%OA	34.9
cfm/ft2	0.73
cfm/ton	111.96
ft2/ton	152.83
Occupancy	861

Table 4.2 AHU Set 2 Analysis



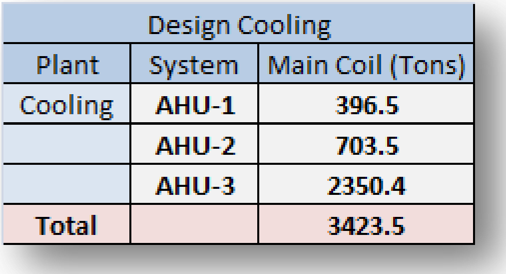
AHU-3	
%OA	34.4
cfm/ft2	0.89
cfm/ton	177.9
ft2/ton	199.5
Occupancy	3516

Table 4.3 AHU Set 3 Analysis

As seen in the tables the %OA for each AHU is around 35%. These all seem relatively high, however, when considering the design ventilation rates for the hospital they make sense. Many of the offices in the hospital have a very high %OA, as do the patient rooms. Many of these spaces are conditioned by AHU Set 3. The reason for AHU Set 2s high %OA is because this set conditions many of the medical rooms, including operating, radiation, recovery, and C-section rooms. AHU Set 1 has a high %OA because it also serves offices on the first floor, as well as the large kitchen areas which required a high percentage of outdoor air.

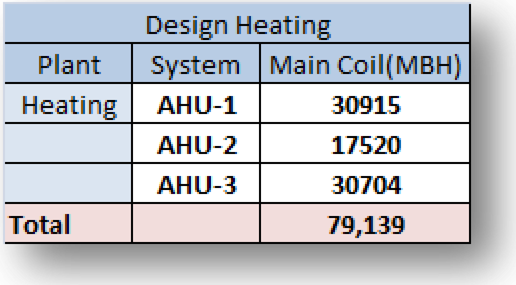
A rule of thumb for a standard building is 400 ft^2/ton. This is for a typical office building however. When looking at the individual AHU sets it is clear that much more energy is used. This makes sense due to the type of building being modeled. A hospital will naturally use much more energy than that of a standard commercial building. According to the DOE (Department of Energy) hospitals can use as much as 2.5 times the amount of energy compared to an office building. When comparing the ft^2/ton for the 3 sets of AHUs it is apparent that they are in the correct range.

Further comparing the ft2/ton for each set to each other also seems to yield accurate results. AHU Set 1 has the highest, at 257.5 ft^2/ton. This is due to the fact that mainly office, lounges, and waiting areas are on this set. It does condition the main kitchen, however, which most likely contributes to it using more energy. The other sets condition spaces that require much more energy. AHU Set 2 uses the most energy, 152 ft^2/ton, since it mainly conditions the operating rooms and medical rooms. AHU Set 3 is in the middle at 199.5 ft^2/ton. Once again, this seems accurate since this supplies most of the patient rooms, and some medical rooms, which require more ventilation than standard offices, such as the ones on AHU Set 1.



Design Cooling		
Plant	System	Main Coil (Tons)
Cooling	AHU-1	396.5
	AHU-2	703.5
	AHU-3	2350.4
Total		3423.5

Table 4.4 Peak Design Cooling



Design Heating		
Plant	System	Main Coil(MBH)
Heating	AHU-1	30915
	AHU-2	17520
	AHU-3	30704
Total		79,139

Table 4.5 Peak Design Heating

Tables 4.4 and4.5 show the peak Design Cooling and Design Heating loads on the main coils, which occurs in May. Comparing the peak loads to each other helps confirm whether they are accurate. AHU Set 3 clearly has the highest peak load, which makes absolute sense since it conditions a significantly larger amount of spaces than the other two sets. AHU Set 2 once again is higher than AHU Set 1 due to the types of spaces it conditions. At first glance the Design Heating loads may seem a bit odd, but further analysis can help explain the peak loads. AHU Set 1 consists of many rooms on ground level, which consists of mainly exterior glazing. A large effort was made to allow as little direct solar gain through the glass. This in turn will decrease the solar gain that can enter into the building and help heat the spaces. These spaces will have infiltration that enters the rooms through any gaps in construction, which is why the heating load may be larger than one would think. The same can be said for the AHU Set 3, however this has a large load due to the large number of spaces served as well. AHU Set 2 has a smaller peak heating load due to its smaller size, and the fact that the spaces being served do not include any exterior glazing, as well as the fact that many of the spaces are not on the exterior of the building.

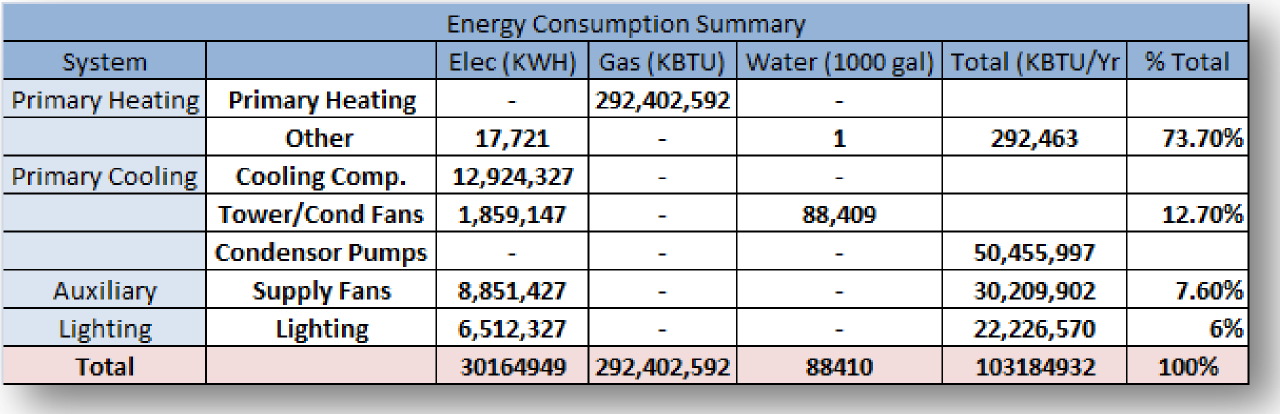
After analyzing the peak loads on the AHU Sets, an energy analysis was performed on the building mechanical plant. Much of the sizing and efficiencies were taken off of the actual design documents to provide accurate modeling of the mechanical equipment. Electrical rates were taken directly off of the Atlantic City Electric Company's website. The breakdown of the rates can be seen in Appendix A. The average value used for the electric rate was $6.30/KW. The rate used for natural gas was $1.2/Therm.

In addition to entering the correct rates, the building schedule was also necessary to enter correctly. Since this is a hospital, many of the spaces will be operating at all hours of the day. All of the patient rooms are running 100% of the time, as well as the nurse and other spaces that serve the patient rooms. Many of the medical rooms, including surgery rooms are also assumed to be operational 100% of the time. The only spaces that are not operational at all times of the day are the many offices throughout the hospital. Many of the offices were given a schedule for operating times from 8 am to 8 pm. While this is a larger amount of time than a standard office schedule, given the type of occupancy for the building it was decided to increase the amount of time the offices were operational.

After entering the correct energy rates and schedules the energy analysis of the building was performed. Table 4.6 shows the overall breakdown for the energy consumption by the building annually. The primary heating for the building comprises of mostly natural gas, since the boilers are responsible for this and they run on natural gas. There are several heat exchangers that also operate throughout the building for additional heating that do use electricity, which mainly comprises the "Other" in Table 4.6 under primary heating. The Primary Cooling consists of the various parts of the chillers, and the cooling towers. As seen in the table all of the cooling equipment runs on electricity, with the chiller cooling compressors using the majority of the energy. It is important to note the amount of water used mainly in the cooling towers as well. The supply fans also use a significant amount of electricity as well. This is because they are powerful fans that must push large amounts of air through high MERV rating filters. This equates to a large pressure drop, making it necessary for large, powerful fans to be used.

When looking at the total percentages for the energy consumptions, it is clear that the primary heating load was a significant part of the overall energy consumption. To make sure that this value is indeed correct it was decided to compare it with the average energy consumption in a hospital. Figure 4.1 shows a breakdown for typical hospitals, provided by the DOE. This figure does show that primary heating for a hospital comprises a lot of the energy use (50%). However, the model for this hospital still had a higher than normal heating load. This could be explained once again by the fact that there is little solar heat gain that penetrates through the exterior glazing. Most likely the average hospital does not have glazing with such a low U-factor, which means that more heating will be required in the winter due to the fact that not as much solar heat will reach the spaces compared to a normal space. This does affect the cooling loads in a positive way. The building will not need to be cooled as much in the summer months since not as much solar heat will penetrate the glazing. This could be an important factor for why the cooling primary load is much lower than the heating primary load. An additional factor could be the large number of boilers and heat exchangers used in the building for heating and domestic hot waters as well.

Another difference to note between the model and the DOE averages is the lighting loads. The lighting loads for this building are much lower than the average. This can be explained by the purposeful attempt to greatly lower the lighting loads in the building. The building uses only fluorescents, and in the patient rooms (large portion of the building) the lighting is greatly reduced to keep it dark so patients can sleep during daylight hours.



Energy Consumption Summary						
System		Elec (KWH)	Gas (KBTU)	Water (1000 gal)	Total (KBTU/Yr	% Total
Primary Heating	**Primary Heating**	-	292,402,592	-		
	Other	17,721	-	1	292,463	73.70%
Primary Cooling	**Cooling Comp.**	12,924,327	-	-		
	Tower/Cond Fans	1,859,147	-	88,409		12.70%
	Condensor Pumps	-	-	-	50,455,997	
Auxiliary	**Supply Fans**	8,851,427	-	-	30,209,902	7.60%
Lighting	**Lighting**	6,512,327	-	-	22,226,570	6%
Total		30164949	292,402,592	88410	103184932	100%

Table 4.6 Energy Consumption Summary

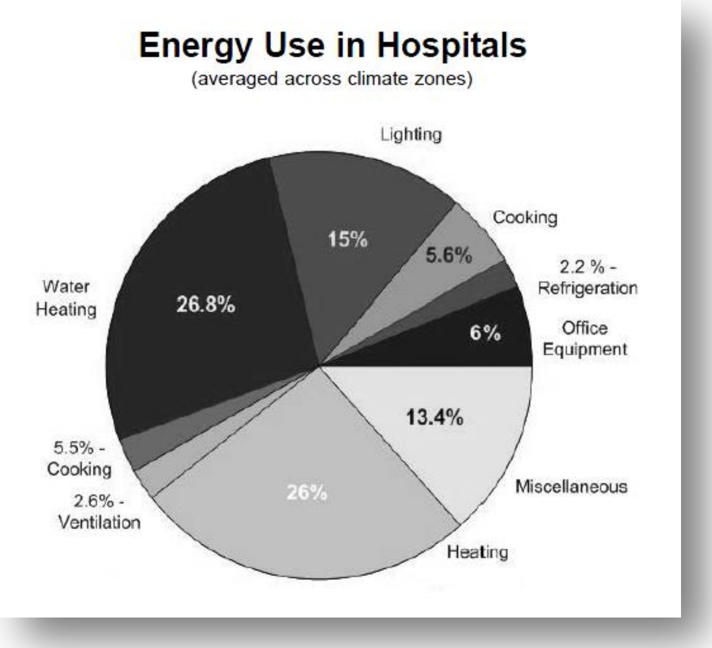
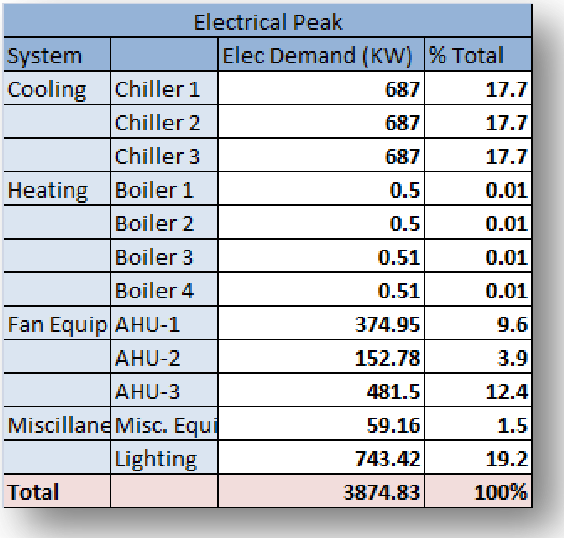


Figure 4.1 Typical Energy Breakdowns in Hospitals

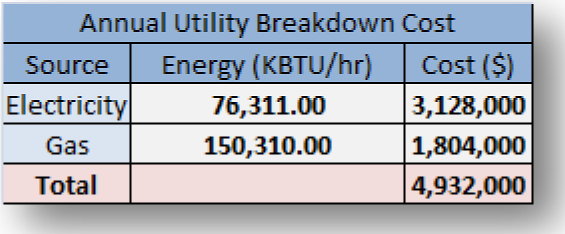
After looking at the overall energy consumption breakdowns, an analysis was done on the main mechanical components for the peak loads. Table 4.7 shows the peak electrical loads demands for the three main chillers and four main steam boilers. As expected, the chillers make up a large percentage of the electrical load during its peak. The boilers use almost no electricity since they run on natural gas. The lighting also makes up a large portion of the electrical load on the building, as well as the three AHU Sets. Once again, AHU Set 3 clearly uses more energy due to its much larger size compared to the other AHU Sets.



Electrical Peak			
System		Elec Demand (KW)	% Total
Cooling	Chiller 1	687	17.7
	Chiller 2	687	17.7
	Chiller 3	687	17.7
Heating	Boiler 1	0.5	0.01
	Boiler 2	0.5	0.01
	Boiler 3	0.51	0.01
	Boiler 4	0.51	0.01
Fan Equip	AHU-1	374.95	9.6
	AHU-2	152.78	3.9
	AHU-3	481.5	12.4
Miscillane	Misc. Equi	59.16	1.5
	Lighting	743.42	19.2
Total		**3874.83**	**100%**

Table 4.7 Electrical Peak Loads

Once the energy usage of the building was known, the annual cost of running the hospital could be calculated. Table 4.8 shows the breakdown of the annual cost for both the electric and gas. As seen in the table the cost of electricity is much higher than the natural gas. Figure 4.2 shows the cost for each component monthly. As you can see the heating and cooling make up a large factor of the cost.



Annual Utility Breakdown Cost		
Source	Energy (KBTU/hr)	Cost ($)
Electricity	**76,311.00**	**3,128,000**
Gas	**150,310.00**	**1,804,000**
Total		**4,932,000**

Table 4.8 Annual Utility Costs

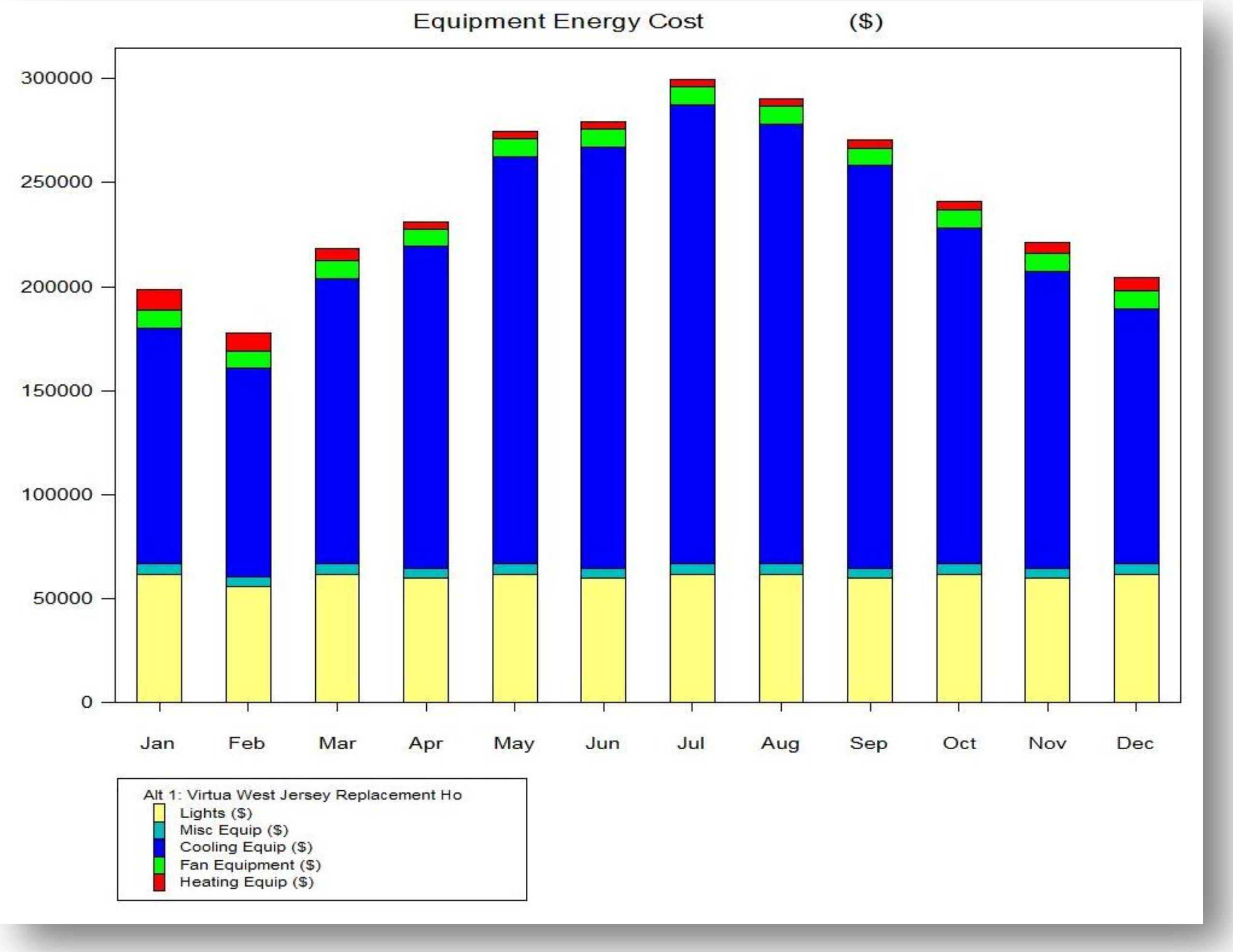


Figure 4.2 Monthly Consumption by Equipment

Tables 4.9 and 4.10 below show the estimated emission factors for the hospital. The data was taken from the total emission factors for delivered electricity for New Jersey. The value given in Table 4.9 was multiplied by KWH to obtain the total emissions. This is just the emissions for the electricity. Table 4.10 shows the emission factors for the gasoline used to run the steam boilers. The cubic feet of gasoline were taken directly from the design documents for each boiler.

Annual Emmission Factors		
Pollutant	lb/KWH in NJ	Building lb/Year
CO2e	9.31E-01	2.81E+07
CO2	8.61E-01	2.60E+07
CH4	2.79E-03	8.42E+04
N20	1.76E-05	5.31E+02
Nox	1.32E-03	3.98E+04
Sox	6.34E-03	1.91E+05
CO	6.69E-04	2.02E+04
TNMOC	6.92E-05	2.09E+03
Lead	4.27E-08	1.29E+00
Mercury	1.44E-08	4.34E-01
PM10	5.14E-05	1.55E+03
Solid Waste	6.23E-02	1.88E+06

Table 4.9 Emission Factors for Electricity

Annual Emmission Factors		
Pollutant	lb/cf	lb/Year
CO2e	1.37E+02	4.13E+09
CO2	1.16E+02	3.50E+09
CH4	8.38E-01	2.53E+07
N20	3.41E-03	1.03E+05
Nox	3.56E+00	1.07E+08
Sox	6.32E-04	1.91E+04
CO	2.29E+00	6.91E+07
VOC	2.06E-03	6.21E+04
Lead	5.00E-07	1.51E+01
Mercury	2.60E-07	7.84E+00
PM10	1.66E-02	5.01E+05

Table 4.10 Emission Factors for Natural Gas

Mechanical System Cost

Unfortunately information was not made available for the direct costs for the specific pieces of equipment. This includes the chillers and boilers. The equipment for this building is standard since the mechanical system does not utilize many special components. It is a standard VAV system; however, the equipment is much larger than in a normal size building. There will also be a lot more ductwork, and in turn, labor to install the mechanical system. This would assumedly make the cost of the mechanical system slightly larger than that of a comparable building.

An additional cost must also be considered for the space for the mechanical system. All of the mechanical equipment other than the AHU's are located in a central utility plant. This plant serves no purpose other than directly housing all of the equipment.

Mechanical Sustainability Assessment – LEED v2.2

The LEED system is broken down into different sections. Sections analyzed for this report include Energy & Atmosphere, and Indoor Air Quality. LEED was not a significant factor in the design of the building. However, due to the high energy cost for a hospital, an energy efficient design was created to help on reducing the energy costs. This will lead to various LEED credits being obtained.

Energy & Atmosphere

For the Energy & Atmosphere section of LEED, the Virtua Hospital did achieve all three of the required credits. The intent of Prerequisite 1 is to verify that the buildings systems are all installed, calibrated, and perform to the initial design. The commissioning will be performed by the division contractor and will be document by the Commissioning Authority (CxA). The commissioning work will include testing and start up for all mechanical equipment, checklists, providing qualified personnel, and providing overall assistance.

Prerequisite 2 is intended to establish a minimum level of energy efficiency. This requires that the systems comply with ASHRAE Standard 90.1-2004. As studied in Tech 1, the mechanical system does comply with Standard 90.1.

Prerequisite 3 is intended to reduce ozone depletion. This requires that heating, ventilation, air conditioning and refrigeration do not use any chlorofluorocarbon based refrigerants, which the systems installed do not use.

The building does earn 5 out of 10points under EA Credit 1: Optimize Energy Performance. This credit is intended to achieve a high level of energy performance above a certain baseline in the prerequisites standards. The comparable baseline energy consumption used for this analysis was calculated using the Building Performance Rating Method in ASHRAE Standard 90.1-2004.

1 credit is earned in AE Credit 3: Enhanced Commissioning. This is because the CxA is very involved in the commissioning of the building and all of the commissioning will be documented.

1 credit is earned in AE Credit 5: Measurement & Verification. The intent of this credit is to provide an ongoing accountability of the buildings energy consumption over time. A documentation system is in

place, and energy usage is recorded. This is especially important due to the occupancy of this building, and energy use is a major expense.

Indoor Air Quality

The hospital does both of the required prerequisites. Prerequisite 1 requires that minimum IAQ performance is achieved. The IAQ must meet the requirements of ASHRAE Standard 62.1-2004. The hospital did comply with this section.

Prerequisite 2 requires that environmental tobacco smoke is controlled. Since no smoking is allowed indoors or anywhere within a certain distance of the building, this requirement is easily met.

5 credits are earned in EQ Credit 4: Low-Emitting Materials. The intent of this credit is to reduce the quantity of indoor air contaminants. An effort was made to use materials throughout the building that do not release odors or any contaminants into the air. This is especially true in operating areas.

1 credit is earned in EQ Credit 6.1: Controllability of Systems: Lighting. This is intended to provide a system of lighting control. This is achieved in the building in two ways. All patient rooms have two settings for lights. A low light level is used for normal periods when the patient is in the room. When the patient is being examined there is a second setting that increases the light level. For many of the other spaces, including offices, occupancy sensors are installed to help control the lighting.

System Operation

All three AHU Sets are to be controlled using a dedicated direct digital controller. All fans will have a dedicated variable speed drive motor and will be interfaced with the BAS system for all start/stop, speed modulation, and monitoring control to maintain the duct static pressure set point 2/3 the way down the duct. The fans will be operated continuously during occupied hours unless they are manually turned off. Return fan speed shall be controlled to maintain a constant negative pressure. When smoke is detected in the building the outside and exhaust air dampers will modulate to 100% open, meanwhile the return air dampers will be close.

Pre-heating will be accomplished by circulating chilled water at 55º F. The supply air temperature will be maintained at 55º F. There will be a reset based on dehumidification needs and outdoor air temperature. The reset will be between 50º F and 60º F. Overall the system will have three modes of operation: pre-heat, outside air economizer, and mechanical cooling.

There will be two safety devices to be on manual reset. If the freeze stat senses leaving air temperature below set point, all fans will be shut down. A high pressure switch will also be installed after the supply fan. If the discharge pressure exceeds 6” in wg, then the fans will stop running.

All VAV boxes will be controlled by a dedicated direct digital controller. The BAS will modulate the VAV box damper and the reheat coil in sequence to satisfy the space temperature set point. When the system is running at unoccupied operation, the set points for the space will be 80º F and 65º F.

For the chilled water the BAS system will enable the chilled water system when outside air temperature is above a user definable set point. The BAS will determine the “lead” chiller based on the least amount of runtime. It will also indicate the sequence designation of each chiller. When a chiller is started, the chilled water pump shall start first. The lead chillers evaporator isolator valve shall be opened next. The condenser water pump will then open next, followed by the condenser isolation valve. Upon proof of flow the chiller will maintain the chilled water supply temperature set point.

The cooling towers shall also be controlled by the BAS system. When the chilled water system is enabled, the “lead cooling tower will be started, based on least amount of runtime. If the cooling tower is not operational within 15 seconds, than an alarm will be issued and the next cooling tower will replace it in sequence. When the cooling tower is started, condenser water will bypass the towers until the water reaches 60º F. When the temperature exceeds the set point, the lead cooling tower fan will start at minimum speed. All isolation valves will be opened and the BAS will modulate the speed to the fan towards 100% to maintain condenser water set point.

System Schematics

Air Side Schematic

Figure 7.1 shows the airside schematic for all AHU sets. The first set of AHU’s serve the first floor of the patient tower, which comprises of dining areas, offices, and kitchens. AHU Set 2 serves the operating rooms, and any other medical space requiring high indoor air quality. AHU Set 3 serves the entire patient tower, and some of the spaces in the ancillary building as well, such as the offices and lounges.

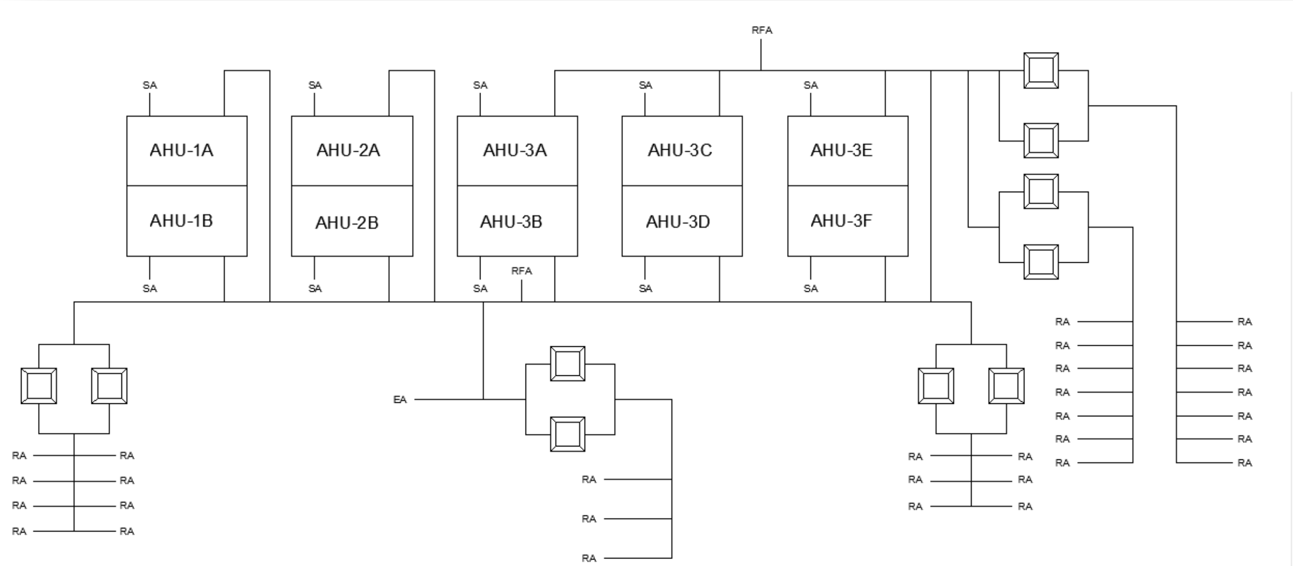


Figure 7.1 Air Side Schematic

Water Side Schematic

Figures 7.2 and 7.3 show the chilled water side schematic. The system includes three chillers that mainly serve the AHU's. Figure 7.2 shows the chilled water leaving the chillers and continuing on to Figure 7.3 where it serves the AHU's.

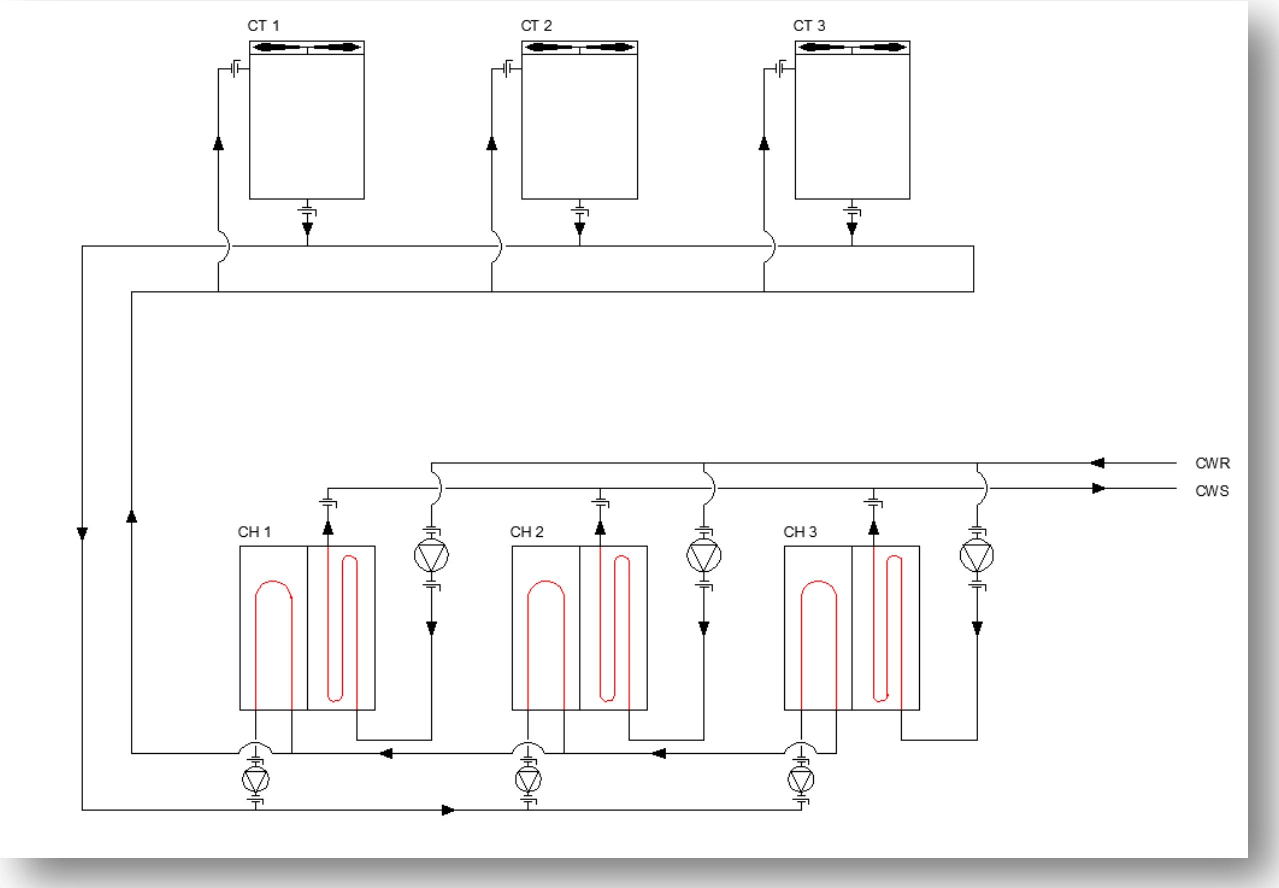


Figure 7.2 Chilled Water Schematic

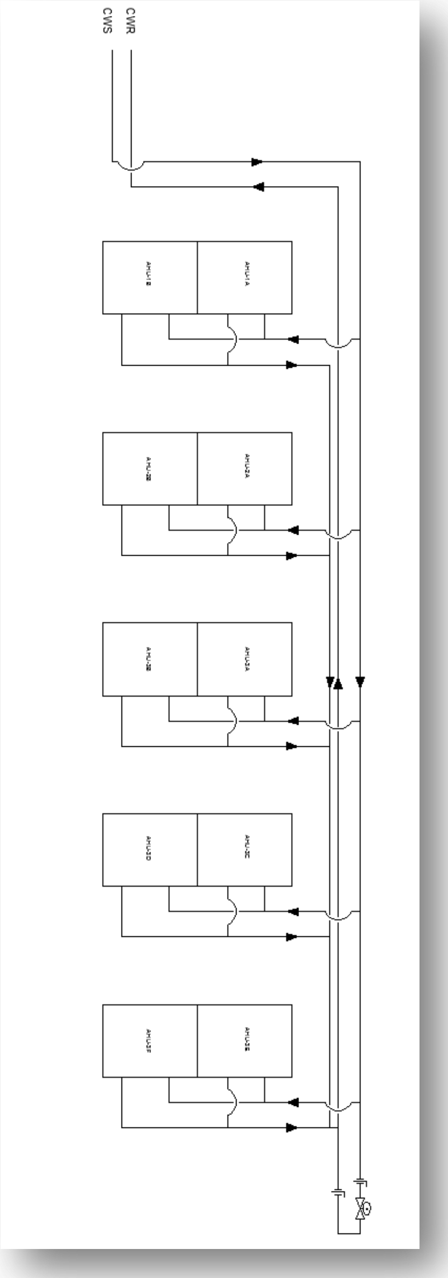

CWR
CWS
AHU-1B
AHU-1A
AHU-2B
AHU-2A
AHU-3B
AHU-3A
AHU-3D
AHU-3C
AHU-3F
AHU-3E

Figure 7.3 Chilled Water Schematic

Figures 7.4, 7.5, and 7.6 show the hot water side schematic. The system includes 6 boilers used for reheat coils in the VAV terminals, as well as utility handlers. Figure 7.4 shows the boiler room schematic. The hot water supply then moves to Figures 7.5 and 7.6, showing the different areas that the hot water is supplied too.

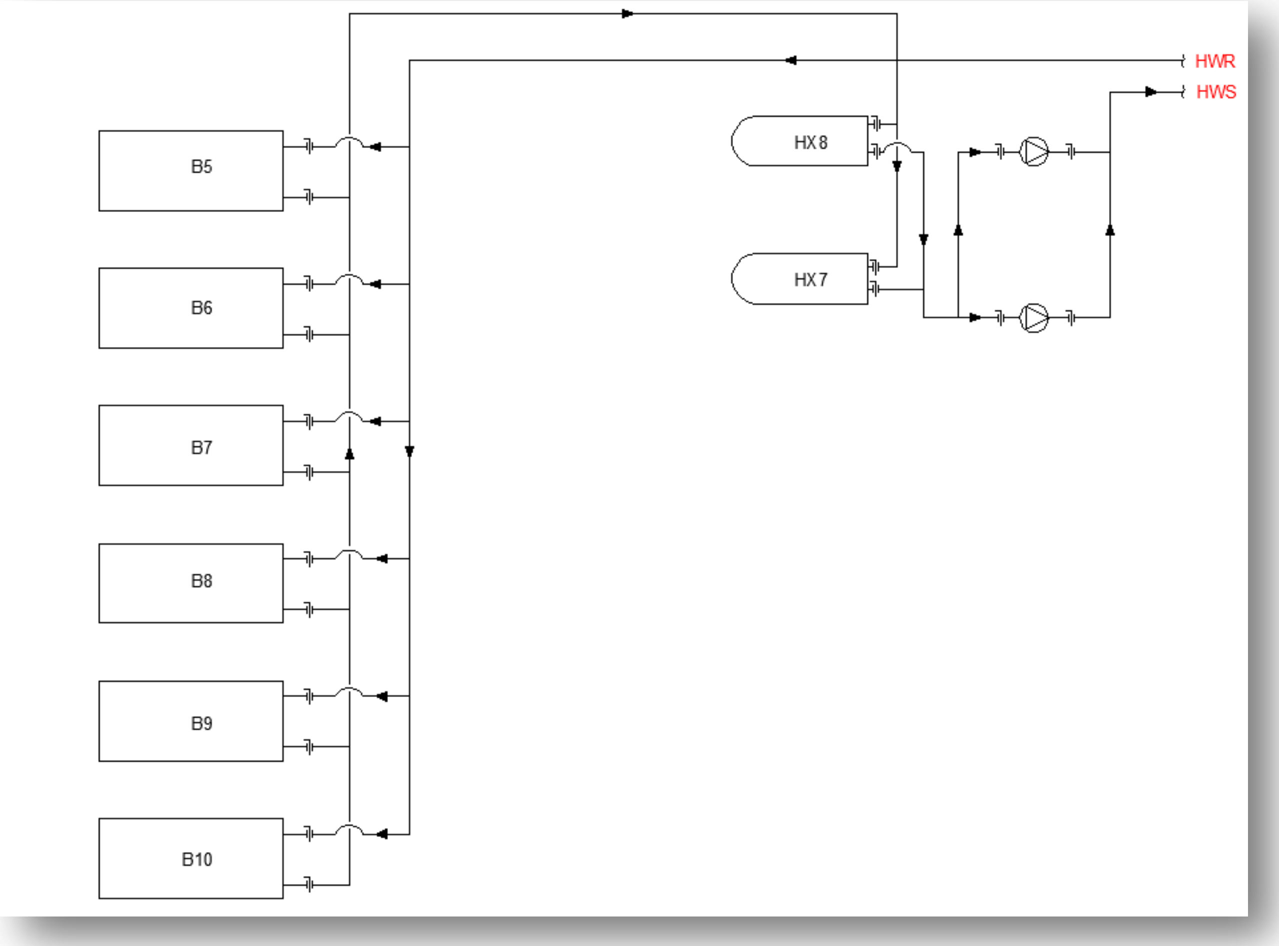


Figure 7.4 Hot Water Schematic

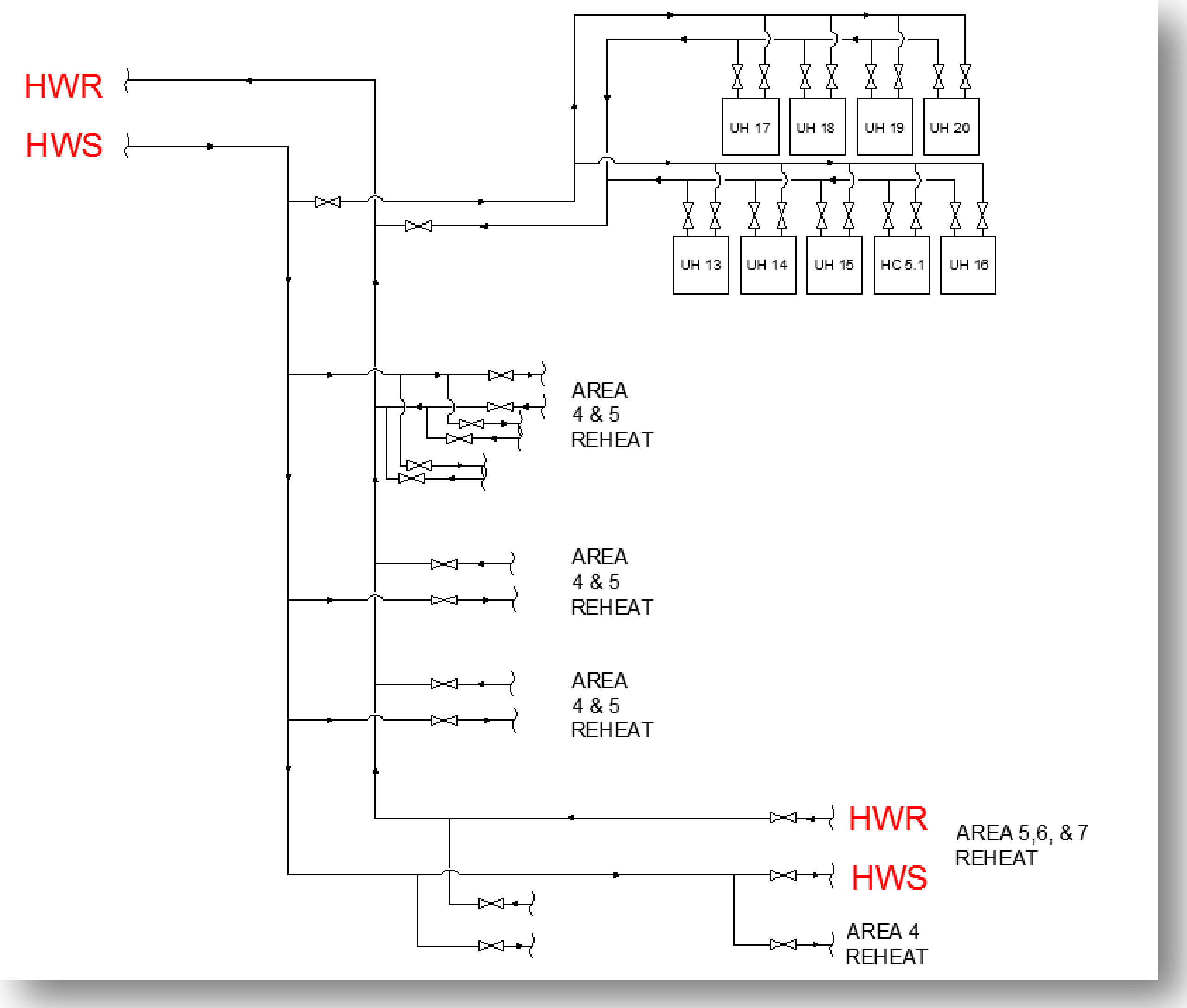


Figure 7.5 Hot Water Schematic

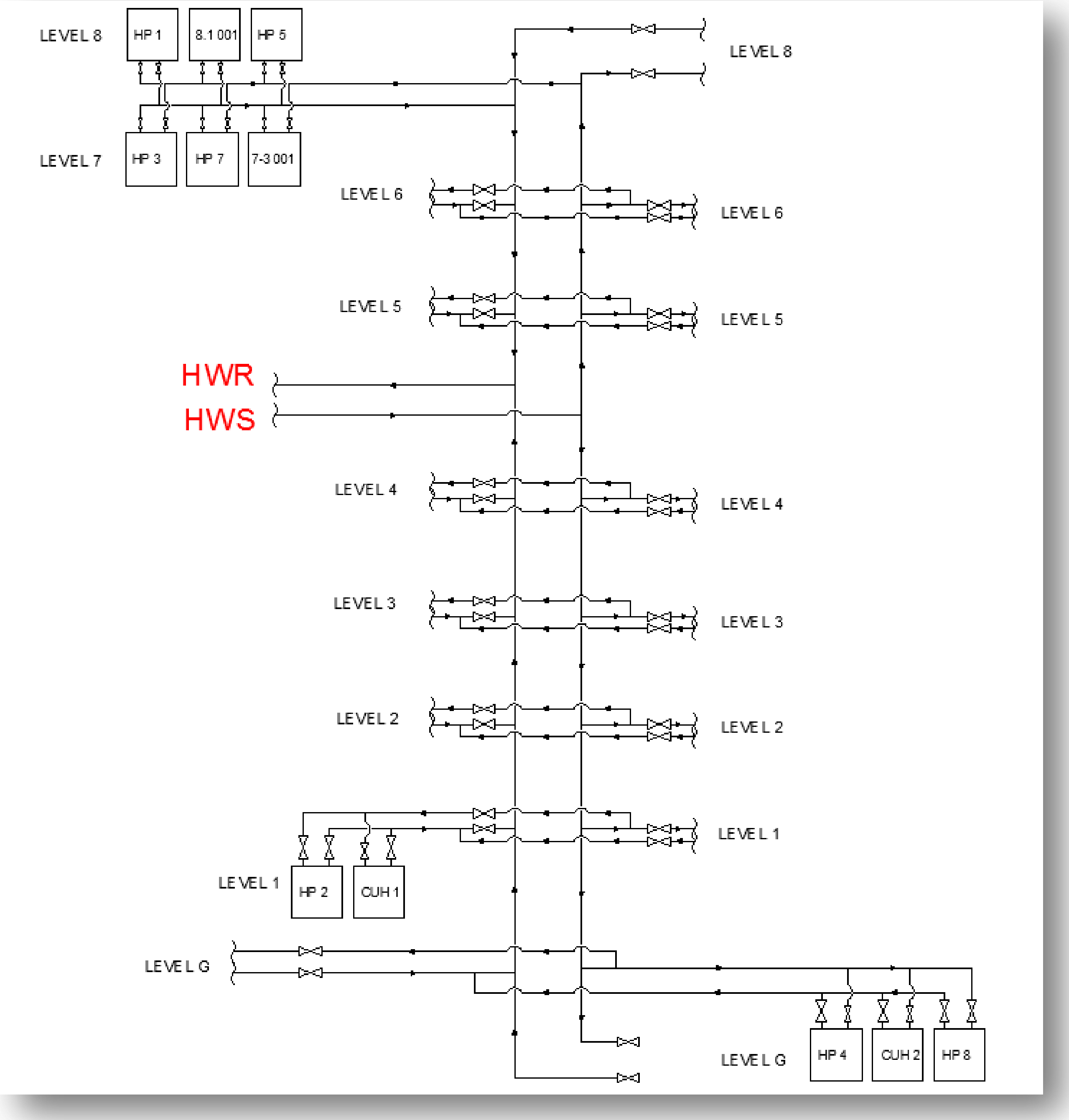


Figure 7.6 Hot Water Schematic

Steam Side Schematic

Figures 7.7 and 7.8 both show the steam schematic for the hospital. Figure 7.7 shows the four steam boilers. They provide both high pressure steam and low pressure steam. The high pressure steam is used for sterilizers located in specific rooms. The low pressure steam is used for the AHU's as well as washing equipment and kettles. This can be seen in Figure 7.8

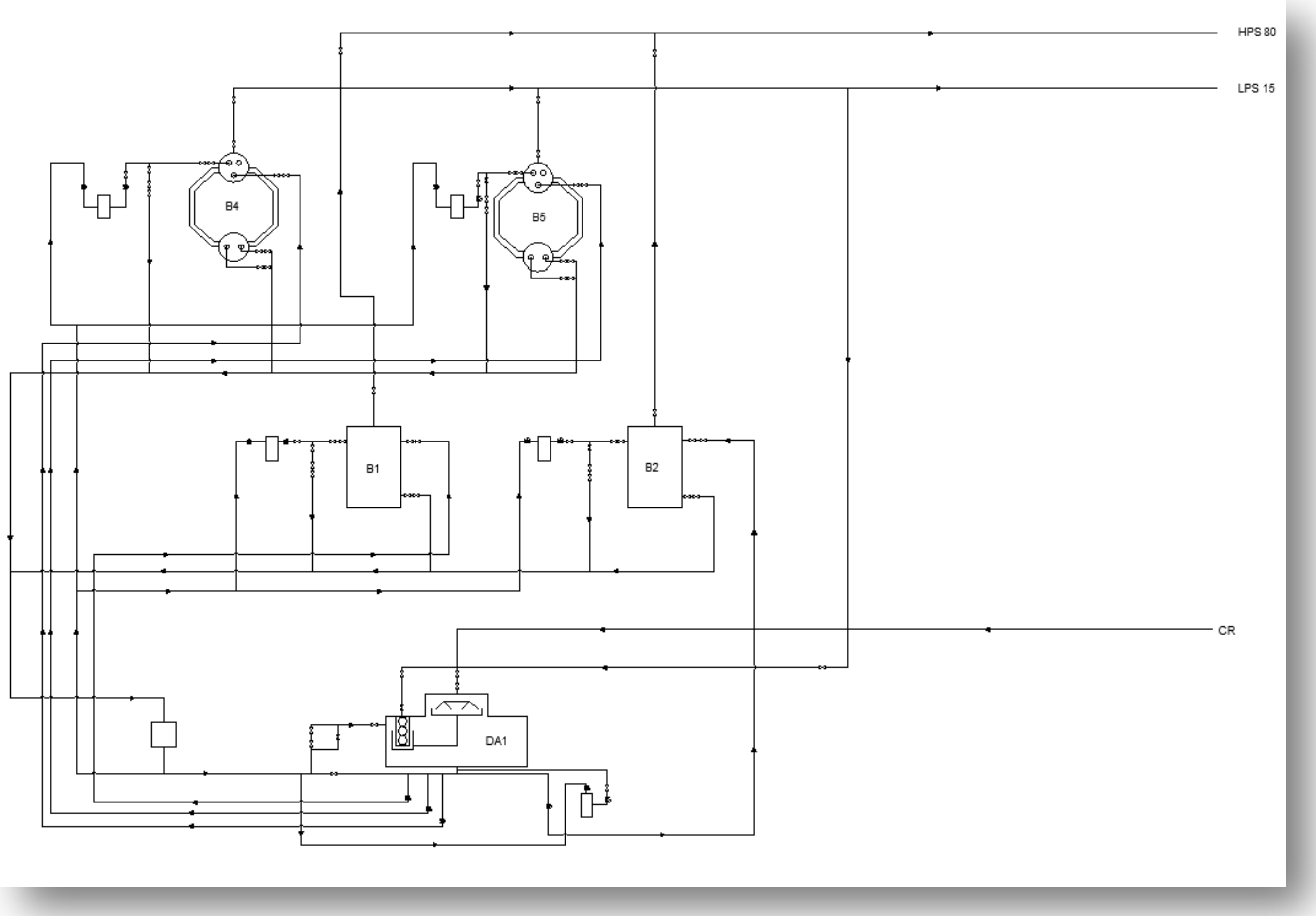


Figure 7.7 Steam Schematic

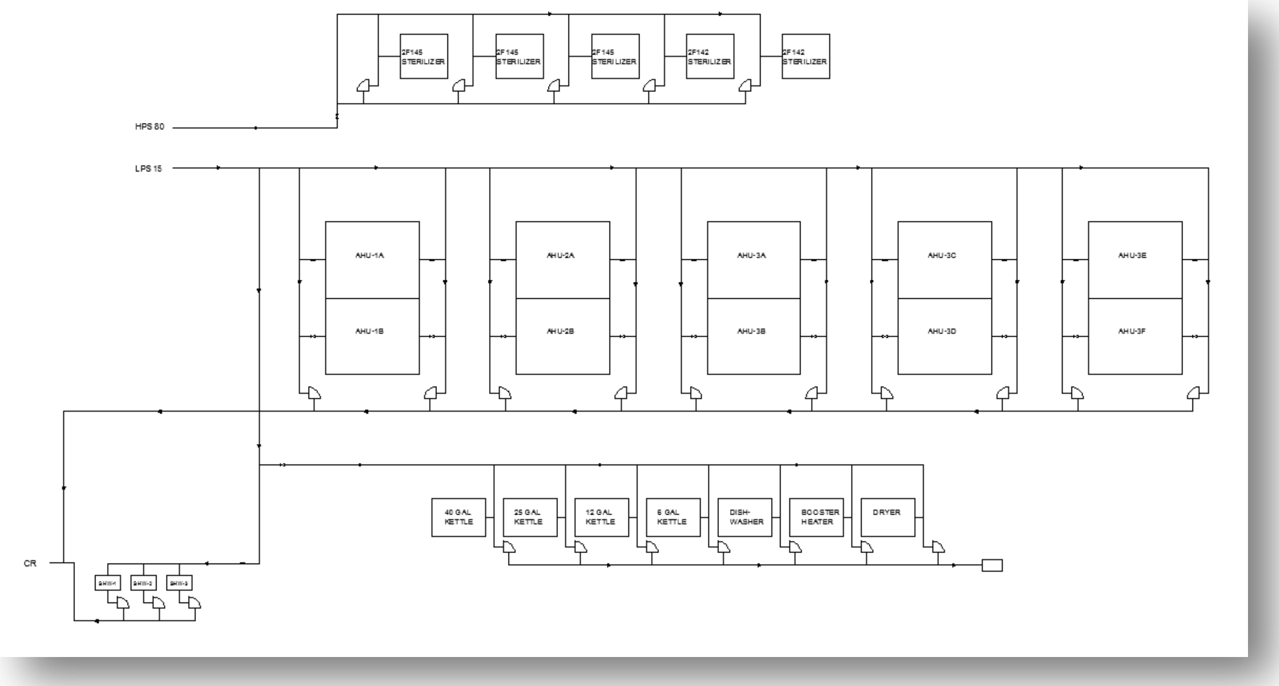


Figure 7.8 Steam Schematic

Final Evaluation

The overall design criterion for the mechanical system in the Virtua West Jersey Replacement Hospital was to create an energy efficient design with exceptional indoor air quality. The mechanical system has to serve two main occupancies. It includes serving office spaces, as well as operating and medical rooms. For obvious reasons the indoor air quality is significantly different for these two spaces. The mechanical system accomplishes this by using three sets of AHU's to serve the individual spaces. The mechanical system mainly uses four steam boilers and three chillers.

Overall I think the system is well designed and is efficient. While this system followed IMC 2003 and AIA 2001, it did comply with ASHRAE Standards 62.1-2004 and 90.1-2004.Tech 1 dealt with the systems indoor air quality. This report showed that the indoor air quality for the building is better than average. The system uses high MERV filters to establish a high indoor air quality. Many of the spaces also have a high outdoor air fraction. Many offices for example are over 50% outdoor air at max supply air.

While the high outdoor air fraction is an absolute necessity for many of these spaces, there are zones that have significantly more outdoor air than required. It seems a waste of energy to have many of the offices to have nearly 100% outdoor air. Since the building is not yet operational, energy costs are not known. According to my Tech Report 2 analysis, the operational cost of the hospital is $2,996,172. While this number is going to be large anyway due to the size and type of building under analysis, I feel it could be less since spaces are over conditioned. There could be an intended reason for this that is not known. For example, a higher outdoor air fraction may have been desired to make the spaces seem more comfortable.

The overall construction cost of the mechanical system was not made available. However, it is a standard VAV system. It will cost more than a standard VAV due to the larger size of the components. The building is very large so the cost of materials and labor will also be greater than a standard hospital.

While the building was not going after any LEED certification, an energy efficient design was desired to help reduce the large operational cost for the hospital. This was done mainly through using energy efficient equipment. All of the boilers and the chillers all have a higher efficiency than required by ASHRAE, and are also above standard equipment efficiencies in general.

The system was also designed to be easily maintained. All of the mechanical equipment is kept in a central utility plant. This plant is quite large and has a lot of space between all the various pieces of equipment. The main piping and ductwork is also exposed in the plant to make for easy maintenance. The AHU's are located in the main spine connecting the patient tower and the ancillary building. The AHU's are stored over 2 levels, making it easy to access them from both the top and the bottom.

Overall the mechanical system for the Virtua Hospital was well designed. Energy efficient equipment was used to help reduce costs, and LEED points could have been obtained if they were to apply for LEED status. While there could be additional energy savings by reducing the outdoor air fraction in spaces such as offices, the rest of the spaces seem to be properly designed in terms of indoor air quality.

Proposed Alternative Systems

Geothermal Heat Pump

One of the major ways I believe energy can be saved for the Virtua West Jersey Replacement Hospital is to incorporate a Geothermal Heat Pump system with the current system to provide renewable energy. This could potentially greatly reduce the cost energy for the hospital. Before tackling this option it is important to see if it is a viable idea for both the location and type of building.

Geothermal plants are being built across the United States, however, they are mainly on the West Coast due to the temperature of the ground being significantly warmer there. The development of new types of power plants, and improvements in drilling and extraction technology have made geothermal heat pumps a viable option in around 80% of the country. Today there are currently 77 geothermal power plants that can produce up to 25 MW. This number shows that geothermal energy is on the rise, and is capable of supporting a large building with high energy demand.

There are four types of geothermal heat pumps currently being used today. The Flash Power Plant uses geothermal heated water under pressure that is separated in a surface vessel into steam and hot water. The steam is then delivered to a turbine, which powers a generator. The water is then injected back into the reservoir in the ground. Figure 9.1 shows how this system works.

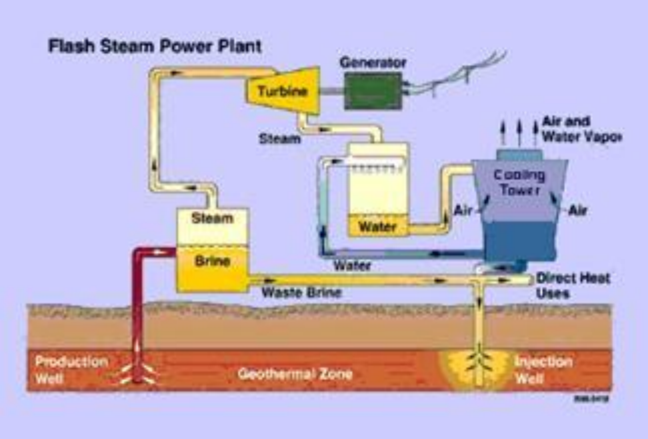


Figure 9.1 Flash Power Plant

The second type of system is a Dry Steam Power Plant. This system, shown in Figure 9.2, uses steam produced directly from the geothermal reservoir to run the turbine that powers the generator. No separation is necessary because the wells only produce steam.

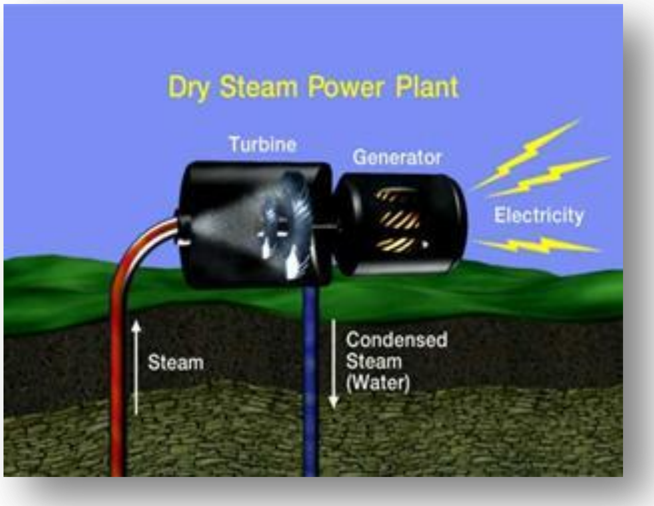


Figure 9.2 Dry Steam Power Plant

The third type of geothermal system is a Binary Power Plant. This type of plant allows for geothermal use for resources with a lower temperature. These plants use a Rankin Cycle system where the geothermal water heats another liquid, for example isobutene or pentaflouropropane, which boils at a lower temperature than the water. The two liquids are kept separate from each other through the use of a heat exchanger, which transfers the heat energy from the geothermal water to the liquid. Using the force of the expanding vapor, similar to steam, the turbine turns to produce electricity. Figure 9.3 shows an example of a Binary Power Plant.

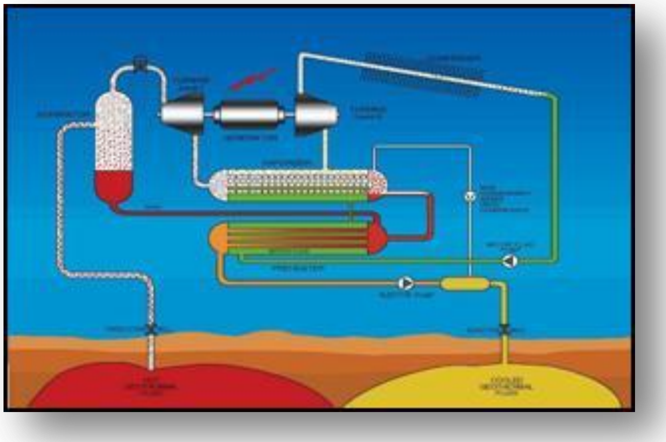


Figure 9.3 Binary Power Plant

The final type of system is a Flash/Binary Combined Cycle. This type of plant uses a combination of the binary and flash technology. A portion of the geothermal water which turns to steam under reduced pressure is first converted to electricity with a backpressure steam turbine. The low pressure steam exiting the backpressure turbine is condensed in a binary system. Figure 9.4 shows a schematic for a flash/binary combined cycle.

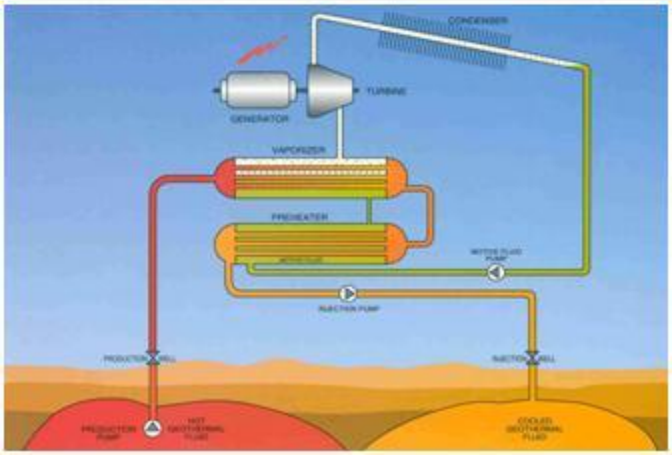


Figure 9.4 Flash/Binary Combined Cycle

In addition to the four types of geothermal plants, there are two main types of wells to use. The first, shown in Figure 9.5, is a two well system. This works by fracturing the rock to improve flow from the ground. Fluid can flow through the interconnected fractures, allowing heat extraction.

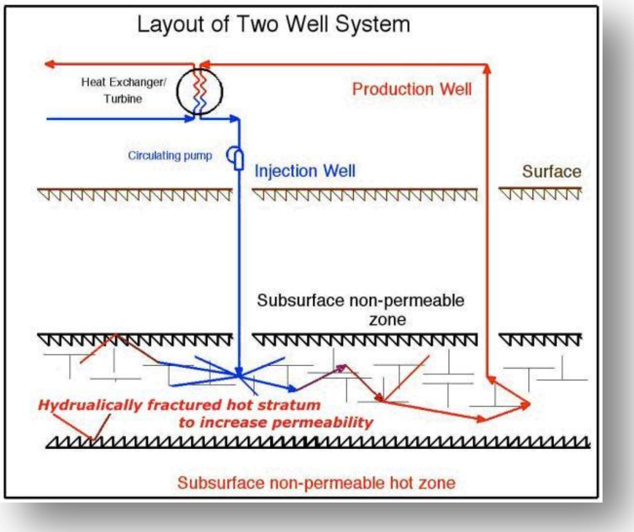


Figure 9.5 Two Well System

The problem with this type of well system is that fracturing can cause the ground to be unstable. In addition to this maintenance costs are escalated due to the contaminants and minerals in the fluid. This is because over time they will corrode the pipes that the fluid is pumped through.

The second type of model is a one well system shown in Figure 9.6. In this model the heat extraction is independent of the heat reservoirs fluid content. A high pressure fluid is sealed from all direct contact with the ground. The fluid would acquire heat by conduction from the hot rock below. This fluid could then turn to steam powering a turbine located above. The cooler water then is pumped back to the subterranean rock to be reheated by the rock. This system does not have the disadvantages of the two well system, and is capable of producing a large amount of megawatts.

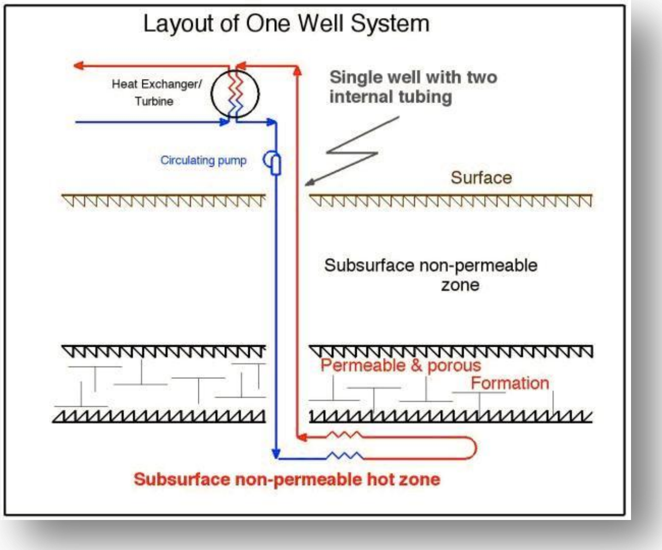


Figure 9.6 One Well System

While geothermal power requires no fuel, the capital cost can be very high. Drilling can potentially account for over half of the cost, and the further the drilling the more expensive it is. For example, a 4.5 MW well in Nevada cost $10 million to drill alone. While the Virtua Hospital will most likely not be able to reproduce this amount of energy due to its location, it shows that first cost is a significant factor in the decision whether to incorporate the system. Overall systems tend to cost above $4 million per MW, which is around $1150 to $3000 per kW. Costs can greatly vary depending on the site. The usual lifetime of a plant is also around 30-45 years.

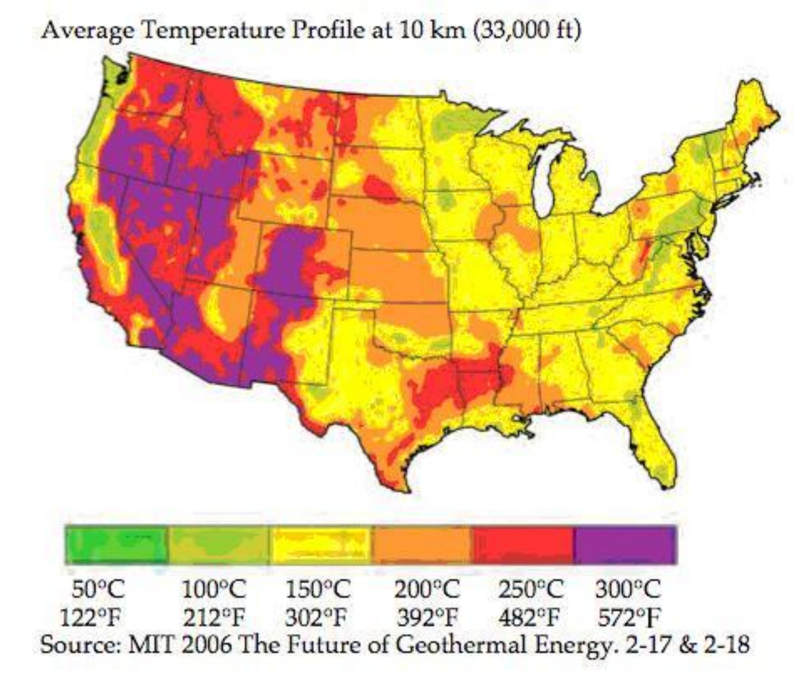
While the first cost of building a geothermal plant can be high, the operating costs compared to that of other plants is fairly low. A geothermal plant cost around $.04/kWh to operate and maintain. A hydropower plant cost around $.07/kWh, while a nuclear plant can cost up to $1.9/kWh. As Figure 9.7 shows, geothermal energy also has a high capacity factor compared to other renewable sources. The capacity factor is the total energy produced/energy produced at full capacity. In addition, geothermal heat pumps are reliable, and do not depend on the weather like many other renewable sources. Since the wells are all underground, the land usage is minimal as well.

Renewable Energy Sources	**Capacity Factor (%)**	**Reliability of Supply**	**Environmental Impact**	**Main Application**
Geothermal	85-95	Continuous & reliable	Minimal land usage	Electricity generation
Bio-mass	83	Reliable	Minimal (non-combustible material handling)	Transportation, heating
Hydro	30-35	Intermittent dependent on weather	Impacts due to dam construction	Electricity generation
Wind	25-40	Intermittent dependent on weather	Unsightly for large-scale generation	Electricity generation (limited)
Solar	24-33	Intermittent dependent on weather	Unsightly for large-scale generation	Electricity generation (limited)

Figure 9.7 Renewable Energy Summary

Figure 9.8 shows a distribution of ground temperatures throughout the United States. While the depth in this figure is 33,000 ft, it shows that the temperatures are consistent through New Jersey, and that digging deeper is an option to increase the heat gain from the rock.

One key advantage to the Virtua West Jersey Hospital is the large site that it sits on. The 120 acre site provides a substantial amount of room for geothermal wells to be placed. Figure 9.9 shows a site plan for the building. The hospital is shaded orange, and it is important to note the vast expanse of parking lots located behind the building. This could be a potential site to place the wells, due to the close proximity of parking lot to the central utility plant located behind the hospital. This is important because not only is the majority of the mechanical equipment stored here, but because there is a significant amount of empty space in the plant. This is because space was created in case future expansion was needed, and additional space may be needed in the future. However, the current empty space could house all of the equipment needed for the geothermal wells. This includes the pumps, heat exchangers, and potentially a steam turbine.



Source: MIT 2006 The Future of Geothermal Energy. 2-17 & 2-18

Figure 9.8 Ground Temperature Profile

Figure 9.9 Virtua West Jersey Replacement Hospital Site Plan

Airflow Redesign

Another area for a potential to save energy is to redesign the outdoor airflow requirements done in the Tech 1 report to comply with ASHRAE St 62.1-2004. When the building was designed, IMC 2003 and AIA 2001 were used to determine OA rates. However, when studying the design outdoor air rates, it was clear that the design rates were significantly larger than that required. Many spaces in the building seem to have been over ventilated. Certain spaces do have a very high outdoor air fraction, such as operating rooms and various other medical rooms. However, there are many other office and patient areas that have an extremely high outdoor air rate.

Many of the offices in the hospital are 100% outdoor air. For example, of the 82 offices located on AHU Set 1 and AHU Set 2, 65 of the offices are 100% outdoor air. This number does not include AHU Set 3, which also has a significant amount of offices on it. Many other spaces throughout the building also have high outdoor air rates, which fall under the office criteria for ASHRAE St 62.1. I feel there could be energy savings if the air rates were redesigned under the ASHRAE St 62.1-2004.

Ground Source Heat Pump (Mechanical Depth)

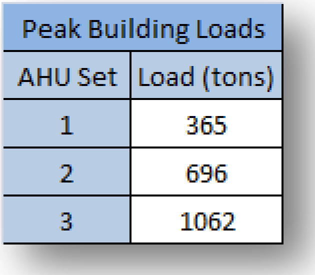
Based on the above research I decided to utilize a one well vertical closed loop system. This is because of the large size of the system, and the water will not be contaminated. The wells will be connected to heat pumps, which will provide chilled water to the air handling units. This is due to the large cooling loads on the buildings, as well as the high cost of electricity for the hospital.

The design process for the Geothermal Heat Pump went as followed:

1. Calculate building loads
2. Select Heat Pumps based on capacity and efficiency
3. Determine ground properties
4. Specify ground properties
5. Specify Tube Size, bore separation, and backfill
6. Calculate required bores
7. Central Loop vs. Multiple Loops
8. Route and Size piping for low pressure losses
9. Select Pumps
10. Weigh pump control options

This design process was the order in which the geothermal system was designed for the hospital. It will also be the order that the work is presented in this report.

The peak building loads were taken for all three AHU sets. These values will be needed to determine the capacity of the heat pumps, as well as the total length needed for the boreholes. Table 10.1 show the peak loads for the three AHUs. AHU 3 is to be designed for half its peak load as shown in the table. The true peak load for AHU 3 is 2124 tons.



Peak Building Loads	
AHU Set	Load (tons)
1	365
2	696
3	1062

Table 10.1 Peak Cooling Loads

The ground source heat pump will be sized for the cooling loads because they are larger than the heating loads. Due to the large loads, a single heat pump cannot be used for each system. The heat pumps being used will be Water to Water Heat Pumps from Commercial Aire Products. The heat pumps provided range from 50 tons to 193 tons. These heat pumps were chosen due to their large capacity. The heat pumps will require 70°F from the ground source to produce 54°F chilled water. For heating the heat pumps will require 50°F from the ground source for 120°F to produce 120° of hot water supply.

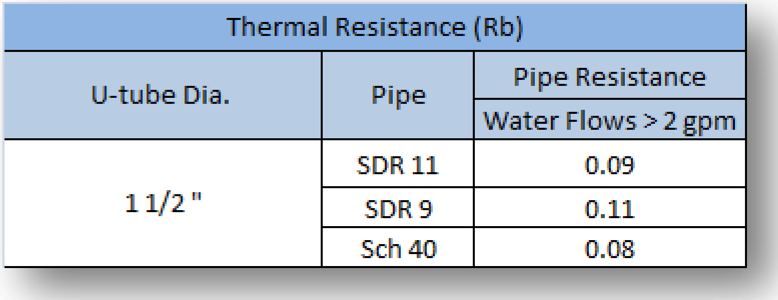
Research on heat pumps has shown multiple companies that do make custom heat pumps, and have designed heat pumps in excess of 500 tons. However, these are custom made, and the specs and pricing information are not available. For the purposes of this report, these custom heat pumps were not used. This is a viable option, however, as they can be made to the specifications of the building.

Borehole Properties

The first step in designing an efficient heat pump system is to determine the borehole properties. This includes the ground properties, as well as the pipe and backfill properties. The overall goal in this step was to minimize the resistance values to help keep the borehole length and numbers to a minimum. Before calculations were even performed, it was known based on comparing loads to other buildings, that this particular system would very large. The design equations for the ground heat pump sizing equations will require four terms for the thermal resistance per unit length of bore.

The first required R value will be that of the borehole. This value will be referred to as R_b. This value can be minimized in two ways, the material of the pipe being used, as well as the construction of the borehole backfill. The pipe material being used will be Schedule 40 pipe. The reason for this is the low thermal resistance, and the capacity that the pipes can hold. The resistance of the pipe will be determined not only by its material properties, but also on the fluid that flowing through it, the flow rate, and the pipe diameter.

The size of pipe being used will be 1 ½ "diameter pipe for each borehole. The design flow rate will be 3 gpm through each borehole. This number was determined due to the lowest flow rate that is required to avoid laminar flow through the pipe. It was also selected to be the lowest possible to ensure the lowest possible pump power, to save energy.



Thermal Resistance (Rb)		
U-tube Dia.	Pipe	Pipe Resistance
		Water Flows > 2 gpm
1 1/2 "	SDR 11	0.09
	SDR 9	0.11
	Sch 40	0.08

Table 10.2 Pipe Thermal Resistance

Table 10.2 shows the thermal resistance for various types of pipes. This is a small portion of a larger table located in the "Ground Source Heat Pumps" from AHSRAE. The resistance will be 0.08h·ft·°F/BTU. Since these resistances were calculated using natural backfills with the same properties as the surrounding soil, resistance adjustments must be made to account for other backfill materials. The resistance for the backfills will be added to the resistance of the pipe. It is important to note that if the conductivity of the backfill is higher than the overall resistance will subtract from the pipe. The backfill resistance is based on the borehole size, pipe size, and the type of material. The borehole itself will have a 6" diameter, due to the pipe size being used and it will decrease the overall thermal resistance. This value is selected from Table 3.2 in the "Ground Source Heat Pumps" design book from ASHRAE. The value is determined to be - .03h·ft·°F/BTU. This makes the total R_b = .08 - .03 = .05 h·ft·°F/BTU.

The first 20 ft at the top of each borehole will be filled with concrete in order to ensure no contamination from surface water will penetrate the boreholes.

The design of the three following resistances is a bit more complicated. The remaining resistances are the effective thermal resistance of the ground annually (R_{ga}), the effective thermal resistance of the ground daily (R_{gd}), and the effective thermal resistance of the ground monthly (R_{gm}). All three of these resistances are calculated using time (τ), the Fourier number (F_o), and the G factor (G).

The following equations are applied:

$F_o = (4\alpha_g\tau)/d^2$

$R_{ga} = (G_f - G_1)/k_g$ $R_{gm} = (G_1\text{-}G_2)/kg$ $R_{gd} = G_2/k_g$

The three time pulses are calculated for a 10 year period (3650 days), a monthly period (30 days), and a six hour period (.25 days). The three times are defined as:

$\tau_1 = 3650$ $\tau_2 = 3650 + 30 = 3680$ $\tau_f = 3650 + 30 + .25 = 3680.25$

The three Fourier numbers are then calculated:

$F_{of}= 212037$ $F_{o1} = 1797$ $F_{o2} = 12$

Using Figure 1.1 the following G factors are selected:

$G_f= 1.05$ $G_1= 0.65$ $G_2 = 0.25$

The ground is assumed to be a sand/clay mixture with a thermal conductivity (K_g) of 1.42 BTU/h·ft·°F. The diffusivity is also determined based on the ground properties, with a value of .9ft^2/day.

Using the calculated values above the following resistances were calculated:

R_{ga} = .282 h·ft·°F/BTU R_{gm} = .282 h·ft·°F/BTU R_{gd} = .176 h·ft·°F/BTU

Figure 10.1 shows a layout of a borehole, as well as the types of soil surrounding it. The image is not to scale.

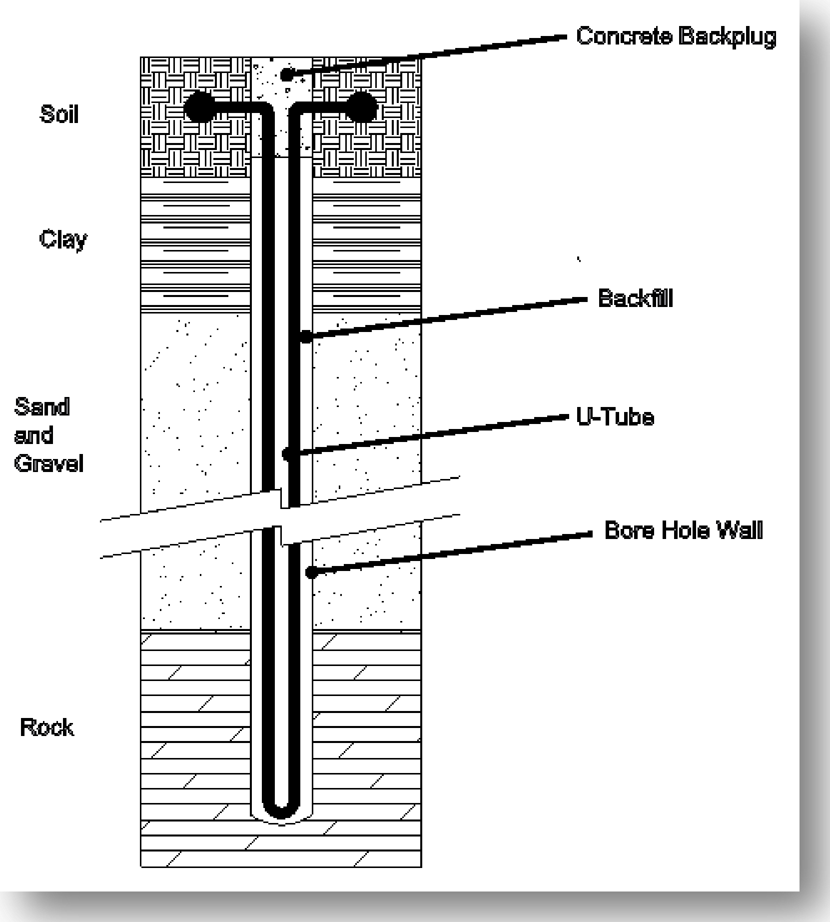


Figure 10.1 Typical Borehole

Bore length Calculation

The next step is to determine the total required length for the boreholes. This is done by using a basic equation, which takes into account the building load, ground properties, and pipe properties. It is essentially a steady state heat transfer equation that represents the variable heat rate of a ground source heat pump by using heat rates in series. The following equation is what was used to calculate the required length:

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

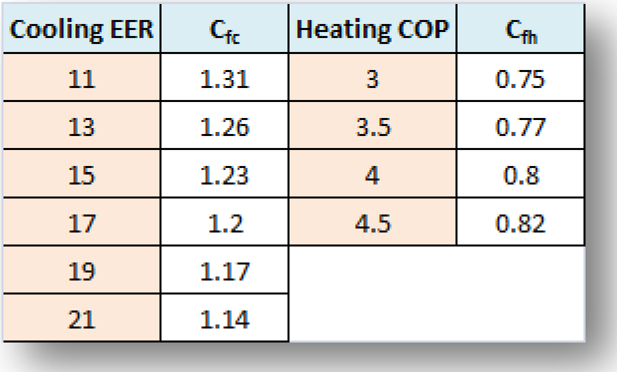
L_c =required bore length (ft)
q_a =net annual average heat transfer to ground (BTU/hr)
C_{fc} = correction factor, cooling
q_{lc} = building design cooling load (Btu/hr)
R_b = thermal resistance of bore (h·ft·°F/BTU)
PLF_m = part load factor during design month
R_{gm} = effective thermal resistance of the ground monthly (h·ft·°F/BTU)
R_{gd} = effective thermal resistance of the ground daily (h·ft·°F/BTU)
R_{ga} = effective thermal resistance of the ground annual (h·ft·°F/BTU)
F_{sc} = short circuit heat loss factor
$\mathrm{t_g}$ = temperature of ground (°F)
$\mathrm{t_{wi}}$ = temperature water in (heat pump) (°F)
$\mathrm{t_{wo}}$ = temperature water out (heat pump) (°F)
$\mathrm{t_p}$ = temperature penalty for adjacent bores (°F)

All four resistances were calculated in the previous sections. To calculate the net annual average heat transfer to the ground (q_a), the following equation is used:

$$q_a = \frac{C_{fc}\ x\ q_{lc}\ x\ EFL\ Hours_c + C_{fh}\ x\ q_{lh}\ x\ EFL\ Hours_h}{8760\ hours}$$

C_{fh} = correction factor, heating
EFL Hours = Effective part load hours, cooling and heating (hrs)
q_{lh} = building design heating load (Btu/hr)

Data from the heat pumps is required in order to determine the correction factors for both heating and cooling (C_{fc}, C_{fh}). Table 10.3 shows the corresponding correction factors based on the heat pump cooling EER and heat COP. The EER and COP for the Heat pumps are 20 and 4, respectively. This leads to a C_{fc} of 1.14 and a C_{fh} of 0.8.



Cooling EER	C_{fc}	Heating COP	C_{fh}
11	1.31	3	0.75
13	1.26	3.5	0.77
15	1.23	4	0.8
17	1.2	4.5	0.82
19	1.17		
21	1.14		

Table 10.3 Correction Factors

The building design cooling load (q_{lc}) is the building peak load, which is shown in Table 1.1. The required bore length was calculated for each AHU. The part load factor (PLF_m) is determined using the following equation:

$$PLF_m = \frac{\sum Load\ \ x\ Hours}{Peak\ Load\ x\ 24}\ x\ \frac{days\ occupied\ per\ month}{Days\ per\ month}$$

The part load factor is determined by summing the peak load over a 4 hour period. This is then multiplied by the 4 hours. The days occupied per month over the days per month will be 1, since the hospital will be occupied at all hours of the day.

The last step to determining the final length is to figure out the relevant temperatures. The first temperature to determine is the ground temperature (t_g). This is determined by using Figure 10.2. The value chosen was 56 °F.

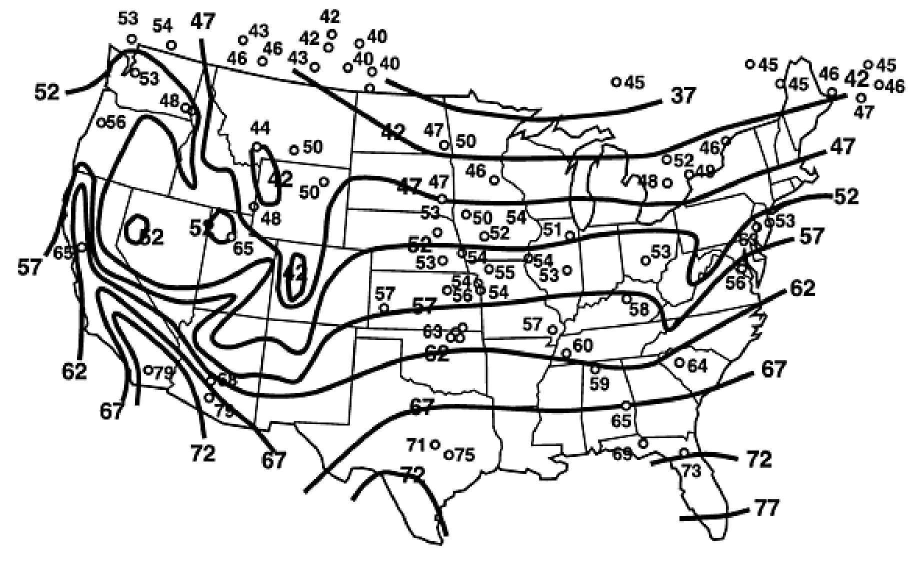


Figure 10.2 Ground Temperatures

The entering and leaving water temperatures are specified by the heat pumps being used. In this case, the t_{wi} = 70 °F and the t_{wo} = 54 °F. The temperature penalty for adjacent bores (t_p) is assumed to be 3 °F. This value accounts for the change in ground temperature over time due to the heat rejected into the soil by the ground source system. It is based on the distance between boreholes. The closer the boreholes are together, the higher the t_p, which is not desirable. This means that the rejected heat from one borehole is affecting the adjacent borehole. To avoid this, boreholes should be placed 20 -25 ft away from each other. The boreholes in this design will have a 20 ft spacing to avoid any interference. Figure 10.3 reflects this idea.

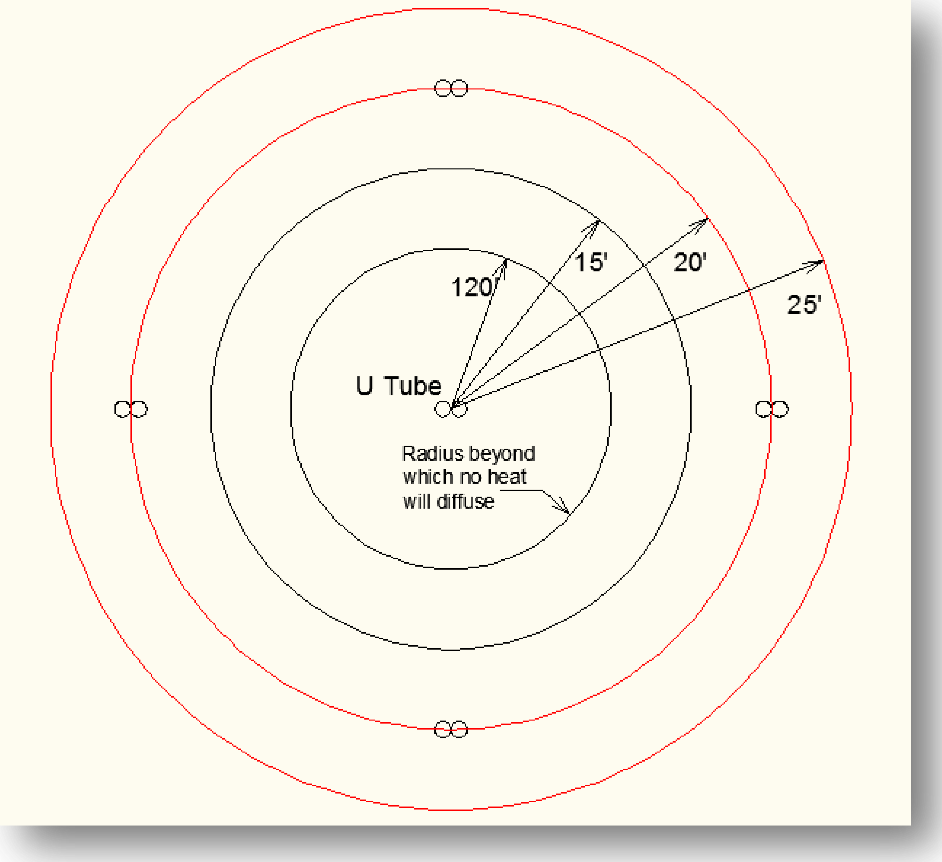
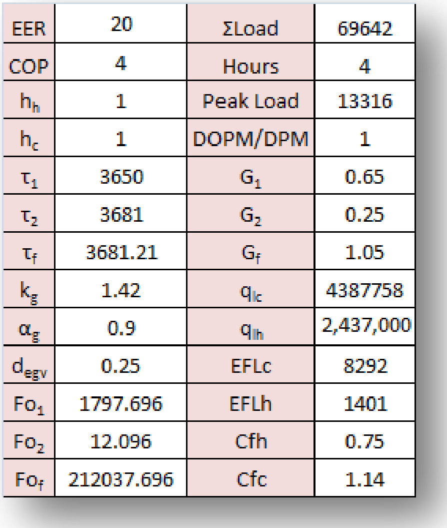
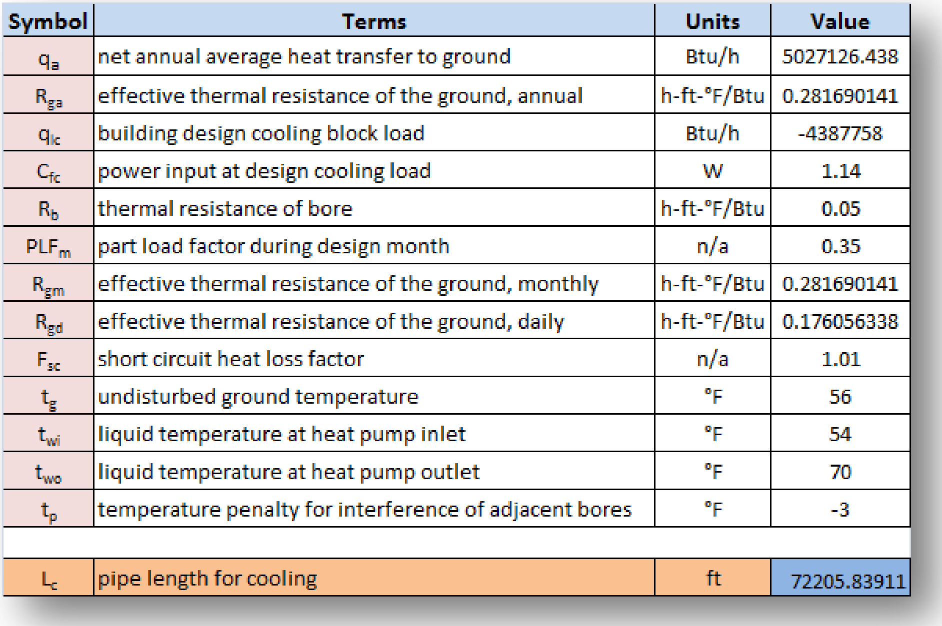


Figure 10.3 Spacing for boreholes

The values for the previous equations are shown in the tables below, as well as the total required borehole length. Table 10.4 shows the values for AHU 1, Table 10.5 shows the values for AHU 2, and Table 10.6 shows the values for AHU 3.

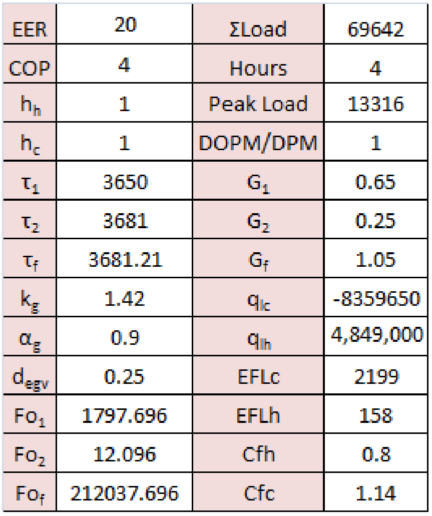


EER	20	ΣLoad	69642
COP	4	Hours	4
h_h	1	Peak Load	13316
h_c	1	DOPM/DPM	1
τ_1	3650	G_1	0.65
τ_2	3681	G_2	0.25
τ_f	3681.21	G_f	1.05
k_g	1.42	q_{lc}	4387758
α_g	0.9	q_{lh}	2,437,000
d_{egv}	0.25	EFLc	8292
Fo_1	1797.696	EFLh	1401
Fo_2	12.096	Cfh	0.75
Fo_f	212037.696	Cfc	1.14

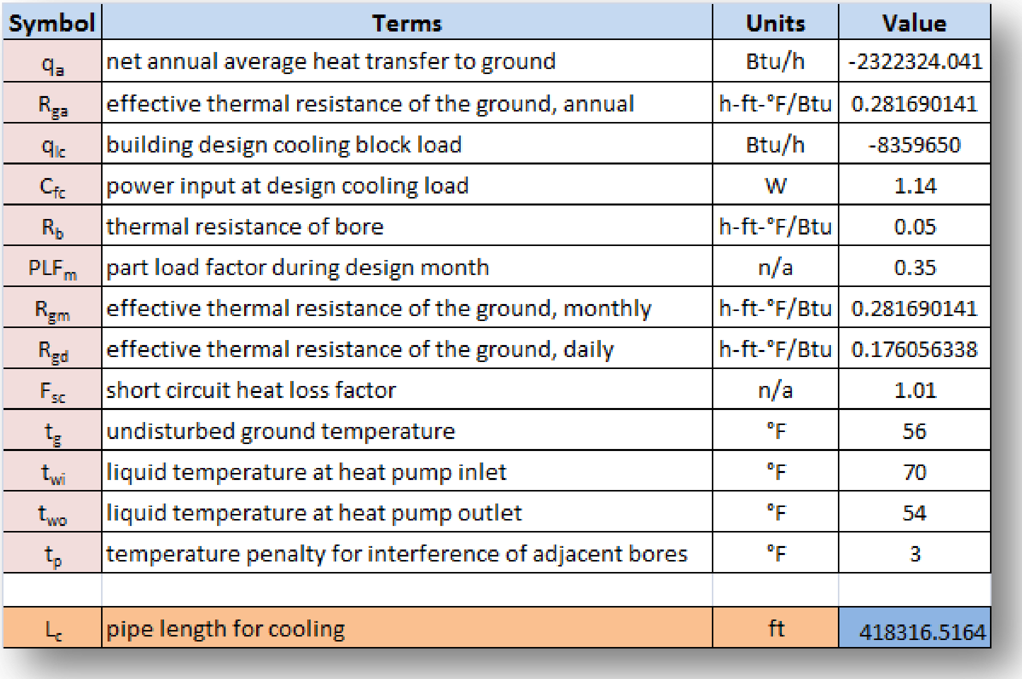


Symbol	Terms	Units	Value
q_a	net annual average heat transfer to ground	Btu/h	5027126.438
R_{ga}	effective thermal resistance of the ground, annual	h-ft-°F/Btu	0.281690141
q_{lc}	building design cooling block load	Btu/h	-4387758
C_{fc}	power input at design cooling load	W	1.14
R_b	thermal resistance of bore	h-ft-°F/Btu	0.05
PLF_m	part load factor during design month	n/a	0.35
R_{gm}	effective thermal resistance of the ground, monthly	h-ft-°F/Btu	0.281690141
R_{gd}	effective thermal resistance of the ground, daily	h-ft-°F/Btu	0.176056338
F_{sc}	short circuit heat loss factor	n/a	1.01
t_g	undisturbed ground temperature	°F	56
t_{wi}	liquid temperature at heat pump inlet	°F	54
t_{wo}	liquid temperature at heat pump outlet	°F	70
t_p	temperature penalty for interference of adjacent bores	°F	-3
L_c	pipe length for cooling	ft	72205.83911

Table 10.4 AHU 1 Required Length

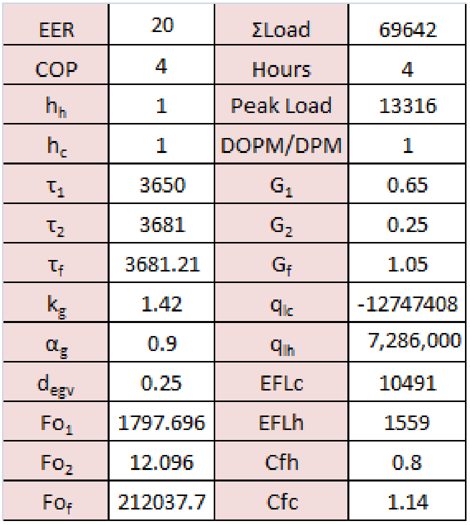


EER	20	ΣLoad	69642
COP	4	Hours	4
h_h	1	Peak Load	13316
h_c	1	DOPM/DPM	1
τ_1	3650	G_1	0.65
τ_2	3681	G_2	0.25
τ_f	3681.21	G_f	1.05
k_g	1.42	q_{lc}	-8359650
α_g	0.9	q_{lh}	4,849,000
d_{egv}	0.25	EFLc	2199
Fo_1	1797.696	EFLh	158
Fo_2	12.096	Cfh	0.8
Fo_f	212037.696	Cfc	1.14

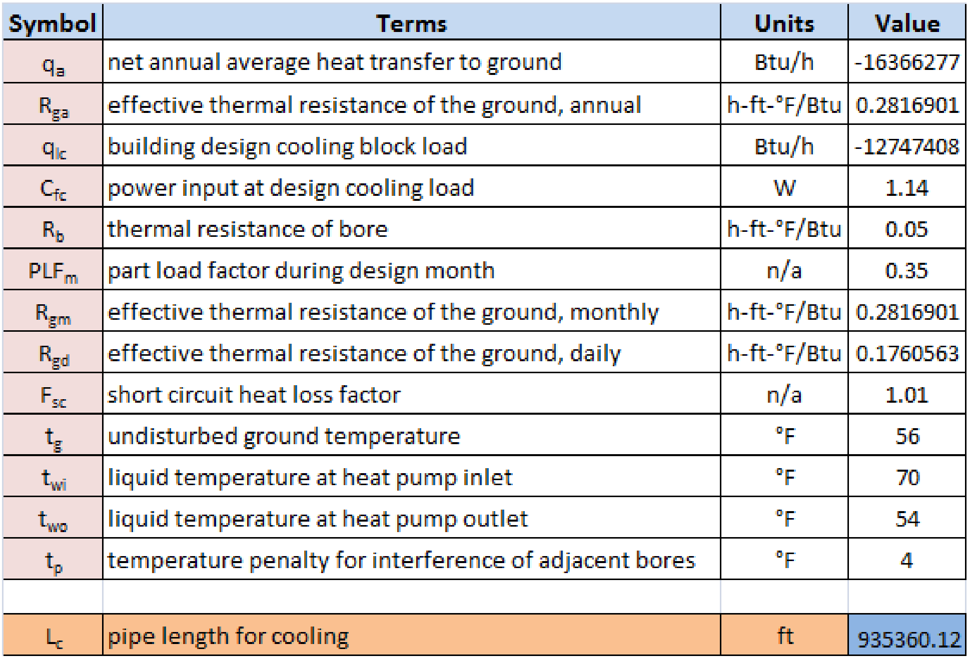


Symbol	Terms	Units	Value
q_a	net annual average heat transfer to ground	Btu/h	-2322324.041
R_{ga}	effective thermal resistance of the ground, annual	h-ft-°F/Btu	0.281690141
q_{lc}	building design cooling block load	Btu/h	-8359650
C_{fc}	power input at design cooling load	W	1.14
R_b	thermal resistance of bore	h-ft-°F/Btu	0.05
PLF_m	part load factor during design month	n/a	0.35
R_{gm}	effective thermal resistance of the ground, monthly	h-ft-°F/Btu	0.281690141
R_{gd}	effective thermal resistance of the ground, daily	h-ft-°F/Btu	0.176056338
F_{sc}	short circuit heat loss factor	n/a	1.01
t_g	undisturbed ground temperature	°F	56
t_{wi}	liquid temperature at heat pump inlet	°F	70
t_{wo}	liquid temperature at heat pump outlet	°F	54
t_p	temperature penalty for interference of adjacent bores	°F	3
L_c	pipe length for cooling	ft	418316.5164

Table 10.5 AHU 2 Required Length



EER	20	ΣLoad	69642
COP	4	Hours	4
h_h	1	Peak Load	13316
h_c	1	DOPM/DPM	1
τ_1	3650	G_1	0.65
τ_2	3681	G_2	0.25
τ_f	3681.21	G_f	1.05
k_g	1.42	q_{lc}	-12747408
α_g	0.9	q_{lh}	7,286,000
d_{egv}	0.25	EFLc	10491
Fo_1	1797.696	EFLh	1559
Fo_2	12.096	Cfh	0.8
Fo_f	212037.7	Cfc	1.14



Symbol	Terms	Units	Value
q_a	net annual average heat transfer to ground	Btu/h	-16366277
R_{ga}	effective thermal resistance of the ground, annual	h-ft-°F/Btu	0.2816901
q_{lc}	building design cooling block load	Btu/h	-12747408
C_{fc}	power input at design cooling load	W	1.14
R_b	thermal resistance of bore	h-ft-°F/Btu	0.05
PLF_m	part load factor during design month	n/a	0.35
R_{gm}	effective thermal resistance of the ground, monthly	h-ft-°F/Btu	0.2816901
R_{gd}	effective thermal resistance of the ground, daily	h-ft-°F/Btu	0.1760563
F_{sc}	short circuit heat loss factor	n/a	1.01
t_g	undisturbed ground temperature	°F	56
t_{wi}	liquid temperature at heat pump inlet	°F	70
t_{wo}	liquid temperature at heat pump outlet	°F	54
t_p	temperature penalty for interference of adjacent bores	°F	4
L_c	pipe length for cooling	ft	935360.12

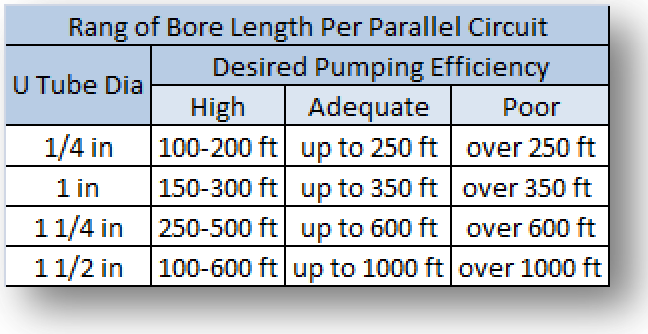
Table 10.6 AHU 3 Required Length

The total length was calculated for the cooling load since this would require a longer length than the heating load. It is important to note that when calculating the cooling required length all values for cooling loads must be entered in as a negative, as well as the t_p. Now that the required lengths are determined, the layout of the system will be designed.

GSHP Layout

Now that the total length is figured out, the depth of the boreholes must be determined to figure out how many holes are needed. Since the lengths required for the AHUs are large, it was decided to not put all the AHUs on one system. 5 Different options will be discussed in this report. These will vary in borehole depth, and the AHU that the GSHP serves. Option 1 will be AHU 1 at a borehole depth of 300 ft. Option 2 will be AHU 1 at a borehole length of 600 ft. Option 3 will be AHU 2 at a borehole length of 600 ft. Option 4 will be AHU 2 at a borehole length of 1000 ft. Option 5 will be half of AHU 3 at a borehole length of 1000 ft.

The borehole lengths were determined based on the typical efficiencies of the system based on length. Table 10.7 shows the efficiencies for various pipe lengths. The borehole lengths were based on these values.



Rang of Bore Length Per Parallel Circuit			
U Tube Dia	Desired Pumping Efficiency		
	High	Adequate	Poor
1/4 in	100-200 ft	up to 250 ft	over 250 ft
1 in	150-300 ft	up to 350 ft	over 350 ft
1 1/4 in	250-500 ft	up to 600 ft	over 600 ft
1 1/2 in	100-600 ft	up to 1000 ft	over 1000 ft

Table 10.7 Desired Efficiencies

The borehole lengths of 600 and 1000 ft were chosen so that the pumping efficiency isn't poor. Another key determining factor was cost. The price of drilling rises exponentially as you get deeper. The initial drilling costs would be very large for any depths greater than 1000 ft. It was for this reason that 1000 ft was the limit. The reason for not going any shorter than 600 ft for the larger AHU 2 and 3 was due to space. The distance of the piping would potentially cause the pumping efficiency to also decrease significantly.

Determining the location of the boreholes was fairly simple. The hospitals central utility plant is located towards the back. Directly behind this is a large open area of land that is large enough to hold each of the 5 options. It is also a critical site because of its short distance to the central utility plant where the heat pumps will be housed. This allows for a much shorter distance and length of pipe, allowing savings in materials and pumping efficiency. Figure 10.4 shows in detail the site plan for the hospital. It is important to take note of the large amount of space behind the hospital.

Figure 1.4 Site Plan

The area marked in blue is the proposed site for the boreholes. The parking lots seen in the image above are currently not in place and are part of potential future expansion. The building is highlighted in orange, and the central utility plant is highlighted in red. As seen in the image they are right beside each other.

Figure 10.5 shows the proposed layout for Option 1. As in all the 5 options, the grid is divided into 3 separate loops. This is done for multiple reasons. The first is for pumping efficiency. Having separate pumps for each loop will reduce the head loss and gpm that the pump will be required to handle. The second reason is for reliability. If the system was only one loop, and a pump should fail the whole system would be unavailable. However, if a pump fails in one loop, there are still two loops running, providing 2/3 of the peak load. The third reason for having 3 loops is because of the number of heat pumps that would have to be tied into one loop. Multiple heat pumps will have to be used for each loop even in the multiple loop system; however, the necessary amount of heat pumps would be too large to place on one loop. Research has indicated that no more than 8 heat pumps should be placed on one loop. This can greatly affect the overall head loss, and thus affect the pumping capabilities of the system. Figure 10.5 shows Option 1, which is AHU 1 at a 300 ft borehole depth. The grid layout is 15 x 16, with a total of 240 boreholes. This gives a total length of 72,000 ft, which is the required length for AHU 1.

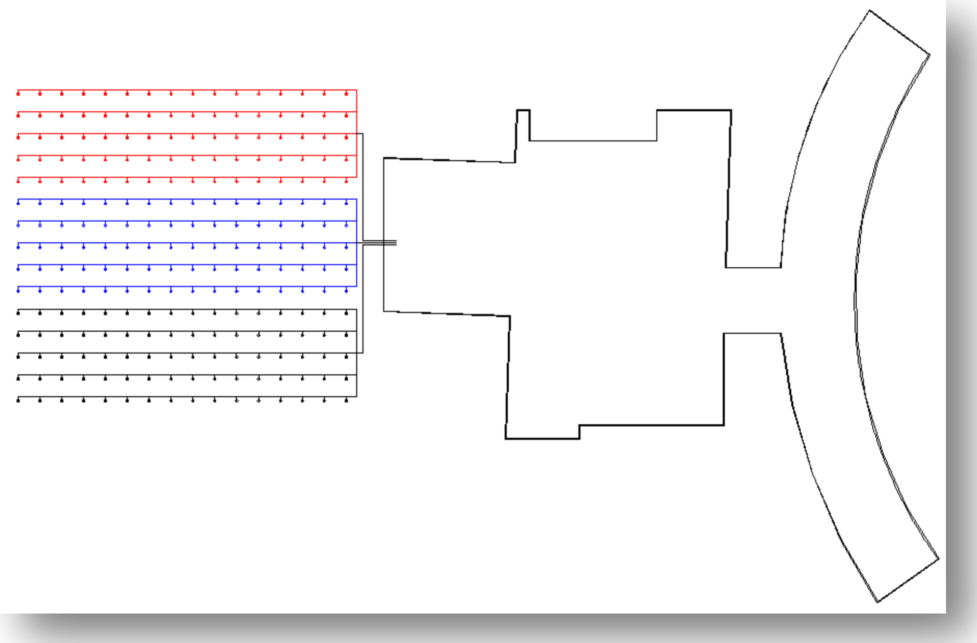


Figure 10.5 AHU 1 300 ft Layout 15 x 16

Figure 10.6 shows Option 2. This is AHU 1 at 600 ft. This option was considered because the increased borehole length will decrease the number of boreholes required. The problem is obviously the increased depth that needs to be drilled.

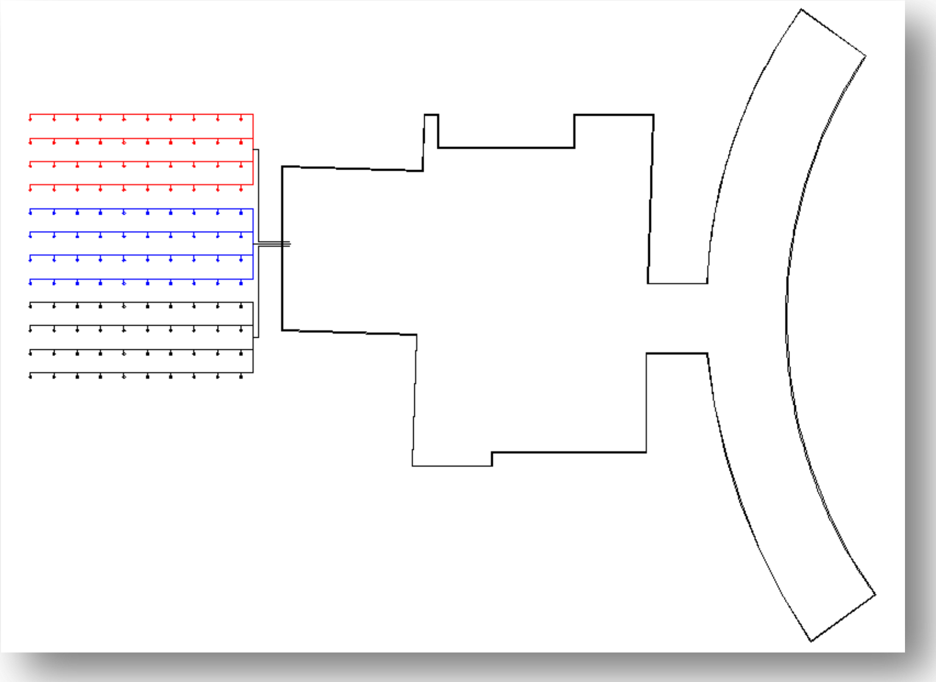


Figure 10.6 AHU 1 600 ft Layout 10 x 12

Option 3 is shown in Figure 10.7. This option contains the boreholes for AHU 2 at a depth of 600 ft. The grid layout is 26 x 27, with a total of 702 boreholes. This equates to 421,000 ft, which is the required length for AHU 2.

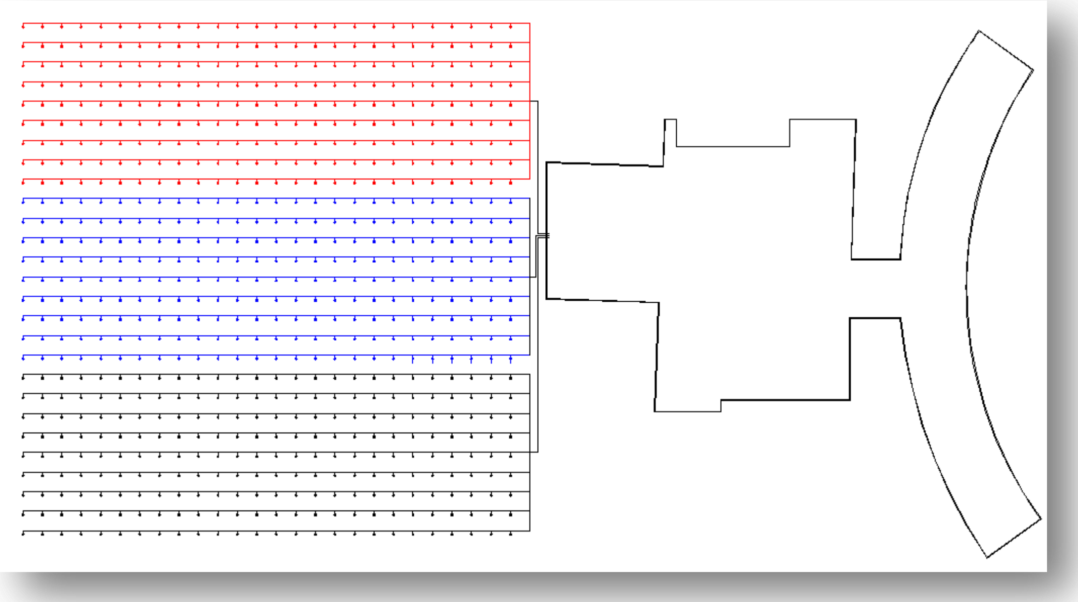


Figure 10.7 AHU 2 600 ft Layout 26 x 27

Figure 10.8 shows Option 4. This is AHU 2 at 1000 ft. The change in depth is made for the same reasons as AHU 1. This has a grid of 19 x 22, with 418 total bores. This is a total length of 418,000.

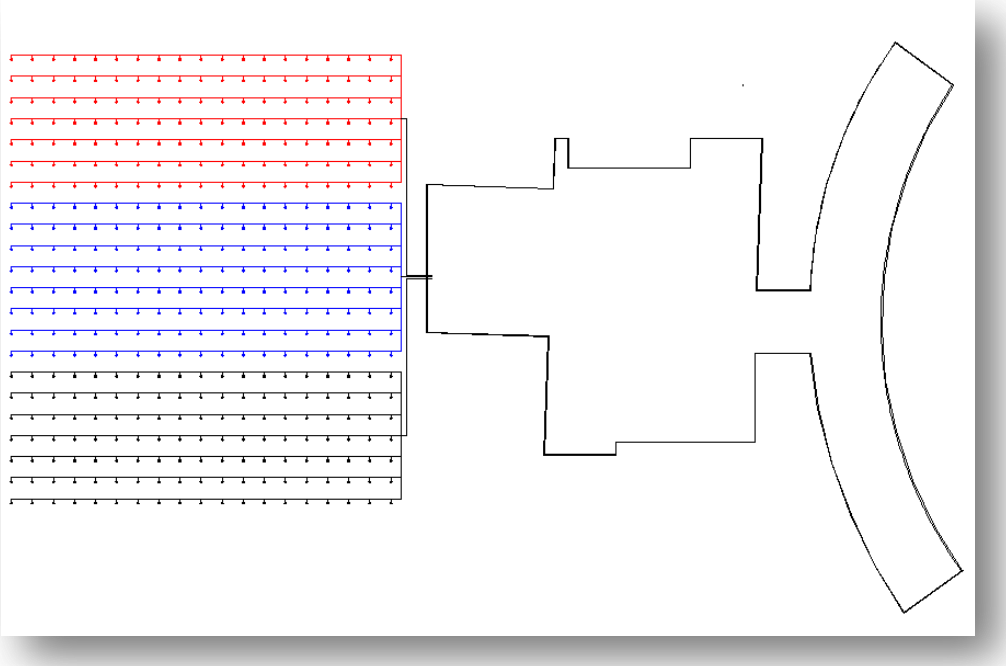


Figure 10.8 AHU 2 1000 ft Layout 19 x 22

The final option shown in Figure 1.10, Option 5, is AHU 3. This is by far the largest of the 3 sets. The borehole length of 1000 ft is necessary due to the space it would require to go any shorter. The grid for AHU 3 is 31 x 30, with a total 930 boreholes. This equates to 930,000 ft.

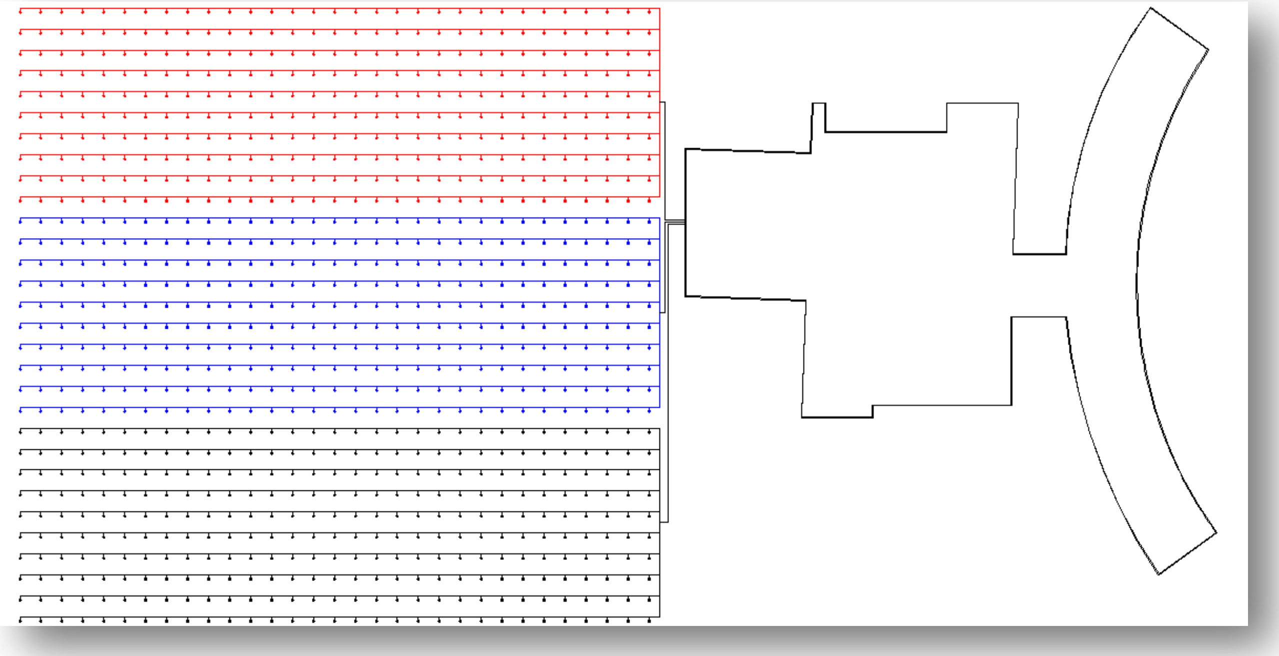


Figure 1.10 AHU 3 1000 ft Layout 31 x 30

Pipe Sizing and Head Loss

The last important step in designing the piping system is to determine the gpm and head loss for the longest run in each loop. Each option will have to be sized for the three different loops. The gpm was determined based on the 3 gpm that is going through each U-tube. The head loss will be determined based on the total length of the pipe with the addition of the equivalent head loss for each fitting and pipe bend. Several guidelines were accepted in the analysis of the head loss in order to make the pumping system more efficient. The most important one was to size the pipes for each section that will result in an acceptable head loss (3 ft/ 100 ft) and be able to handle the designed flow rate. When determining the pipe size it was decided to not go above 2 ft/ 100 ft of head loss.

Option 1 AHU 1 300ft

Like all the other options, Option 1 is divided into 3 separate ground loops. Each of these will have their own pumping system, requiring the longest length to be calculated for each loop. Figure 10.11 shows the 3 loops for Option 1.

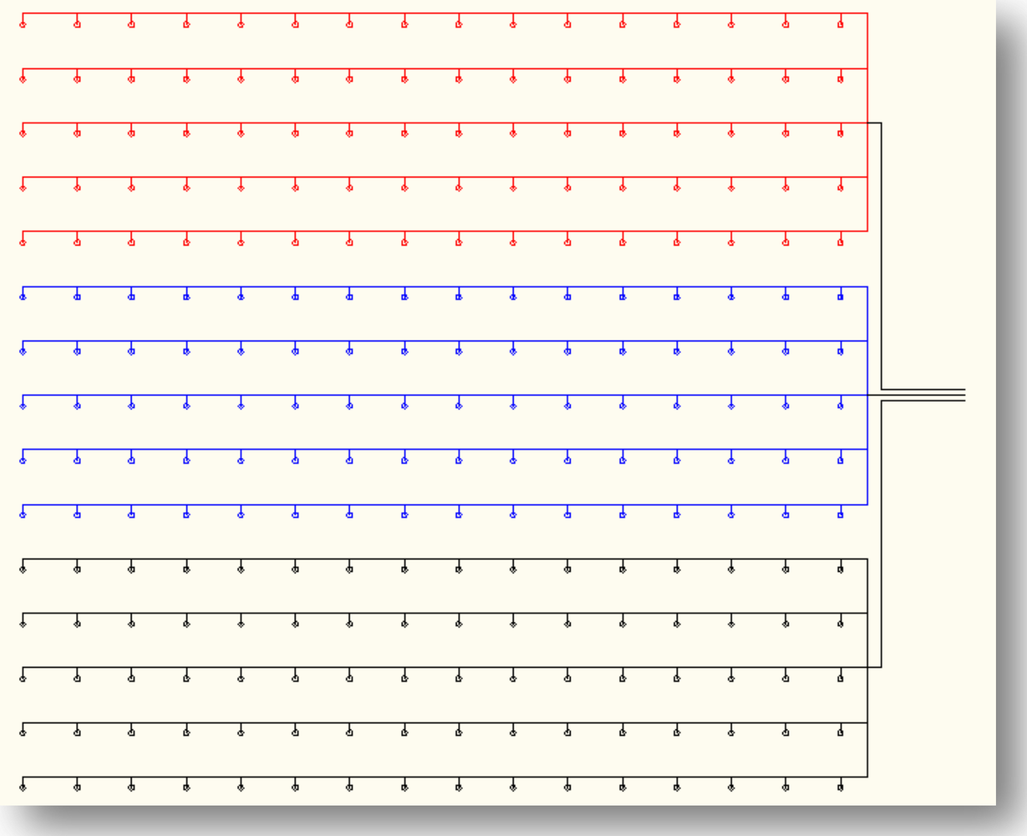


Figure 10.11 Option 1 Loops

Only the supply lines are shown in the above image. The first loop in red is shown with its dimensions below in Figure 10.12. The segment is broken down into several different lengths, and the piping size steps down as it continues down the boreholes. This is done to save on pipe costs, since the required flow rate is smaller as it passes each borehole. Table 10.9 shows the calculations done to determine the overall head loss. The pipe size was determined based on Table 10.8. The fittings were also taken from the loop plan. In order to determine the loss from the fittings the resistance coefficients had to be determined, as well as the friction factors based on the pipe diameter. Once K and the friction factor are found, they are multiplied by each other, and the equivalent length is determined based on the equivalent lengths chart. These tables and figures can be found in textbook “Heating, Ventilating, and Air Conditioning”. The process of calculating the head loss is shown in Table 10.10. In both Tables 10.9 and 10.10 the length values are doubled compared to the values seen in Figure 10.12. This is because Figure 10.12 only shows the supply piping. The system must be sized for both return and supply, which would be double the supply.

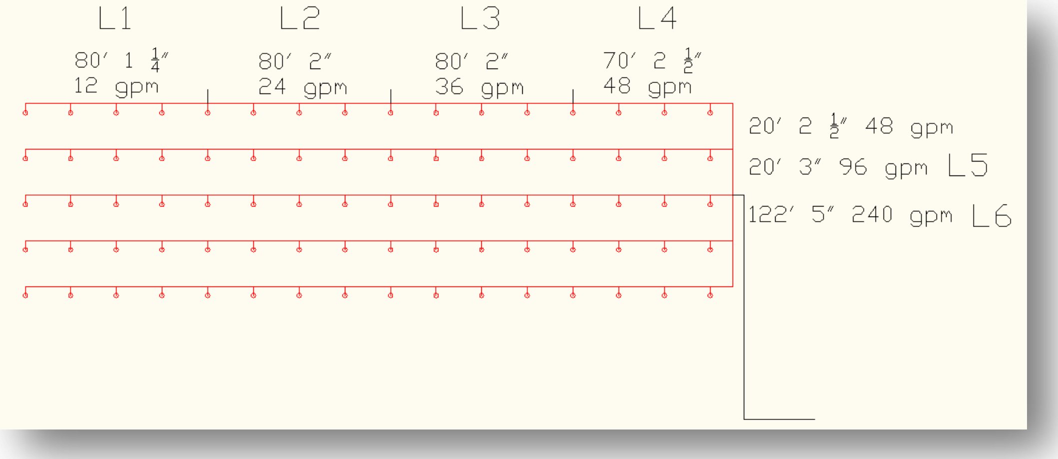


Figure 10.12 Loop 1 Diagram

Section	Length	Size	GPM	Head Loss ft/100 ft	Eq. Length	Head Loss
Utube	600	1	3	0.7	622	4.354
L1	160	1.25	12	2.1	160	3.36
L2	160	2	24	1.2	160	1.92
L3	160	2	36	2.4	160	3.84
L4	180	2 1/2	48	1.6	188	3.008
L5	40	3	96	2.1	122	2.562
L6	244	5	240	1	366	3.66
Total						22.704

Table 10.9 Overall Head Loss for Loop 1

Section	Fitting	KF_t	Size	F_t	K	L_{eq}
U tube	-	-	-	-	-	22
L4	90° Bend	30	2.5	0.018	0.54	8
L5	ST Run	20	3	0.018	0.36	12
L5	ST Branch	60	3	0.018	1.08	30
L5	Gate Valve	8	3	0.018	0.144	40
L6	ST Branch	60	5	0.016	0.96	50
L6	ST Run	20	5	0.016	0.32	20
L6	90° Bend	30	5	0.016	0.48	26
L6	90° Bend	30	5	0.016	0.48	26

Table 10.10 Head Loss for Loop 1 Fittings

The areas highlighted yellow are the design conditions for Loop 1. Loop 3 will be the exact same as Loop 1, so this loop will not be shown in the report. Loop 2 is shown below in Figure 10.13. The core of the Loop is the same as the other two; however the main pipe entering the central utility plant is much shorter than the other two loops. The following overall head loss and fittings head loss are shown in Tables 10.11 and 10.12, respectively.

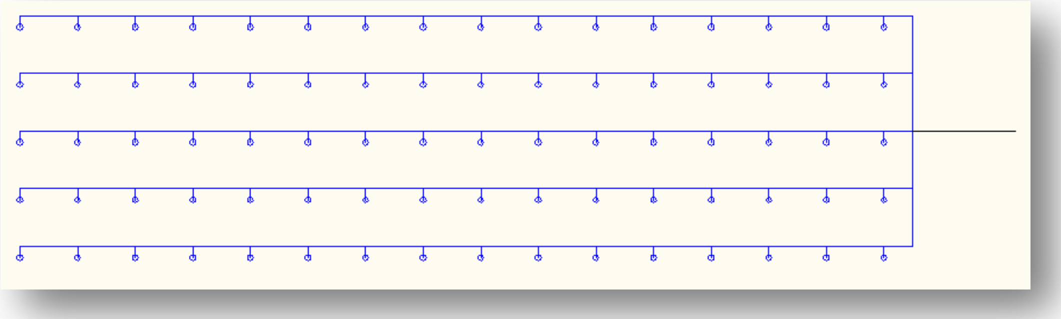
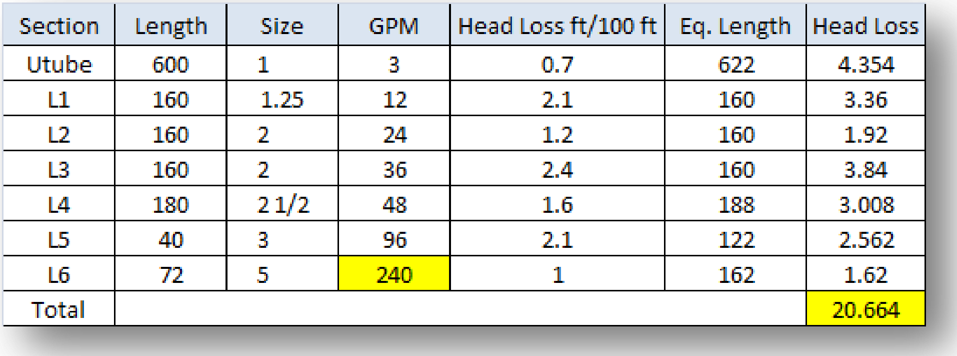
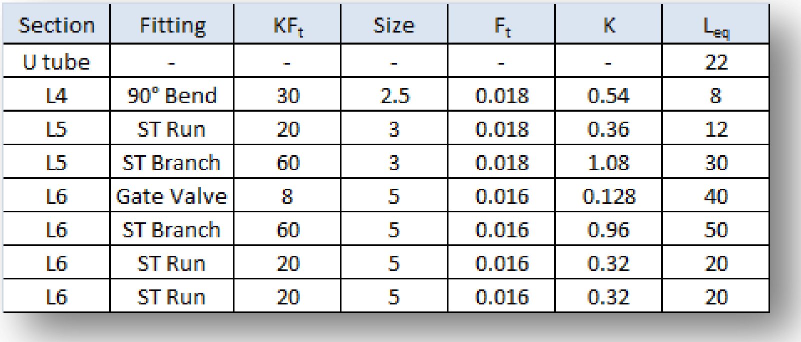


Figure 10.13 Loop 2 Diagram



Section	Length	Size	GPM	Head Loss ft/100 ft	Eq. Length	Head Loss
Utube	600	1	3	0.7	622	4.354
L1	160	1.25	12	2.1	160	3.36
L2	160	2	24	1.2	160	1.92
L3	160	2	36	2.4	160	3.84
L4	180	2 1/2	48	1.6	188	3.008
L5	40	3	96	2.1	122	2.562
L6	72	5	240	1	162	1.62
Total						20.664

Table 10.11 Overall Head Loss for Loop 2



Section	Fitting	KF_t	Size	F_t	K	L_{eq}
U tube	-	-	-	-	-	22
L4	90° Bend	30	2.5	0.018	0.54	8
L5	ST Run	20	3	0.018	0.36	12
L5	ST Branch	60	3	0.018	1.08	30
L6	Gate Valve	8	5	0.016	0.128	40
L6	ST Branch	60	5	0.016	0.96	50
L6	ST Run	20	5	0.016	0.32	20
L6	ST Run	20	5	0.016	0.32	20

Table 10.12 Head Loss for Loop 2 Fittings

Option 2 AHU 1 600ft

Figure 10.14 shows the diagram for Loop 1 for Option 2. All calculations are the same as Option 1. The gpm and head loss are both less than Option 1 because of the increased depth of the boreholes.

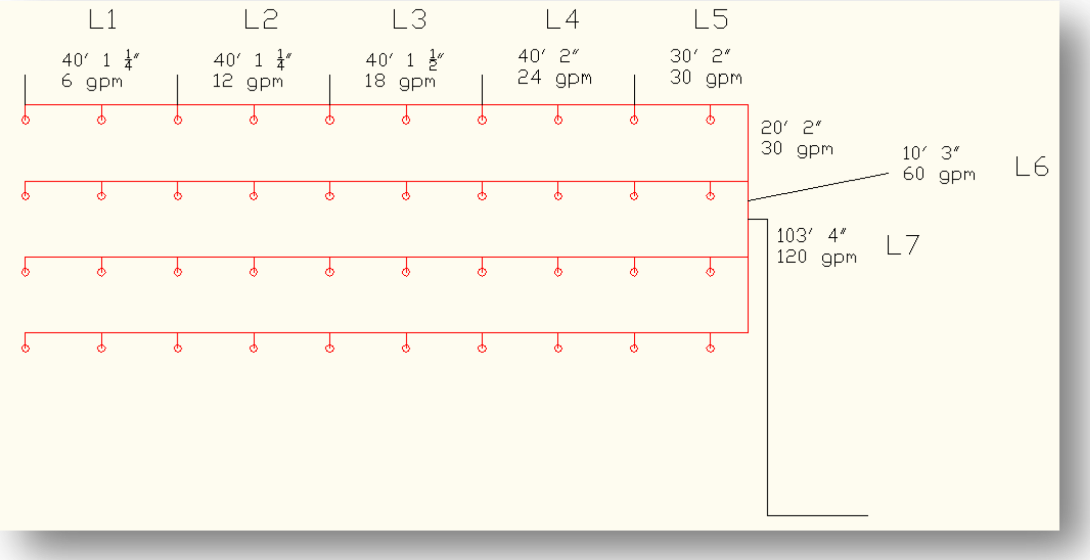
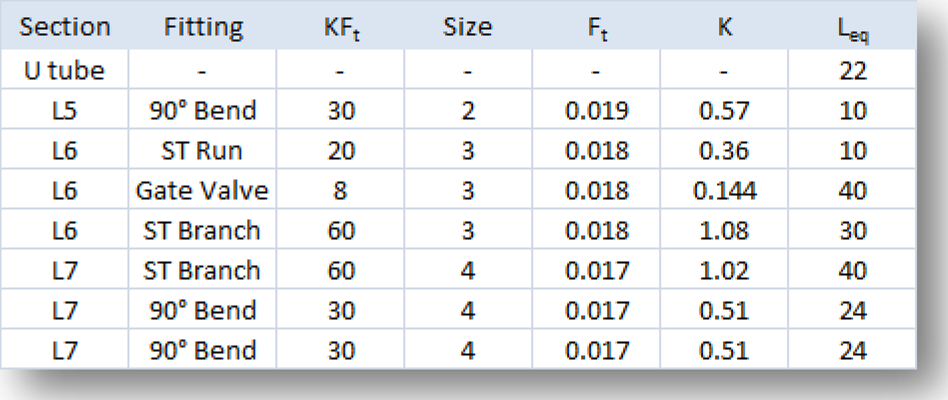


Table 10.14 Loop 1 Diagram

Tables 10.13 and 10.14 show the overall head loss and flow rates for the system and fittings.

Section	Length	Size	GPM	Head Loss ft/100 ft	Eq. Length	Head Loss
Utube	1200	1	3	0.7	1222	8.554
L1	80	1.25	6	0.8	80	0.64
L2	80	1 1/4	12	2	80	1.6
L3	80	1 1/2	18	2.1	80	1.68
L4	80	2	24	1.2	80	0.96
L5	100	2	30	1.5	110	1.65
L6	20	3	60	0.9	100	0.9
L7	206	4	120	0.9	294	2.646
Total						18.63

Table 10.13 Overall Head Loss for Loop 1



Section	Fitting	KF_t	Size	F_t	K	L_{eq}
U tube	-	-	-	-	-	22
L5	90° Bend	30	2	0.019	0.57	10
L6	ST Run	20	3	0.018	0.36	10
L6	Gate Valve	8	3	0.018	0.144	40
L6	ST Branch	60	3	0.018	1.08	30
L7	ST Branch	60	4	0.017	1.02	40
L7	90° Bend	30	4	0.017	0.51	24
L7	90° Bend	30	4	0.017	0.51	24

Table 10.14 Head Loss for Loop 1 Fittings

Loops 1 and 3 are both the same for Option 2 as well. Figure 10.15 below shows the layout for Loop 2. This is similar to Loops 1 and 3 except for the main pipe that leads to the central utility plant. This length is much shorter, causing the head loss to be shorter. Tables 10.15 and 10.16 show the overall head loss and the head loss due to fittings, respectively.

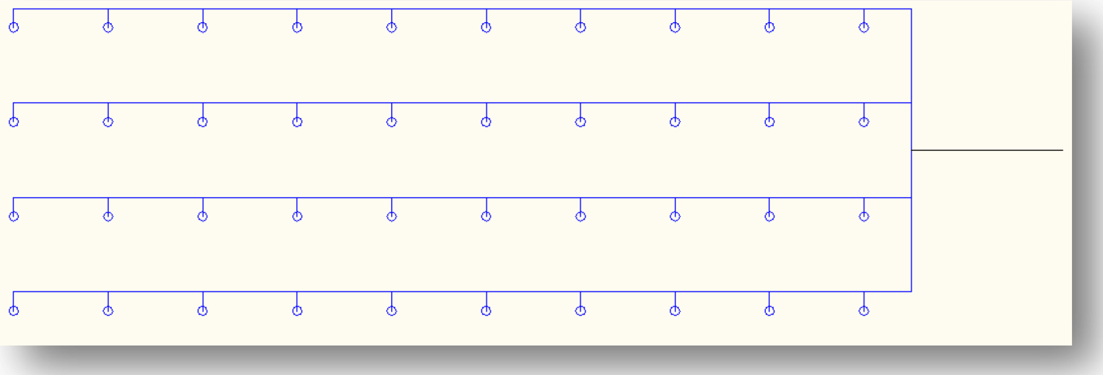
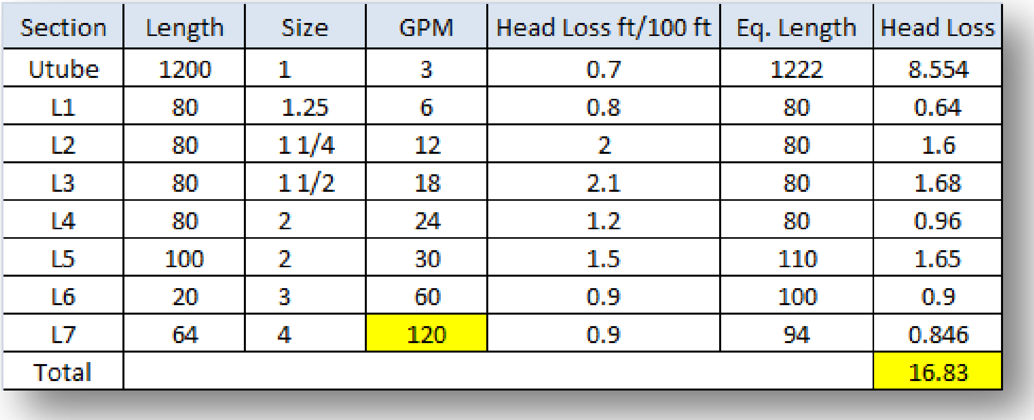
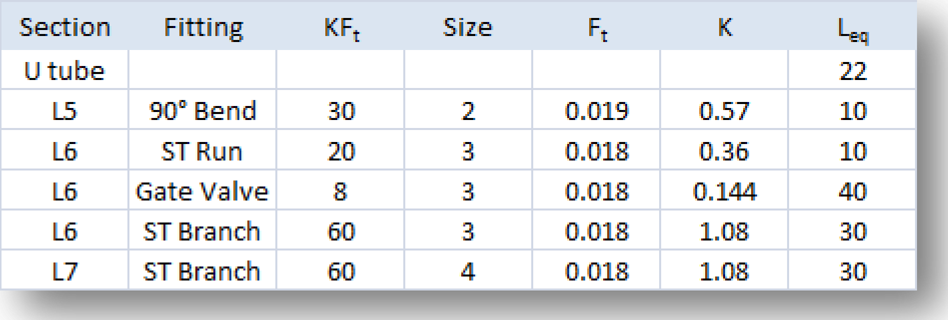


Figure 10.15 Loop 2 Diagram



Section	Length	Size	GPM	Head Loss ft/100 ft	Eq. Length	Head Loss
Utube	1200	1	3	0.7	1222	8.554
L1	80	1.25	6	0.8	80	0.64
L2	80	1 1/4	12	2	80	1.6
L3	80	1 1/2	18	2.1	80	1.68
L4	80	2	24	1.2	80	0.96
L5	100	2	30	1.5	110	1.65
L6	20	3	60	0.9	100	0.9
L7	64	4	120	0.9	94	0.846
Total						16.83

Table 10.15 Overall Head Loss for Loop 2



Section	Fitting	KF_t	Size	F_t	K	L_{eq}
U tube						22
L5	90° Bend	30	2	0.019	0.57	10
L6	ST Run	20	3	0.018	0.36	10
L6	Gate Valve	8	3	0.018	0.144	40
L6	ST Branch	60	3	0.018	1.08	30
L7	ST Branch	60	4	0.018	1.08	30

Table 10.16 Overall Head loss for Loop 2 Fittings

Option 3 AHU 2 600ft

Option 3 contains the ground loop system for AHU 2. The flow rate and head loss will be larger than that of Options 1 and 2 due to the much larger size. The calculated values were performed the same way as Option 1. Figure 10.16 shows the layout of Loop 1. Tables 10.17 and 10.18 show the overall head loss and head loss for the fittings for Loop 1.

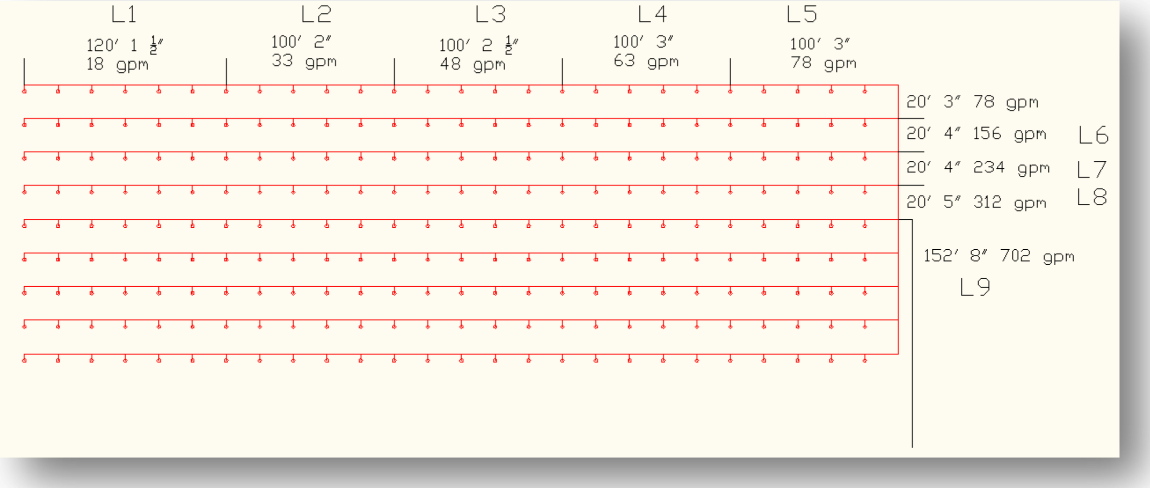
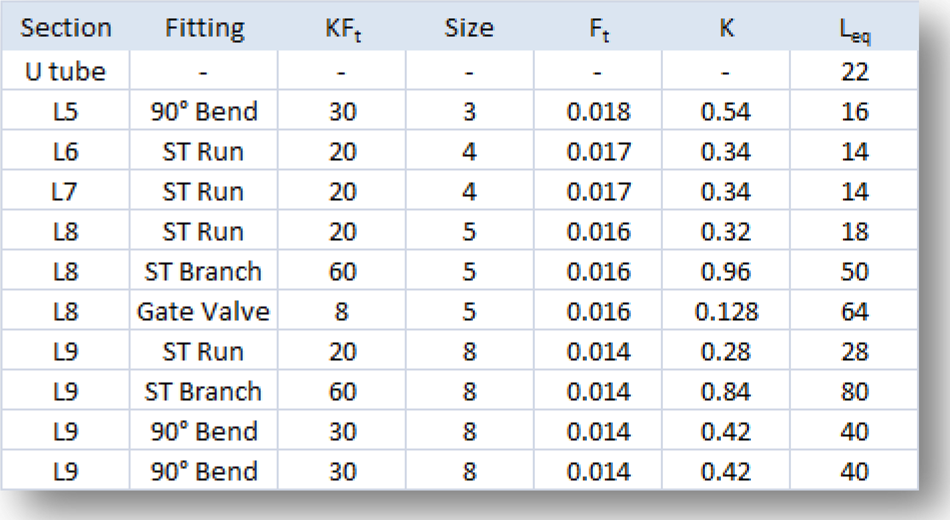


Figure 10.16 Loop 1 Diagram

Section	Length	Size	GPM	Head Loss ft/100 ft	Eq. Length	Head Loss
Utube	1200	1	3	0.7	1222	8.554
L1	240	1.5	18	2.3	240	5.52
L2	200	2	33	1.5	200	3
L3	200	2 1/2	48	1.9	200	3.8
L4	200	3	63	0.9	200	1.8
L5	240	3	78	1.5	256	3.84
L6	40	4	156	1.5	54	0.81
L7	40	4	234	2.7	54	1.458
L8	40	5	312	1.5	172	2.58
L9	304	8	702	0.9	492	4.428
Total						35.79

Table 10.17 Head Loss for Loop 1



Section	Fitting	KF_t	Size	F_t	K	L_{eq}
U tube	-	-	-	-	-	22
L5	90° Bend	30	3	0.018	0.54	16
L6	ST Run	20	4	0.017	0.34	14
L7	ST Run	20	4	0.017	0.34	14
L8	ST Run	20	5	0.016	0.32	18
L8	ST Branch	60	5	0.016	0.96	50
L8	Gate Valve	8	5	0.016	0.128	64
L9	ST Run	20	8	0.014	0.28	28
L9	ST Branch	60	8	0.014	0.84	80
L9	90° Bend	30	8	0.014	0.42	40
L9	90° Bend	30	8	0.014	0.42	40

Table 10.18Overall Head Loss for Loop 1 Fittings

Loop 2 is shown in Figure 10.17. The overall head loss and head loss for fittings are shown in Tables 10.19 and 10.20

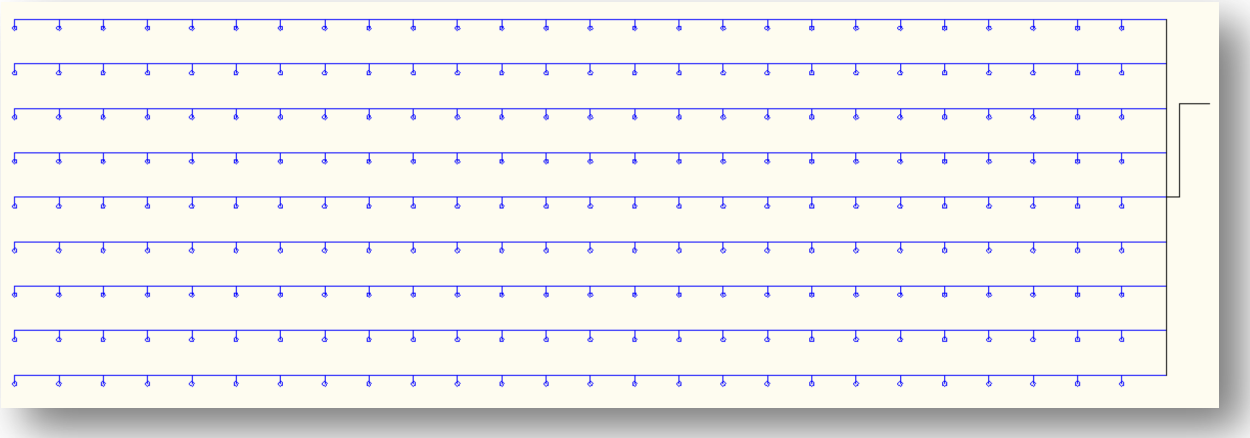
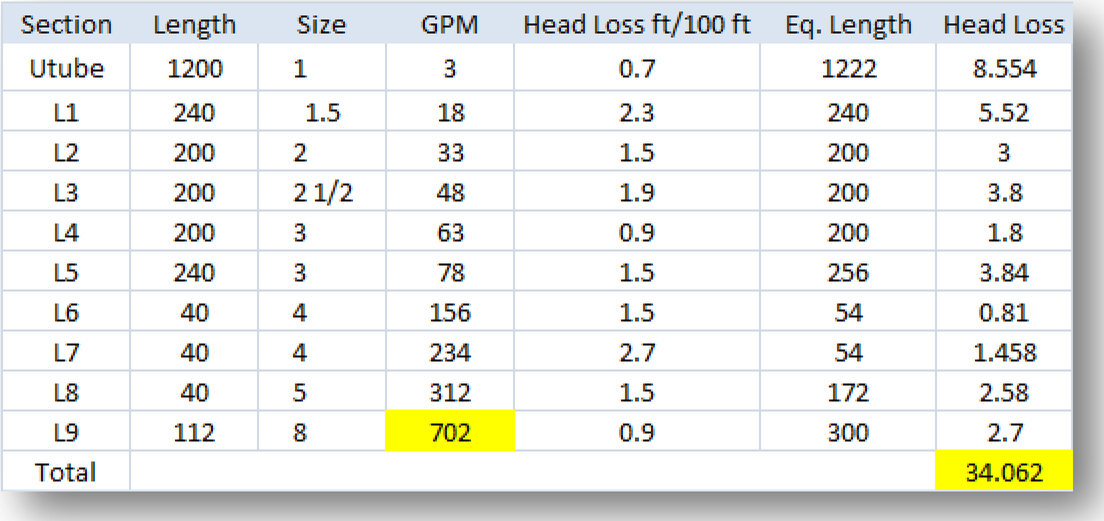
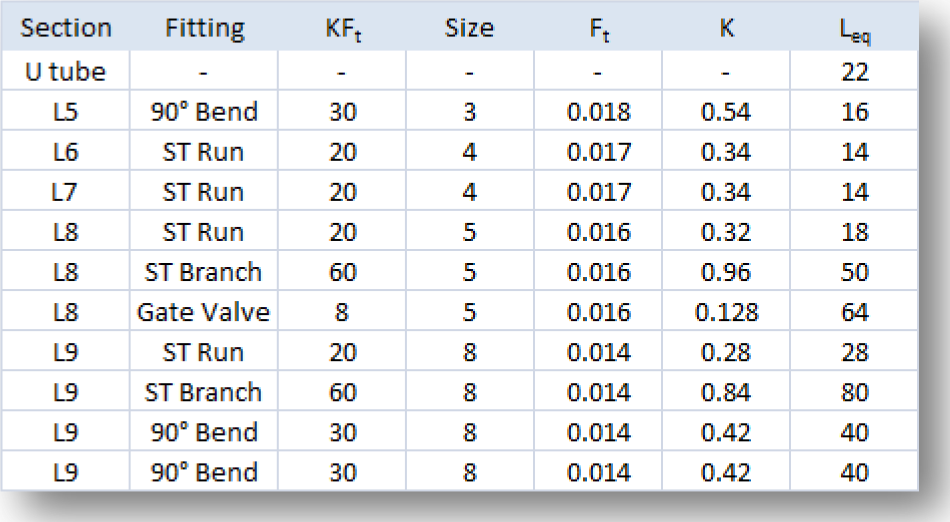


Figure 10.17 Loop 2 Diagram



Section	Length	Size	GPM	Head Loss ft/100 ft	Eq. Length	Head Loss
Utube	1200	1	3	0.7	1222	8.554
L1	240	1.5	18	2.3	240	5.52
L2	200	2	33	1.5	200	3
L3	200	2 1/2	48	1.9	200	3.8
L4	200	3	63	0.9	200	1.8
L5	240	3	78	1.5	256	3.84
L6	40	4	156	1.5	54	0.81
L7	40	4	234	2.7	54	1.458
L8	40	5	312	1.5	172	2.58
L9	112	8	702	0.9	300	2.7
Total						34.062

Table 10.19 Overall Head Loss for Loop 2



Section	Fitting	KF_t	Size	F_t	K	L_{eq}
U tube	-	-	-	-	-	22
L5	90° Bend	30	3	0.018	0.54	16
L6	ST Run	20	4	0.017	0.34	14
L7	ST Run	20	4	0.017	0.34	14
L8	ST Run	20	5	0.016	0.32	18
L8	ST Branch	60	5	0.016	0.96	50
L8	Gate Valve	8	5	0.016	0.128	64
L9	ST Run	20	8	0.014	0.28	28
L9	ST Branch	60	8	0.014	0.84	80
L9	90° Bend	30	8	0.014	0.42	40
L9	90° Bend	30	8	0.014	0.42	40

Table 10.20 Overall Head Loss for Fittings Loop 2

Loop 3 in this case is not the same as Loop 1. Loop 3 is farther away from the central utility plant, having a longer main pipe that connects to it. Figure 10.18 shows the layout for Loop 3. Tables 10.21 and 10.22 show the overall head loss and the head loss for the fittings for Loop 3.

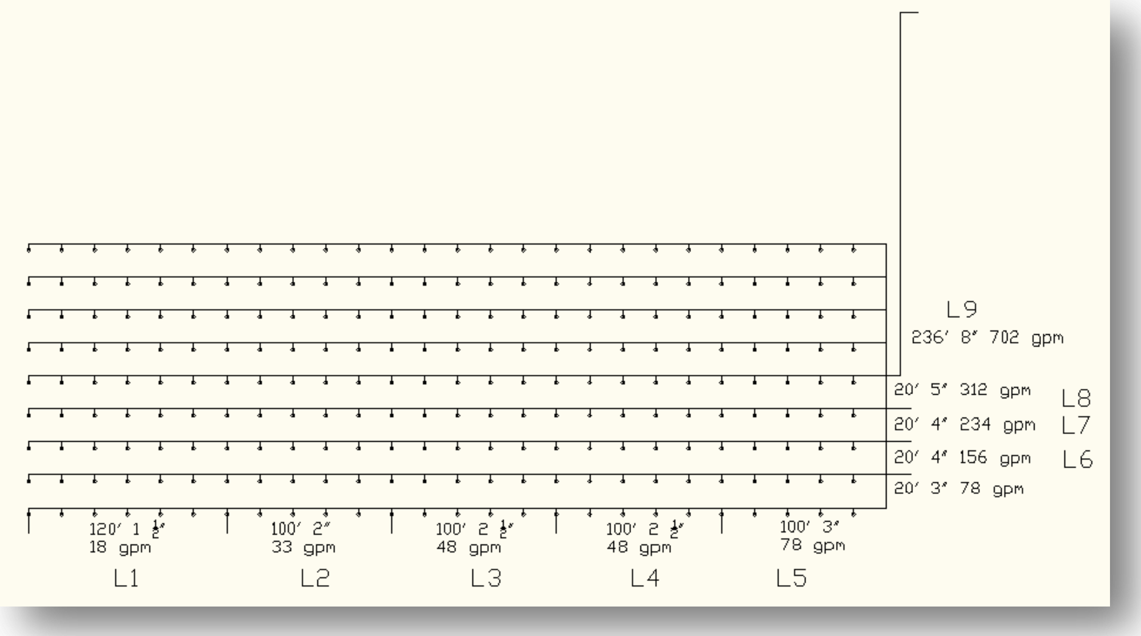
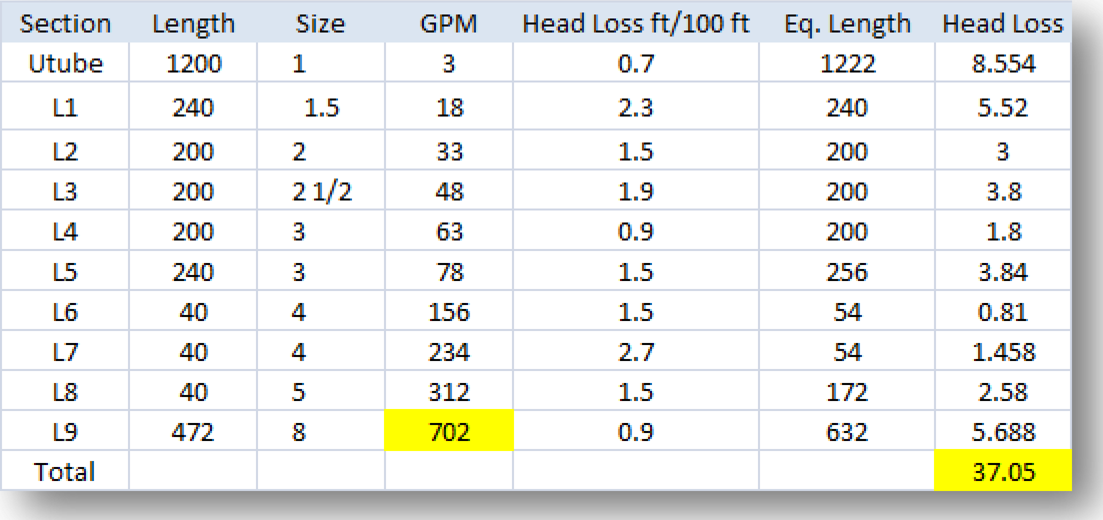
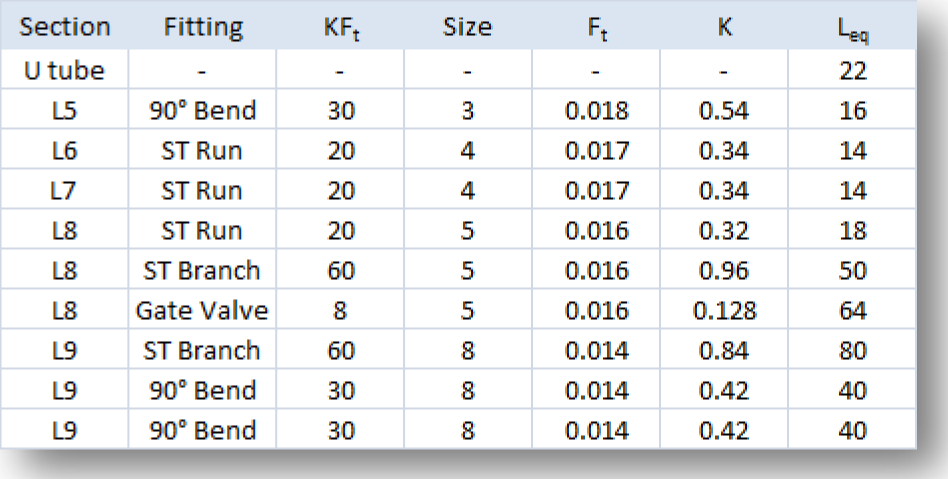


Figure 10.18 Loop 3 Diagram



Section	Length	Size	GPM	Head Loss ft/100 ft	Eq. Length	Head Loss
Utube	1200	1	3	0.7	1222	8.554
L1	240	1.5	18	2.3	240	5.52
L2	200	2	33	1.5	200	3
L3	200	2 1/2	48	1.9	200	3.8
L4	200	3	63	0.9	200	1.8
L5	240	3	78	1.5	256	3.84
L6	40	4	156	1.5	54	0.81
L7	40	4	234	2.7	54	1.458
L8	40	5	312	1.5	172	2.58
L9	472	8	702	0.9	632	5.688
Total						37.05

Table 10.21 Overall Head Loss for Loop 3



Section	Fitting	KF_t	Size	F_t	K	L_{eq}
U tube	-	-	-	-	-	22
L5	90° Bend	30	3	0.018	0.54	16
L6	ST Run	20	4	0.017	0.34	14
L7	ST Run	20	4	0.017	0.34	14
L8	ST Run	20	5	0.016	0.32	18
L8	ST Branch	60	5	0.016	0.96	50
L8	Gate Valve	8	5	0.016	0.128	64
L9	ST Branch	60	8	0.014	0.84	80
L9	90° Bend	30	8	0.014	0.42	40
L9	90° Bend	30	8	0.014	0.42	40

Table 10.22 Overall Head Loss for Fittings Loop 3

Option 4 AHU 2 1000 ft

The 4th Option is for AHU 2 at a 1000 ft borehole. The gpm will be lower compared to Option 4 due to the increased bore length. The head loss however has increased in this option. Figure 10.19 shows the piping layout for Loop 1.

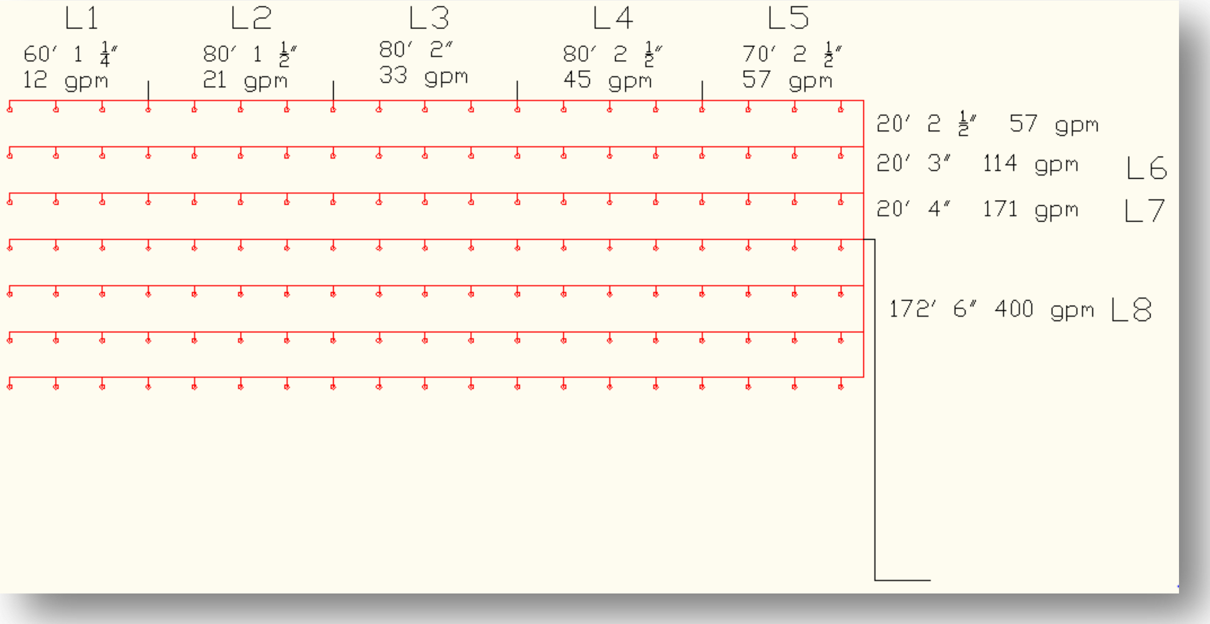
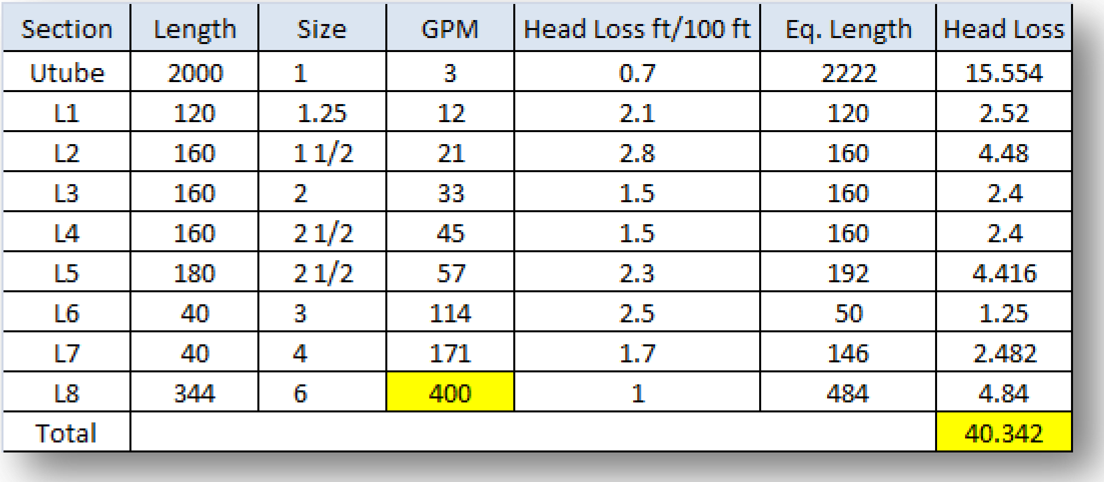


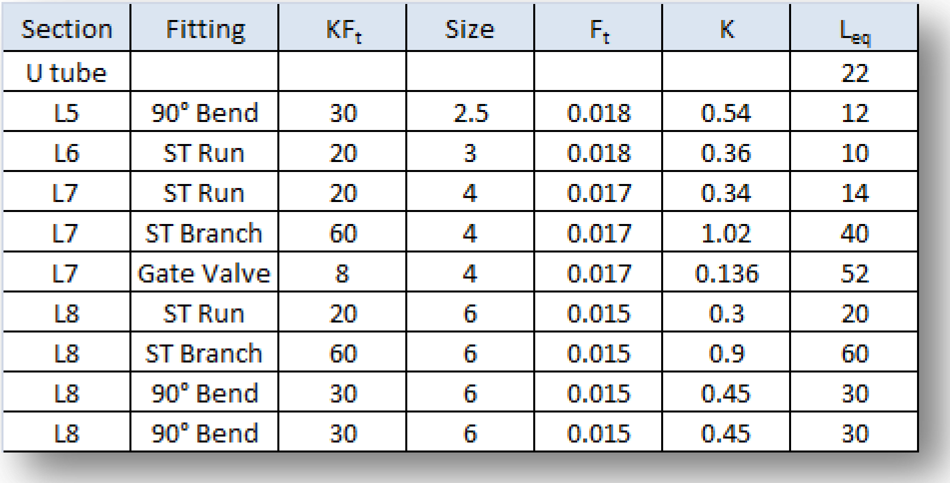
Figure 10.19 Loop 1 Diagram

Tables 10.23 and 10.24 show the overall head loss and fittings loss for Loop 1.



Section	Length	Size	GPM	Head Loss ft/100 ft	Eq. Length	Head Loss
Utube	2000	1	3	0.7	2222	15.554
L1	120	1.25	12	2.1	120	2.52
L2	160	1 1/2	21	2.8	160	4.48
L3	160	2	33	1.5	160	2.4
L4	160	2 1/2	45	1.5	160	2.4
L5	180	2 1/2	57	2.3	192	4.416
L6	40	3	114	2.5	50	1.25
L7	40	4	171	1.7	146	2.482
L8	344	6	400	1	484	4.84
Total						40.342

Table 10.23 Overall Head Loss for Loop 1



Section	Fitting	KF_t	Size	F_t	K	L_{eq}
U tube						22
L5	90° Bend	30	2.5	0.018	0.54	12
L6	ST Run	20	3	0.018	0.36	10
L7	ST Run	20	4	0.017	0.34	14
L7	ST Branch	60	4	0.017	1.02	40
L7	Gate Valve	8	4	0.017	0.136	52
L8	ST Run	20	6	0.015	0.3	20
L8	ST Branch	60	6	0.015	0.9	60
L8	90° Bend	30	6	0.015	0.45	30
L8	90° Bend	30	6	0.015	0.45	30

Table 10.24 Overall Head Loss for Fittings Loop 1

Loops 1 and 2 are the same in this case. Loop 2 has an additional run of boreholes. It also has a shorter pipe length leading to the central utility plant. This gives a lower head loss compared to the other loops. Figure 10.20 shows the layout for Loop 2. Tables 10.25 and 10.26 show the overall head loss and the head loss for the fittings as well.

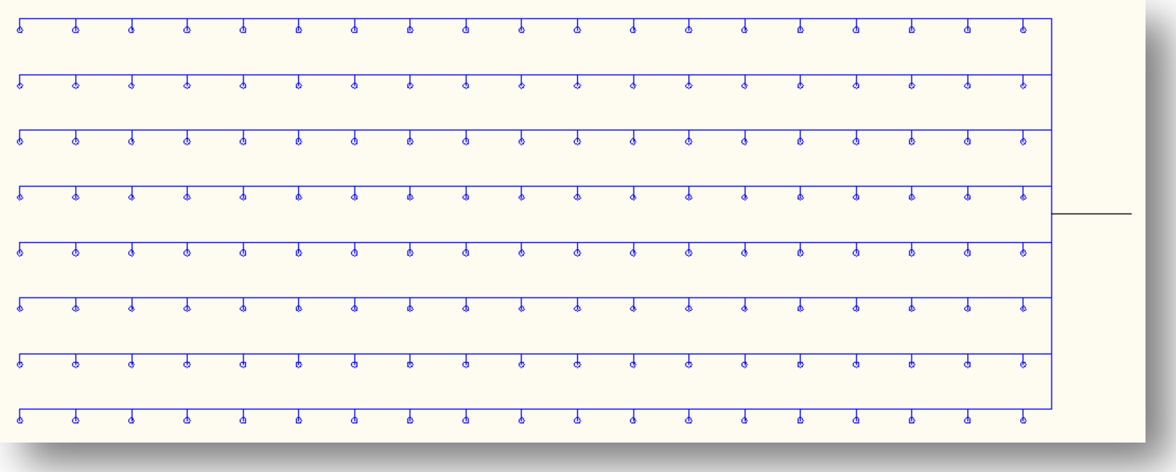
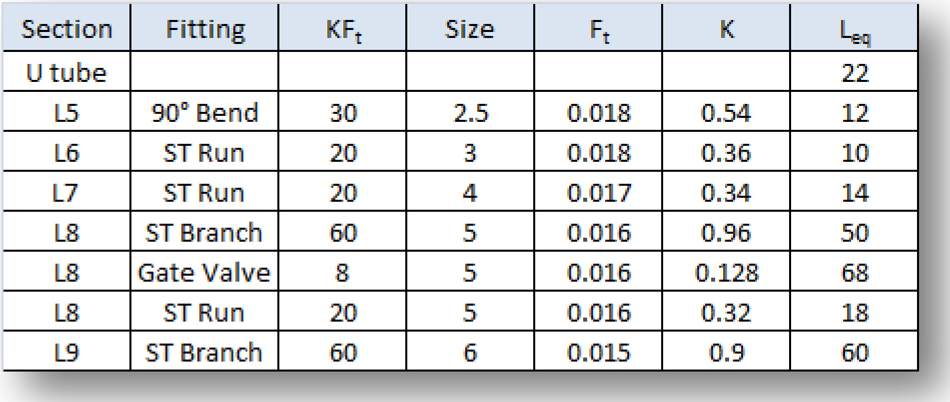


Figure 10.20 Loop 2 Diagram

Section	Length	Size	GPM	Head Loss ft/100 ft	Eq. Length	Head Loss
Utube	2000	1	3	0.7	2222	15.554
L1	120	1.25	12	2.1	120	2.52
L2	160	1 1/2	21	2.8	160	4.48
L3	160	2	33	1.5	160	2.4
L4	160	2 1/2	45	1.5	160	2.4
L5	180	2 1/2	57	2.3	192	4.416
L6	40	3	114	2.5	50	1.25
L7	40	4	171	1.7	54	0.918
L8	20	5	238	1	156	1.56
L9	58	6	456	1.5	118	1.77
Total						37.268

Table 10.25 Overall Head Loss for Loop 2



Section	Fitting	KF_t	Size	F_t	K	L_{eq}
U tube						22
L5	90° Bend	30	2.5	0.018	0.54	12
L6	ST Run	20	3	0.018	0.36	10
L7	ST Run	20	4	0.017	0.34	14
L8	ST Branch	60	5	0.016	0.96	50
L8	Gate Valve	8	5	0.016	0.128	68
L8	ST Run	20	5	0.016	0.32	18
L9	ST Branch	60	6	0.015	0.9	60

Table 10.26 Overall Head Loss for Fittings Loop 2

Option 5 AHU 3 1000 ft

The final option is for AHU 3. The gpm and head loss for this option will be significantly larger than the other four. This is because AHU 3 larger than AHU 2 and 1. The layout for Loop 1 is shown in Figure 10.21. Tables 10.26 and 10.27 show the overall head loss and the head loss for the fittings.

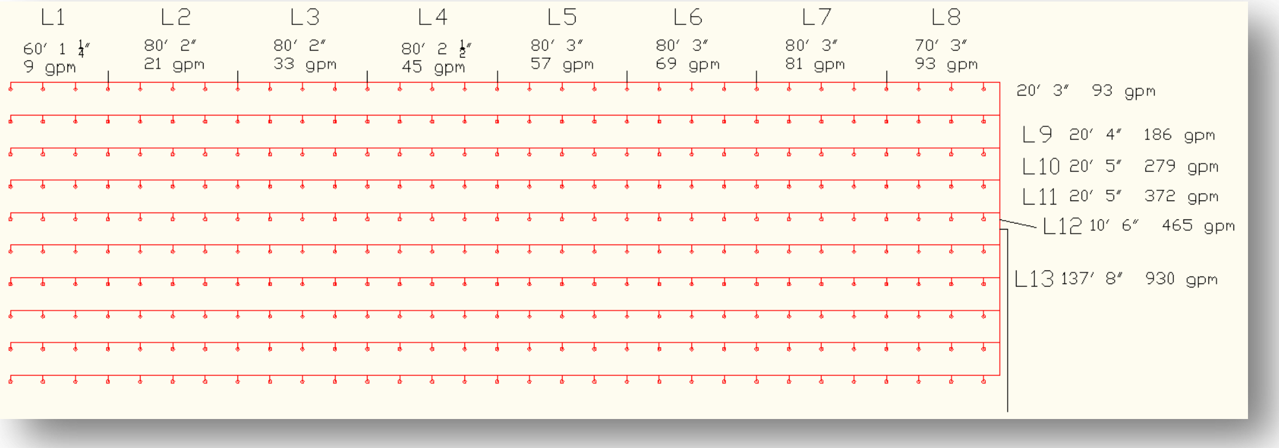
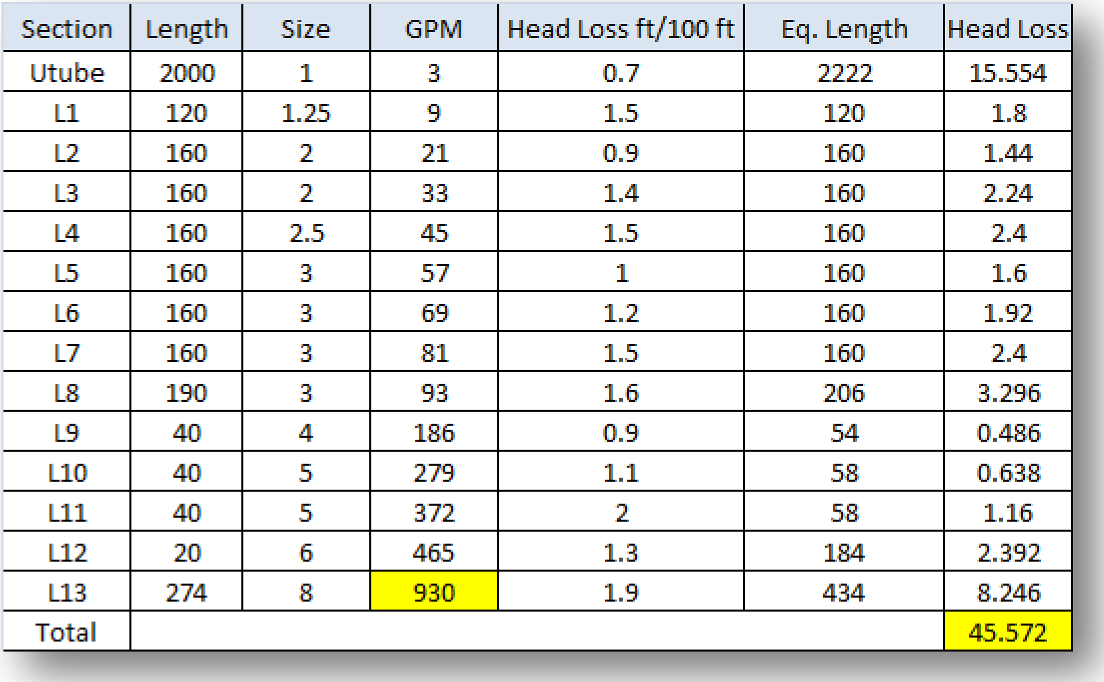
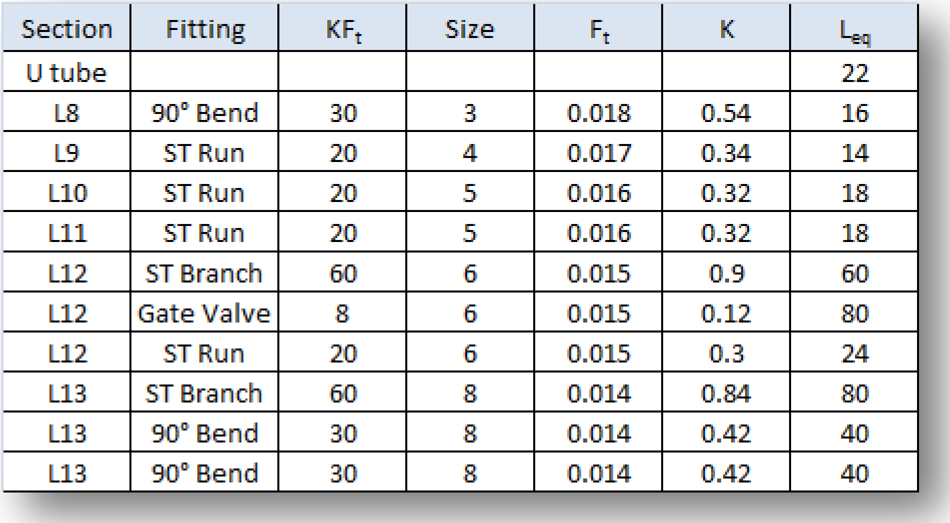


Figure 10.21 Loop 1 Diagram



Section	Length	Size	GPM	Head Loss ft/100 ft	Eq. Length	Head Loss
Utube	2000	1	3	0.7	2222	15.554
L1	120	1.25	9	1.5	120	1.8
L2	160	2	21	0.9	160	1.44
L3	160	2	33	1.4	160	2.24
L4	160	2.5	45	1.5	160	2.4
L5	160	3	57	1	160	1.6
L6	160	3	69	1.2	160	1.92
L7	160	3	81	1.5	160	2.4
L8	190	3	93	1.6	206	3.296
L9	40	4	186	0.9	54	0.486
L10	40	5	279	1.1	58	0.638
L11	40	5	372	2	58	1.16
L12	20	6	465	1.3	184	2.392
L13	274	8	930	1.9	434	8.246
Total						45.572

Table 10.26 Overall Head Loss for Loop 1



Section	Fitting	KF_t	Size	F_t	K	L_{eq}
U tube						22
L8	90° Bend	30	3	0.018	0.54	16
L9	ST Run	20	4	0.017	0.34	14
L10	ST Run	20	5	0.016	0.32	18
L11	ST Run	20	5	0.016	0.32	18
L12	ST Branch	60	6	0.015	0.9	60
L12	Gate Valve	8	6	0.015	0.12	80
L12	ST Run	20	6	0.015	0.3	24
L13	ST Branch	60	8	0.014	0.84	80
L13	90° Bend	30	8	0.014	0.42	40
L13	90° Bend	30	8	0.014	0.42	40

Table 10.27 Overall Head Loss for Fittings Loop 1

Loop 2 is similar to Loop 1. Like the other options, the main pipe entering the central utility plant is shorter than the other loops. Figure 10.22 shows the diagram for Loop 2. Tables 10.28 and 10.29 show the overall head loss and the fittings head loss.

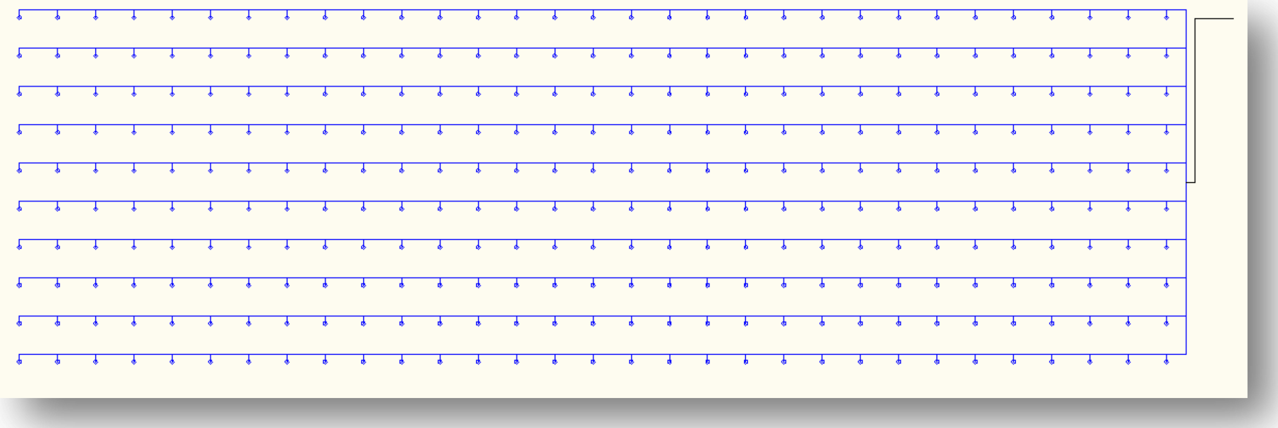
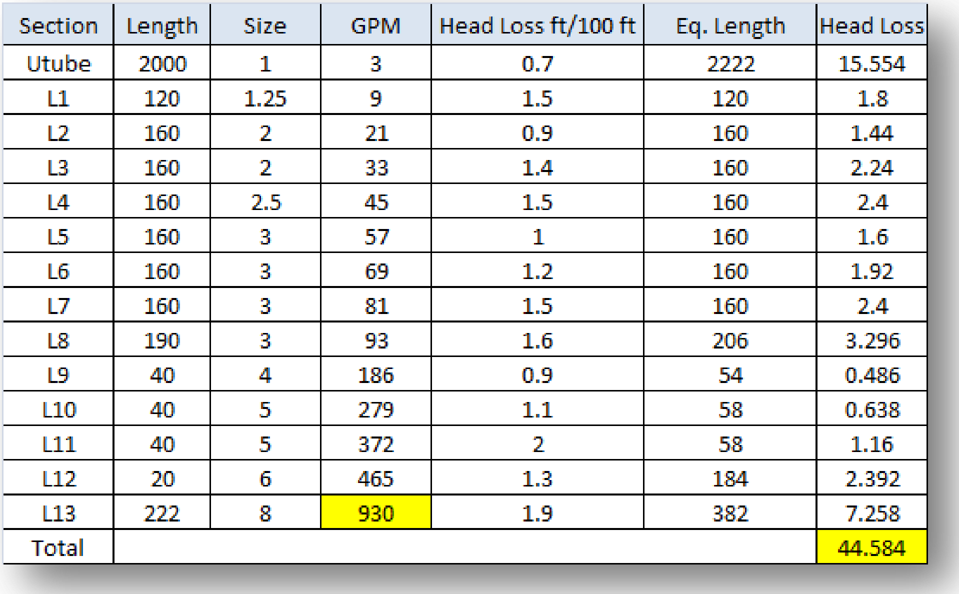


Figure 10.22 Loop 2 Diagram



Section	Length	Size	GPM	Head Loss ft/100 ft	Eq. Length	Head Loss
Utube	2000	1	3	0.7	2222	15.554
L1	120	1.25	9	1.5	120	1.8
L2	160	2	21	0.9	160	1.44
L3	160	2	33	1.4	160	2.24
L4	160	2.5	45	1.5	160	2.4
L5	160	3	57	1	160	1.6
L6	160	3	69	1.2	160	1.92
L7	160	3	81	1.5	160	2.4
L8	190	3	93	1.6	206	3.296
L9	40	4	186	0.9	54	0.486
L10	40	5	279	1.1	58	0.638
L11	40	5	372	2	58	1.16
L12	20	6	465	1.3	184	2.392
L13	222	8	930	1.9	382	7.258
Total						44.584

Table 10.28 Overall Head Loss Loop 2

Section	Fitting	KF_t	Size	F_t	K	L_{eq}
U tube						22
L8	90° Bend	30	3	0.018	0.54	16
L9	ST Run	20	4	0.017	0.34	14
L10	ST Run	20	5	0.016	0.32	18
L11	ST Run	20	5	0.016	0.32	18
L12	ST Branch	60	6	0.015	0.9	60
L12	Gate Valve	8	6	0.015	0.12	80
L12	ST Run	20	6	0.015	0.3	24
L13	ST Branch	60	8	0.014	0.84	80
L13	90° Bend	30	8	0.014	0.42	40
L13	90° Bend	30	8	0.014	0.42	40

Table 10.29 Overall Head Loss for Fittings Loop 2

Loop 3 is different than Loop 1 in this case. Loop 3 is farther away from the central utility plant, thus the head loss is going to be larger. Figure 10.23 shows the layout for Loop 3. Tables 10.30 and 10.31 show the overall head loss and head loss for the fittings.

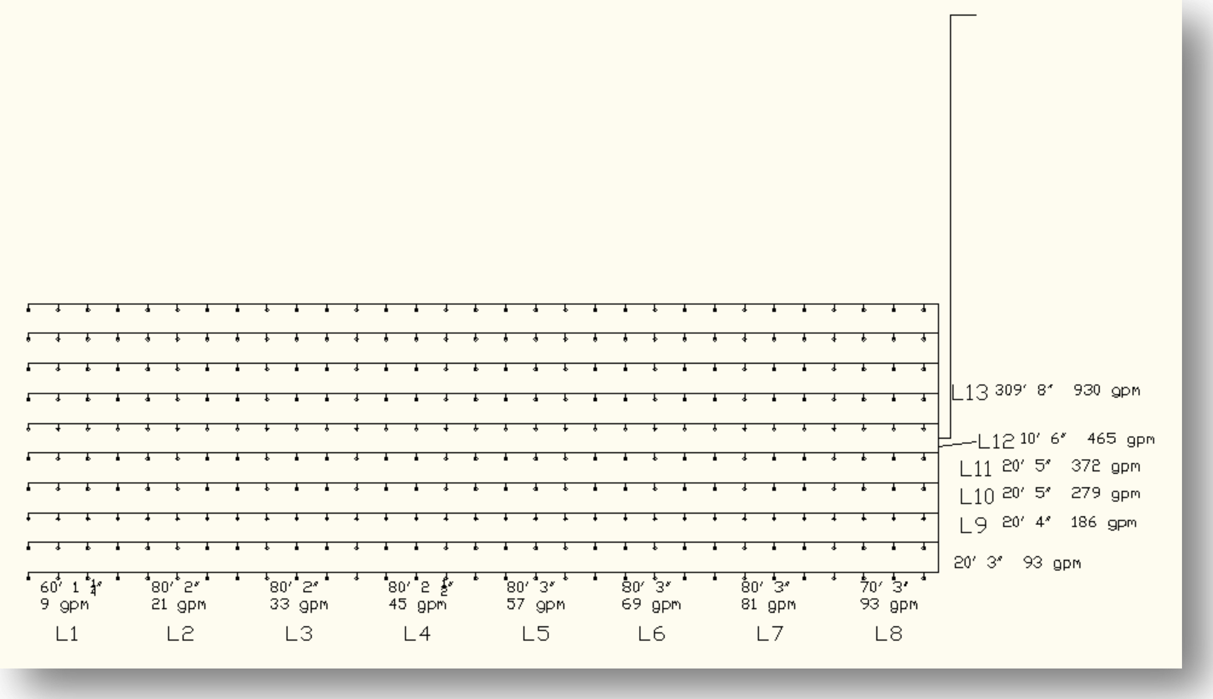
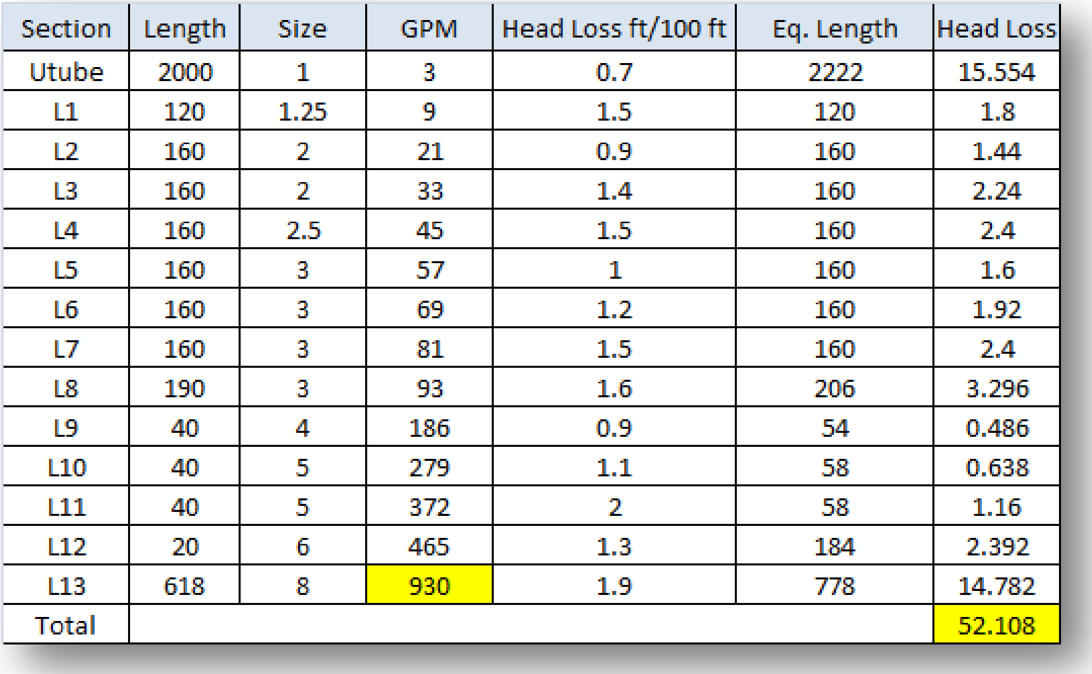
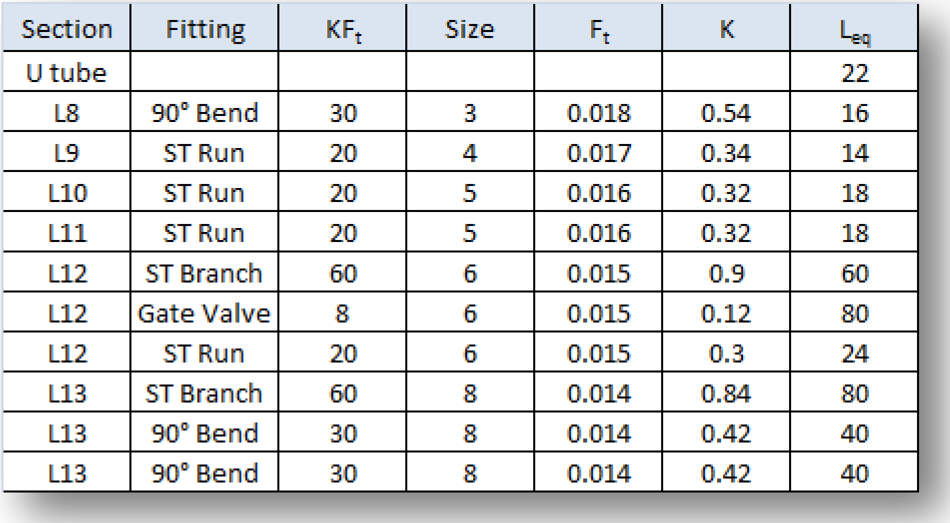


Figure 10.23 Loop 3 Diagram



Section	Length	Size	GPM	Head Loss ft/100 ft	Eq. Length	Head Loss
Utube	2000	1	3	0.7	2222	15.554
L1	120	1.25	9	1.5	120	1.8
L2	160	2	21	0.9	160	1.44
L3	160	2	33	1.4	160	2.24
L4	160	2.5	45	1.5	160	2.4
L5	160	3	57	1	160	1.6
L6	160	3	69	1.2	160	1.92
L7	160	3	81	1.5	160	2.4
L8	190	3	93	1.6	206	3.296
L9	40	4	186	0.9	54	0.486
L10	40	5	279	1.1	58	0.638
L11	40	5	372	2	58	1.16
L12	20	6	465	1.3	184	2.392
L13	618	8	930	1.9	778	14.782
Total						52.108

Table 10.30 Overall Head Loss Loop 3



Section	Fitting	KF_t	Size	F_t	K	L_{eq}
U tube						22
L8	90° Bend	30	3	0.018	0.54	16
L9	ST Run	20	4	0.017	0.34	14
L10	ST Run	20	5	0.016	0.32	18
L11	ST Run	20	5	0.016	0.32	18
L12	ST Branch	60	6	0.015	0.9	60
L12	Gate Valve	8	6	0.015	0.12	80
L12	ST Run	20	6	0.015	0.3	24
L13	ST Branch	60	8	0.014	0.84	80
L13	90° Bend	30	8	0.014	0.42	40
L13	90° Bend	30	8	0.014	0.42	40

Table 10.31 Overall Head Loss for Fittings Loop 3

The equivalent length was totaled by adding the length of the pipes, plus the equivalent length of the fittings on each pipe. This was then multiplied by the head loss in ft/100 ft. The total gpm and head loss for each loop were totaled and this is what the pumps will be sized from. It was important to keep the head loss below 3 ft/100 ft so that the pumping efficiency would not be compromised. If the pumps are oversized, then the system could potentially use significantly more energy than it should.

It is also important to show the layout of the piping to fully understand how the system works. Figure 10.24 shows a close up top view schematic of how the piping step down will operate.

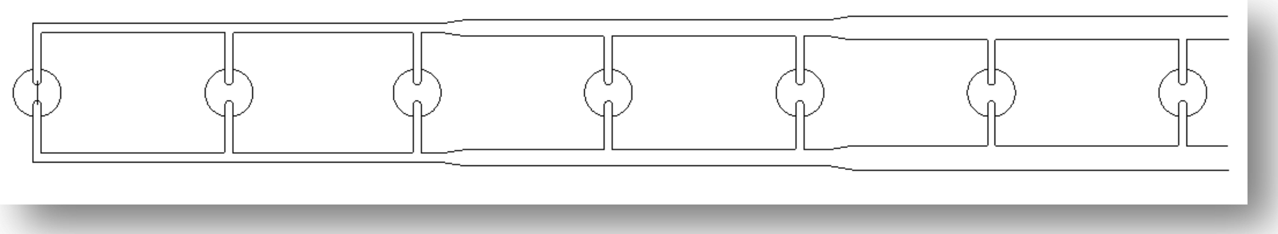


Figure 10.24 Piping Schematic

The pipes will step down incrementally as they reach the end of a borehole run. This is done to prevent air trapping and save on pipe material costs. The price of piping increases significantly based on the diameter. The image above shows both the supply and return piping. The supply piping is located on the right side of the boreholes and the return piping is on the left. The return piping will step up at the same places of the supply to handle the flow rates, and once again prevent air trapping. The image is not to scale, and typically on size of pipe will have 4 to 5 boreholes on it. Figure 10.25 shows in depth view of the fittings that will be used to connect the borehole piping to the supply and return pipes.

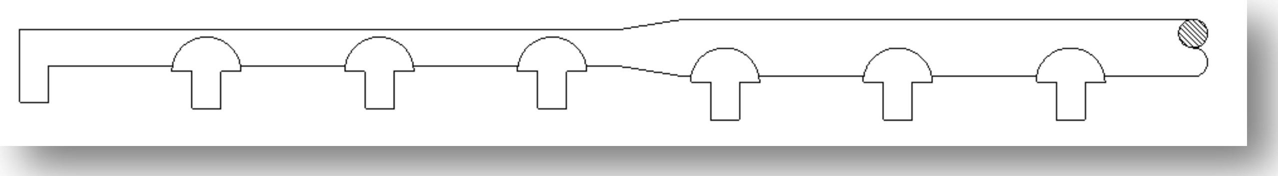


Figure 10.25 Saddle Fittings for Borehole Pipes

The type of fittings used will be 1 ½" saddle fittings. The image above shows the saddle fittings for the supply line, but it will be the exact same for the return since the piping is exactly the same. Once again this image is not to scale and there will be 4-5 boreholes per step down in the piping. Figure 10.26 below shows an isometric view of how the U-tube system will work. Both the supply and return lines are shown.

Figure 10.26 Isometric View of U-tube design

Figure 10.27, below, shows a cut through of the U-tube design as well.

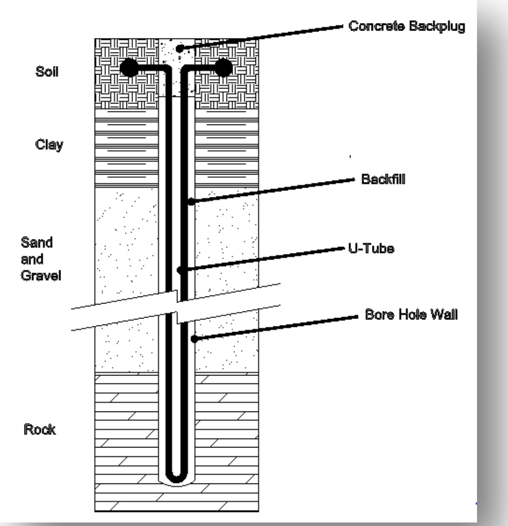


Figure 10.27 U-tube Design

Another feature in the piping layout is a valve vault to be located where the borehole loop connects to the main pipe leading into the central utility plant. There will be two types of vaults, since the connection to the main pipe differs based on the loop. Figure 10.28 shows the typical location for the vault. The location of the vaults will be same for all loops in all options.

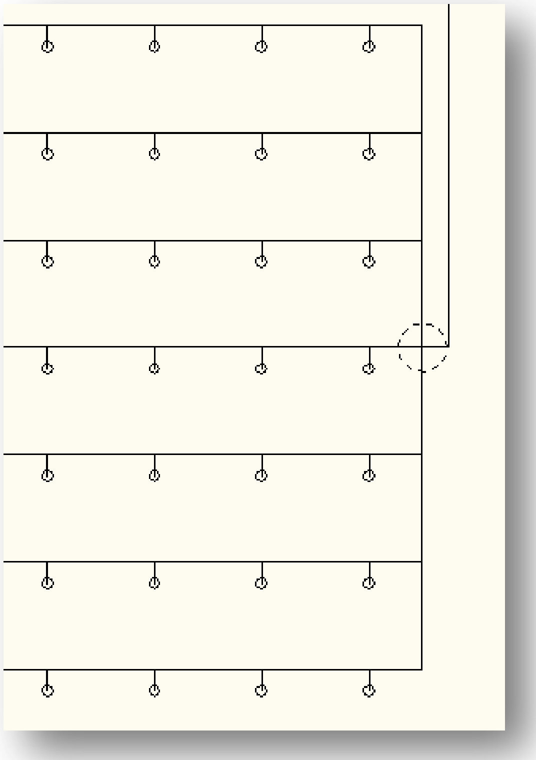


Figure 10.28 Valve Vault Location

The circled region is where the vault will be located. As seen in this example there are 3 branches entering the vault. Figure 10.29 below shows a close up of the vault. Shown is the supply lines, however, return lines will also be located in these vaults. With a valve vault for each loop, there will 3 for every option. Options 1, 3, and 4 use the layout shown below with 3 branches.

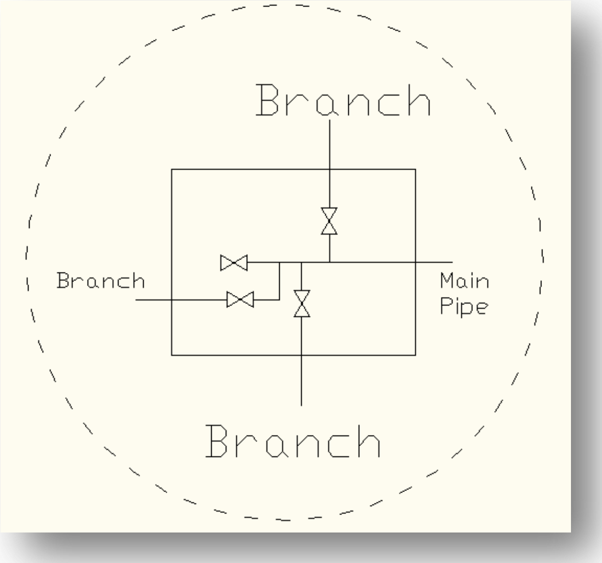


Figure 10.29 3 Branch Valve Vault

The second layout for the vault is when only 2 branches are connected. This applies to Options 4, and 5. Option 4 uses two 3 branch vaults, and one 2 branch vault. The two branch system is shown in Figures 10.30 and 10.31 below.

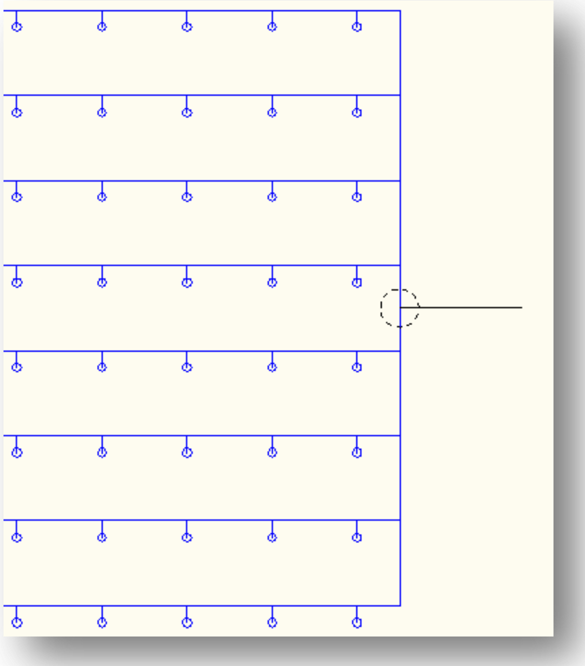


Figure 10.30 Valve Vault Location

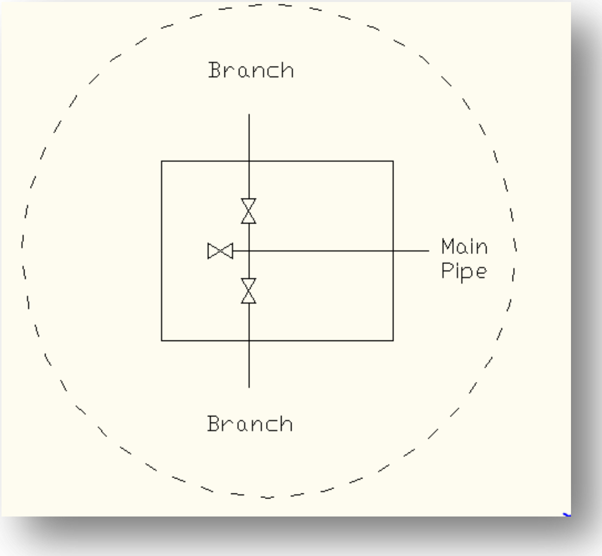


Figure 10.31 2 Branch Valve Vault

The vaults located at each loop will allow for easy access to the pipes. As shown in the figures, there is also a purge valve in each vault to clear the lines if needed. The vaults are necessary to ensure a maintainable system. Shown in the vaults are the gate valves that are taken into account in the head loss equations. These are there to turn off the flow to the branches.

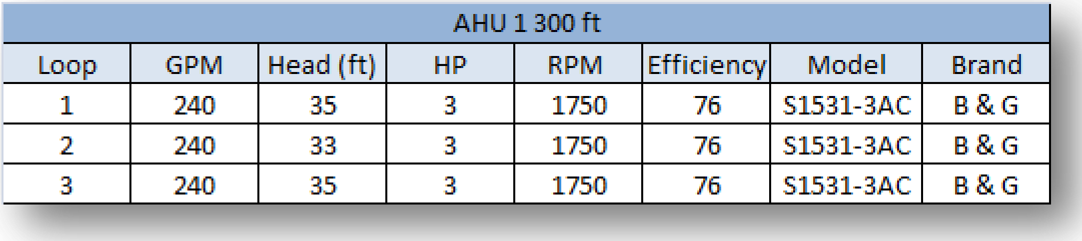
Pumps and Energy

After calculating the appropriate head losses and flow rates the pumps are sized to handle these parameters. Two methods were done to determine the pumps. The first was using only one pump per loop. This was initially done due to the belief that it may be cheaper to only run one pump. The second method was to use two pumps. This was done because two pumps could potentially save more money because they will be more efficient at part load, and they will be smaller. Each pump in the two pump method was sized for 60% capacity of the gpm and head loss. The two pump system is also more reliable because if one pump fails, there is still one running that can continue to operate. In the one pump system, if that pump fails, then the whole loop will be shut down.

Method 1 One Pump Per Loop

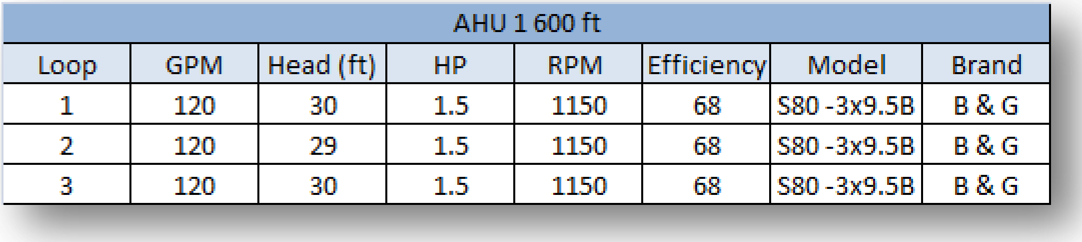
The first method required selecting one pump for each loop. This would have to be able to handle the max gpm and head loss. It was important for both methods to select pumps that would operate very close to the pumps max efficiency. The manufacturer for the pumps selected was Bell & Gossett. This is because much of the mechanical equipment for the building is from this manufacturer. All the pump curves for the pumps selected with the operating points shown can be seen in Appendix E.

The following tables show the pump selections and criteria for each option. Option 1 was the first system to be sized. Table 10.32 shows the required gpm and head loss for each loop, as well as the selected pumps.



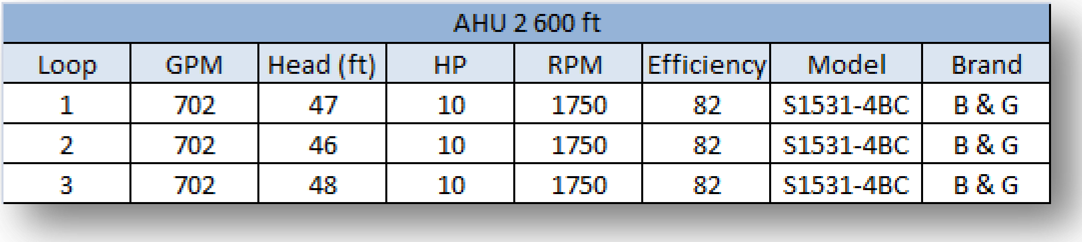
AHU 1 300 ft							
Loop	GPM	Head (ft)	HP	RPM	Efficiency	Model	Brand
1	240	35	3	1750	76	S1531-3AC	B & G
2	240	33	3	1750	76	S1531-3AC	B & G
3	240	35	3	1750	76	S1531-3AC	B & G

Table 10.32 Pump Selections for Option 1



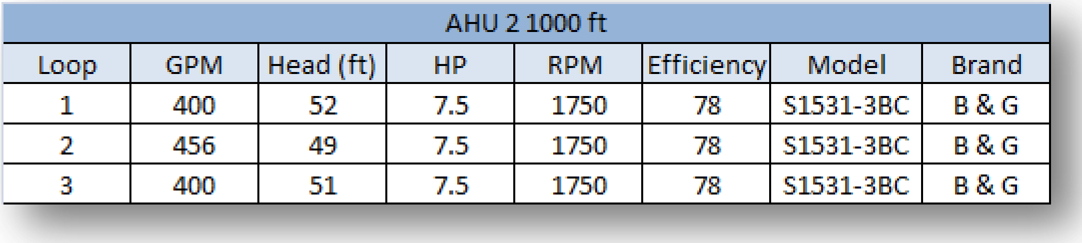
AHU 1 600 ft							
Loop	GPM	Head (ft)	HP	RPM	Efficiency	Model	Brand
1	120	30	1.5	1150	68	S80 -3x9.5B	B & G
2	120	29	1.5	1150	68	S80 -3x9.5B	B & G
3	120	30	1.5	1150	68	S80 -3x9.5B	B & G

Table 10.33 Pump Selections for Option 2



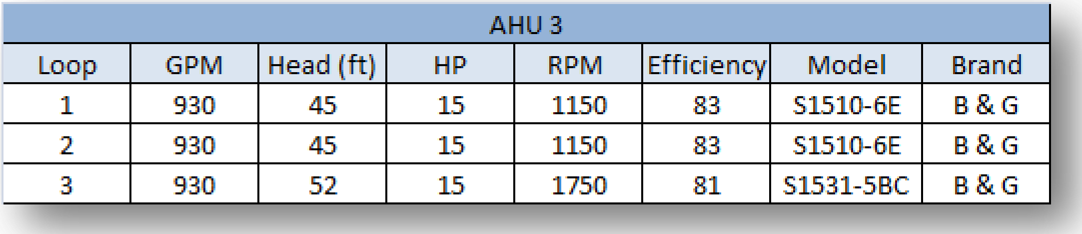
AHU 2 600 ft							
Loop	GPM	Head (ft)	HP	RPM	Efficiency	Model	Brand
1	702	47	10	1750	82	S1531-4BC	B & G
2	702	46	10	1750	82	S1531-4BC	B & G
3	702	48	10	1750	82	S1531-4BC	B & G

Table 10.34 Pump Selections for Option 3



AHU 2 1000 ft							
Loop	GPM	Head (ft)	HP	RPM	Efficiency	Model	Brand
1	400	52	7.5	1750	78	S1531-3BC	B & G
2	456	49	7.5	1750	78	S1531-3BC	B & G
3	400	51	7.5	1750	78	S1531-3BC	B & G

Table 10.35 Pump Selections for Option 4



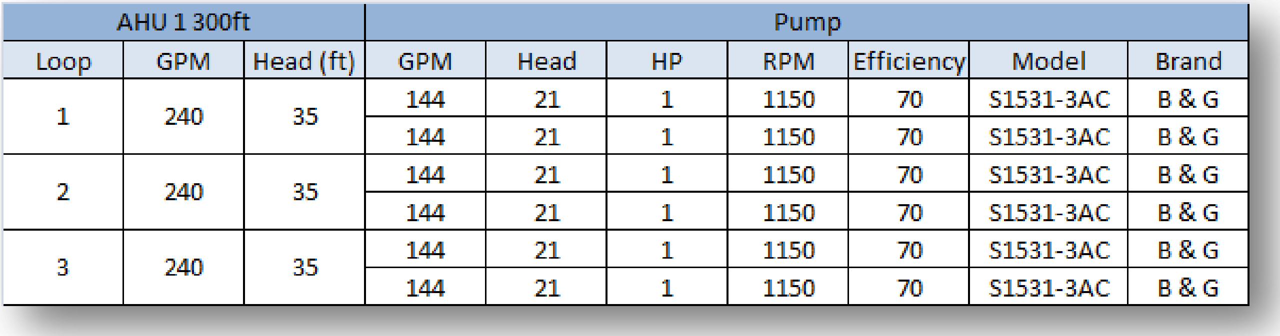
AHU 3							
Loop	GPM	Head (ft)	HP	RPM	Efficiency	Model	Brand
1	930	45	15	1150	83	S1510-6E	B & G
2	930	45	15	1150	83	S1510-6E	B & G
3	930	52	15	1750	81	S1531-5BC	B & G

Table 1.36 Pump Selections for Option 5

As seen in the above tables, the greater the size of the system, the better the efficiency of the pumps selected. It was difficult to find a pump for the smaller systems with efficiency above 65%. Research has shown that a pump efficiency of 70% is acceptable. The lowest efficiency for the one pump systems is 68%, with the other efficiencies being well above that. Another key factor is the horsepower. For the one pump system the horsepower required by the pumps is quite large, and that will play a significant factor in determine if a one pump or two pump system is more economical.

Method 2 2 Pumps Per Loop

Method 2 contains two pumps per loop. It was already known that this system would be more reliable than a one pump system, but energy use is another important factor for the pumps. The following tables contain the pump information for the different options using Method 2.



AHU 1 300ft			Pump						
Loop	GPM	Head (ft)	GPM	Head	HP	RPM	Efficiency	Model	Brand
1	240	35	144	21	1	1150	70	S1531-3AC	B & G
			144	21	1	1150	70	S1531-3AC	B & G
2	240	35	144	21	1	1150	70	S1531-3AC	B & G
			144	21	1	1150	70	S1531-3AC	B & G
3	240	35	144	21	1	1150	70	S1531-3AC	B & G
			144	21	1	1150	70	S1531-3AC	B & G

Table 10.37 Pump Selections for Option 1

AHU 1 600 ft			Pump						
Loop	GPM	Head (ft)	GPM	Head	HP	RPM	Efficiency	Model	Brand
1	120	30	72	18	0.5	1150	66	S1531-1/2AC	B & G
			72	18	0.5	1150	66	S1531-1/2AC	B & G
2	120	29	72	18	0.5	1150	66	S1531-1/2AC	B & G
			72	18	0.5	1150	66	S1531-1/2AC	B & G
3	120	30	72	18	0.5	1150	66	S1531-1/2AC	B & G
			72	18	0.5	1150	66	S1531-1/2AC	B & G

Table 10.38 Pump Selections for Option 2

AHU 2 600 ft			Pump						
Loop	GPM	Head (ft)	GPM	Head	HP	RPM	Efficiency	Model	Brand
1	702	47	421	28	5	1150	82.5	S1510-4BC	B & G
			421	28	5	1150	82.5	S1510-4BC	B & G
2	702	46	421	28	5	1150	82.5	S1510-4BC	B & G
			421	28	5	1150	82.5	S1510-4BC	B & G
3	702	48	421	28	5	1150	82.5	S1510-4BC	B & G
			421	28	5	1150	82.5	S1510-4BC	B & G

Table 10.39 Pump Selections for Option 3

AHU 2 1000 ft			Pump						
Loop	GPM	Head (ft)	GPM	Head	HP	RPM	Efficiency	Model	Brand
1	400	52	240	31	3	1150	76	S1531-3BC	B & G
			240	31	3	1150	76	S1531-3BC	B & G
2	456	49	273	31	3	1150	78	S1531-3BC	B & G
			273	31	3	1150	78	S1531-3BC	B & G
3	400	51	240	31	3	1150	76	S1531-3BC	B & G
			240	31	3	1150	76	S1531-3BC	B & G

Table 10.40 Pump Selections for Option 4

AHU 3			Pump						
Loop	GPM	Head (ft)	GPM	Head	HP	RPM	Efficiency	Model	Brand
1	930	45	558	27	5	1150	83	S1531-4BC	B & G
			558	27	5	1150	83	S1531-4BC	B & G
2	930	45	558	27	5	1150	83	S1531-4BC	B & G
			558	27	5	1150	83	S1531-4BC	B & G
3	930	52	558	31	5	1150	83	S1531-4BC	B & G
			558	31	5	1150	83	S1531-4BC	B & G

Table 10.41 Pump Selections for Option 5

The efficiencies of the pumps are very similar compared to that of Method 1. However, the hp of the pumps for Method 2 is lower, but there are more pumps. It is necessary to calculate the energy used by the pumps. This will ultimately decide whether a one pump or two pump system is used.

Pump and Heat Pump Energy Calculations

The pump energy was calculated using the following equation:

$$\dot{W} = \frac{.746\ x\ HP}{\eta}$$

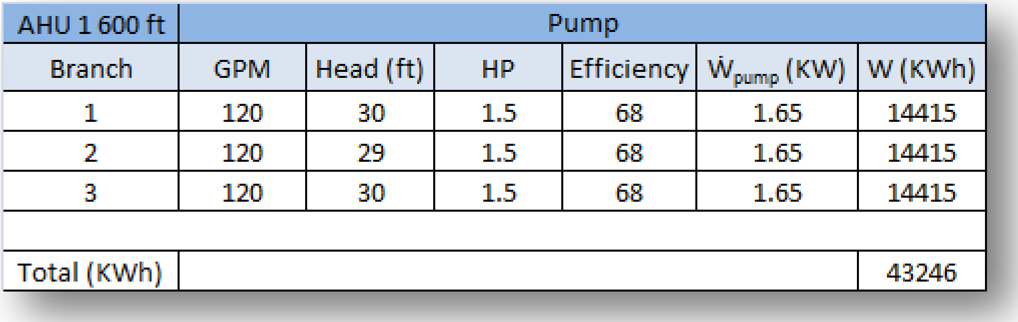
$\dot{w}$ = pump energy use (KW)
HP = horsepower (hp)
η = pump efficiency

The pump energy was then multiplied by the amount of hours it would be running to obtain the KWh. The calculations are assuming that the pump will be running at all hours.

The calculated values for Method 1 are shown in the tables below.

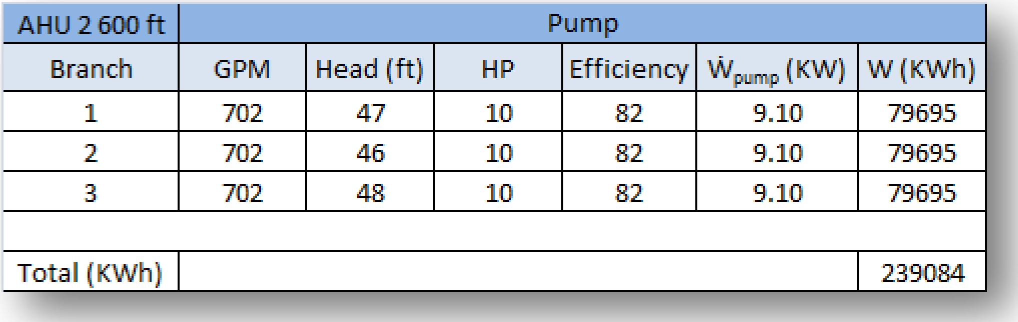
AHU 1 300 ft	Pump					
Branch	GPM	Head (ft)	HP	Efficiency	$\dot{W}_{pump}$ (KW)	W (KWh)
1	240	35	3	76	2.94	25796
2	240	33	3	76	2.94	25796
3	240	35	3	76	2.94	25796
Total (KWh)						77388

Table 10.42 Pump Power for Option 1



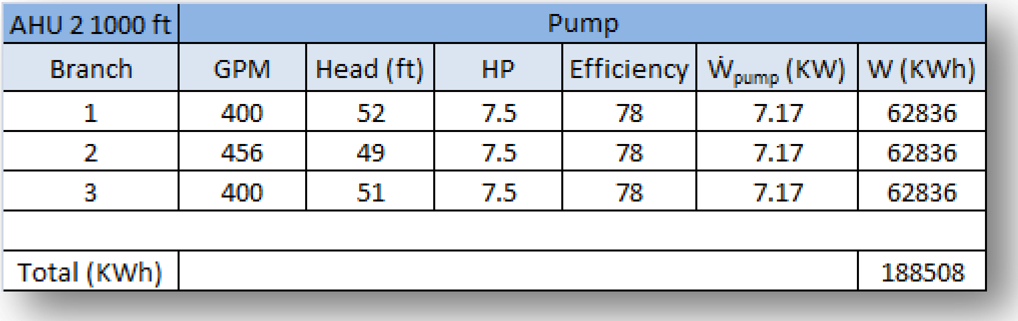
AHU 1 600 ft	Pump					
Branch	GPM	Head (ft)	HP	Efficiency	$\dot{W}_{pump}$ (KW)	W (KWh)
1	120	30	1.5	68	1.65	14415
2	120	29	1.5	68	1.65	14415
3	120	30	1.5	68	1.65	14415
Total (KWh)						43246

Table 10.42 Pump Power for Option 2



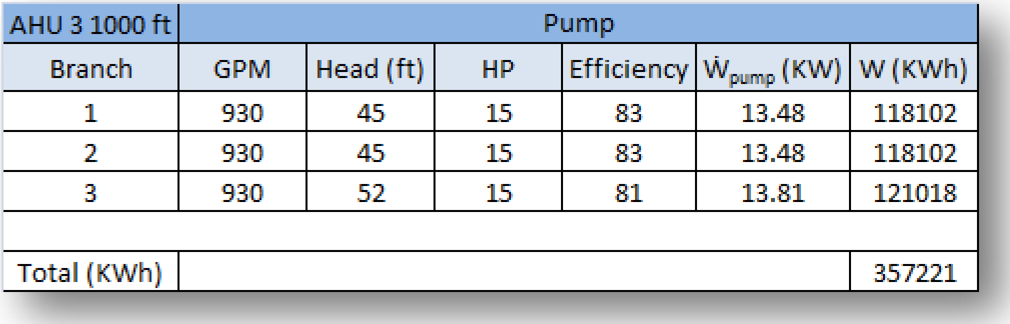
AHU 2 600 ft	Pump					
Branch	GPM	Head (ft)	HP	Efficiency	$\dot{W}_{pump}$ (KW)	W (KWh)
1	702	47	10	82	9.10	79695
2	702	46	10	82	9.10	79695
3	702	48	10	82	9.10	79695
Total (KWh)						239084

Table 10.43 Pump Power for Option 3



AHU 2 1000 ft	Pump					
Branch	GPM	Head (ft)	HP	Efficiency	$\dot{W}_{pump}$ (KW)	W (KWh)
1	400	52	7.5	78	7.17	62836
2	456	49	7.5	78	7.17	62836
3	400	51	7.5	78	7.17	62836
Total (KWh)						188508

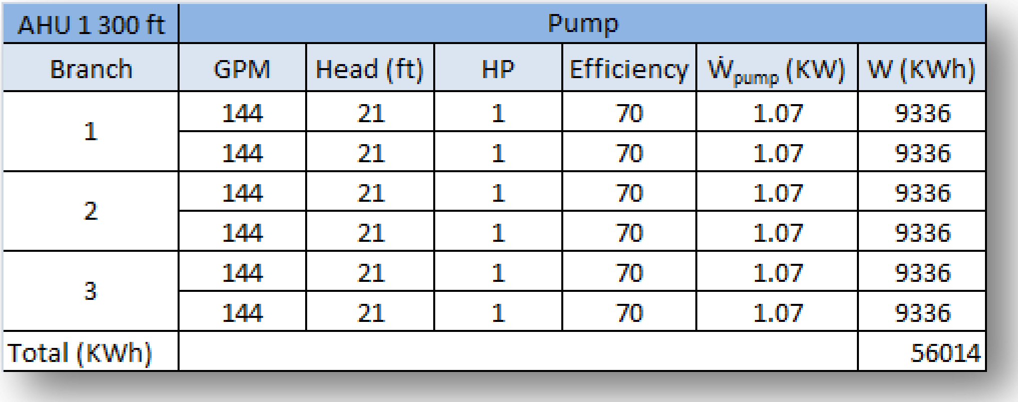
Table 10.44 Pump Power for Option 4



AHU 3 1000 ft	Pump					
Branch	GPM	Head (ft)	HP	Efficiency	$\dot{W}_{pump}$ (KW)	W (KWh)
1	930	45	15	83	13.48	118102
2	930	45	15	83	13.48	118102
3	930	52	15	81	13.81	121018
Total (KWh)						357221

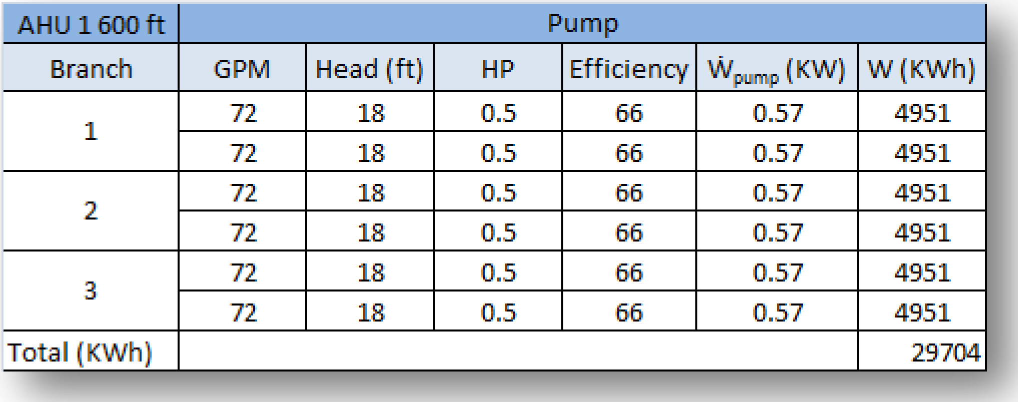
Table 10.45 Pump Power for Option 5

The total power of the pumps was added up for each option. Obviously as the system gets larger, the pump power increases as well. These numbers are going to be compared to Method 2 values which are shown in the tables below.



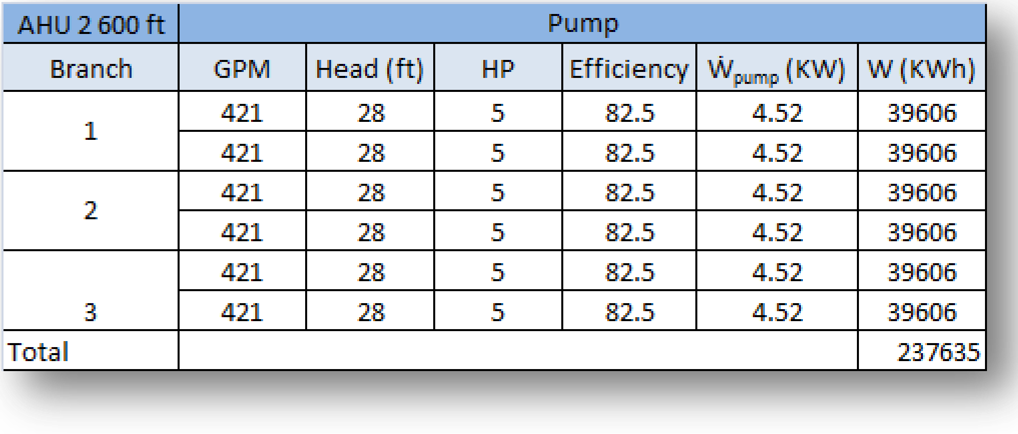
AHU 1 300 ft	Pump					
Branch	GPM	Head (ft)	HP	Efficiency	$\dot{W}_{pump}$ (KW)	W (KWh)
1	144	21	1	70	1.07	9336
	144	21	1	70	1.07	9336
2	144	21	1	70	1.07	9336
	144	21	1	70	1.07	9336
3	144	21	1	70	1.07	9336
	144	21	1	70	1.07	9336
Total (KWh)						56014

Table 10.46 Pump Power for Option 1



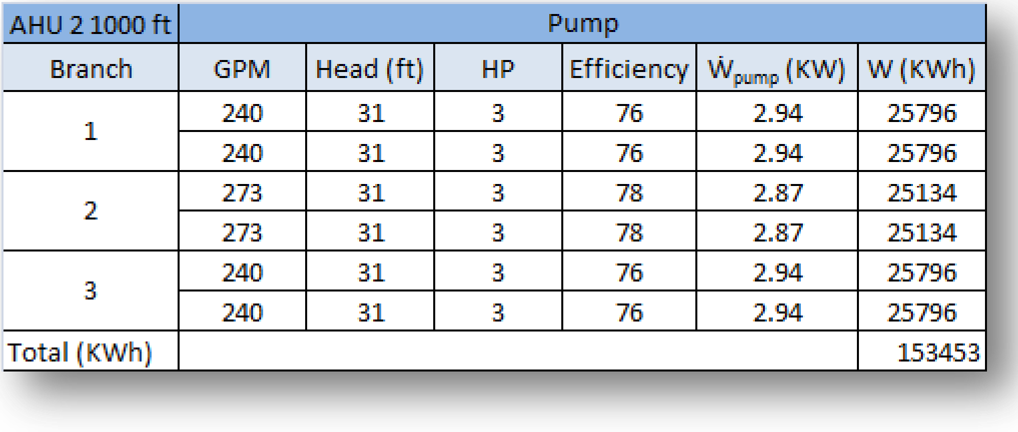
AHU 1 600 ft	Pump					
Branch	GPM	Head (ft)	HP	Efficiency	$\dot{W}_{pump}$ (KW)	W (KWh)
1	72	18	0.5	66	0.57	4951
	72	18	0.5	66	0.57	4951
2	72	18	0.5	66	0.57	4951
	72	18	0.5	66	0.57	4951
3	72	18	0.5	66	0.57	4951
	72	18	0.5	66	0.57	4951
Total (KWh)						29704

Table 10.47 Pump Power for Option 2



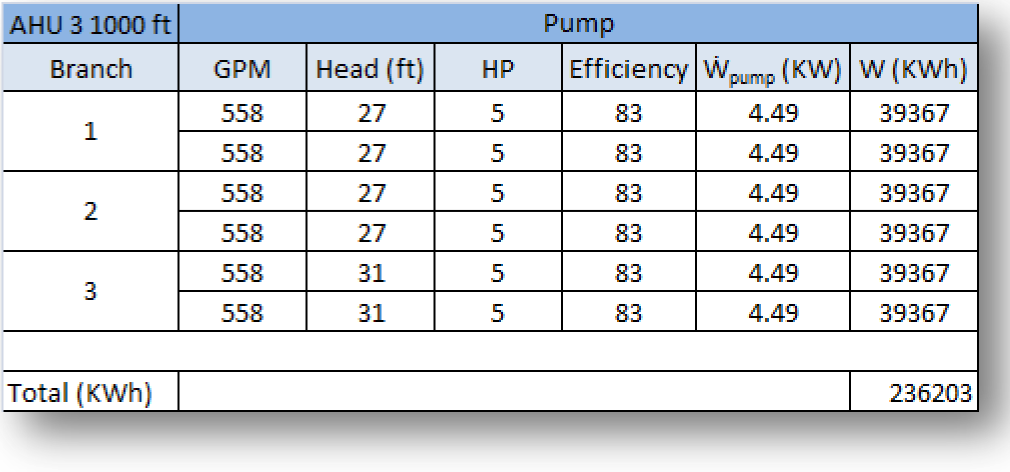
AHU 2 600 ft	Pump					
Branch	GPM	Head (ft)	HP	Efficiency	$\dot{W}_{pump}$ (KW)	W (KWh)
1	421	28	5	82.5	4.52	39606
	421	28	5	82.5	4.52	39606
2	421	28	5	82.5	4.52	39606
	421	28	5	82.5	4.52	39606
	421	28	5	82.5	4.52	39606
3	421	28	5	82.5	4.52	39606
Total						237635

Table 10.48 Pump Power for Option 3



AHU 2 1000 ft	Pump					
Branch	GPM	Head (ft)	HP	Efficiency	$\dot{W}_{pump}$ (KW)	W (KWh)
1	240	31	3	76	2.94	25796
	240	31	3	76	2.94	25796
2	273	31	3	78	2.87	25134
	273	31	3	78	2.87	25134
3	240	31	3	76	2.94	25796
	240	31	3	76	2.94	25796
Total (KWh)						153453

Table 10.49 Pump Power for Option 4



AHU 3 1000 ft	Pump					
Branch	GPM	Head (ft)	HP	Efficiency	$\dot{W}_{pump}$ (KW)	W (KWh)
1	558	27	5	83	4.49	39367
	558	27	5	83	4.49	39367
2	558	27	5	83	4.49	39367
	558	27	5	83	4.49	39367
3	558	31	5	83	4.49	39367
	558	31	5	83	4.49	39367
Total (KWh)						236203

Table 10.50 Pump Power for Option 5

After comparing Methods 1 and 2 it is apparent that the two pump system will be cheaper to operate. Most options require less pump energy than a one pump system. This is ideal because the two pump system will also be more reliable. Option 5 has a large drop off in pump energy when using a two pump system, saving 120,000 KWh. All the other 2 pumps systems use anywhere from 20,000 to 30,000 KWh. This confirms the decision that a two pump configuration will be used in the GSHP design.

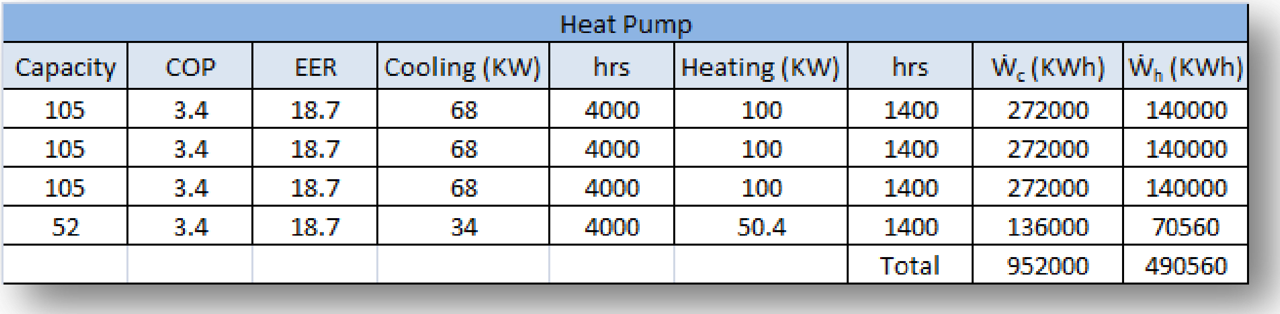
The next step is to calculate the energy used for the Heat Pumps themselves. The manufacturer of the heat pumps, Commercial Aire, provided the amount of energy used at the specific tonnage. Different sized heat pumps and configurations were used in the different options.

The energy used for the heat pumps was calculated by taking the manufacturers energy specifications (KW) and multiplying it by the amount of hours the system would be running. This would give a value of KWh, which will then be added to the pump power to determine the overall system energy use for each option.

Once again, 2 methods were used to determine the amount of heat pumps required. Method 1 will be designed for the minimal amount of heat pumps on the system. Method 2 will use more heat pumps with a smaller capacity for the total system. The purpose of this is to investigate whether it saves energy to use more smaller units, or less larger units.

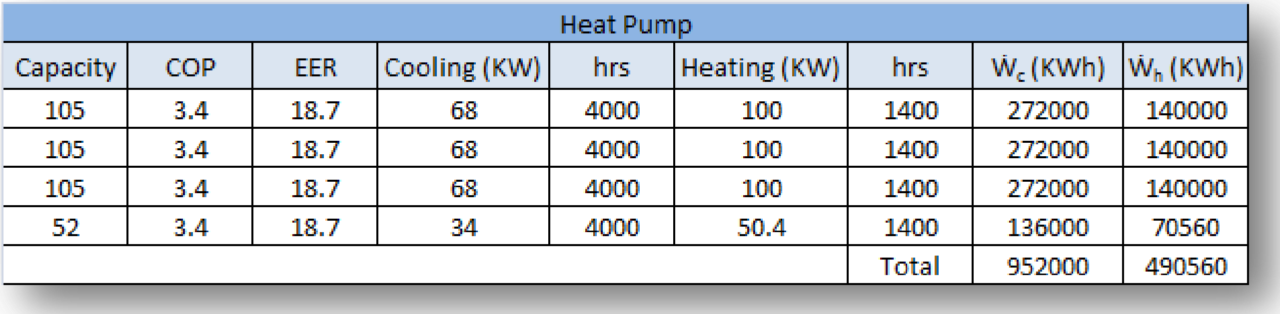
Method 1 Large Units

The tables below show the results for Method 1, the minimal amount of heat pumps on the system with a larger capacity. All four options will require 4 heat pumps total. The maximum size of heat pump found that was commercially made was 193 tons.



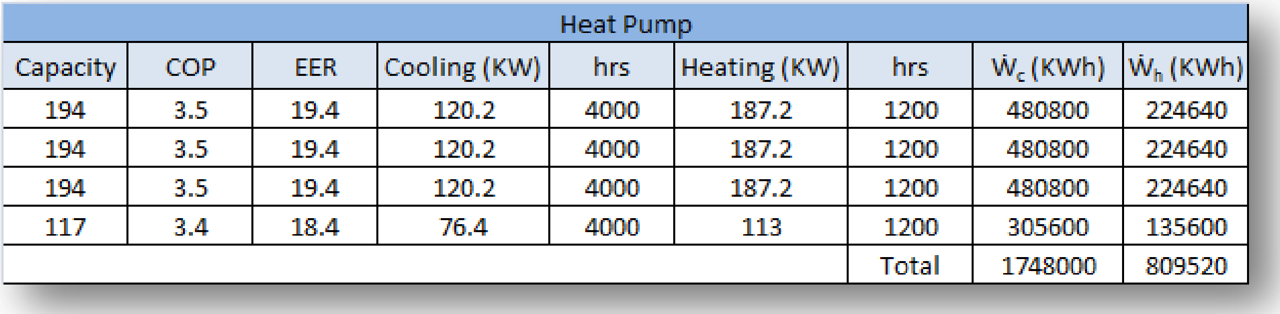
Heat Pump								
Capacity	COP	EER	Cooling (KW)	hrs	Heating (KW)	hrs	$\dot{W}_c$ (KWh)	$\dot{W}_h$ (KWh)
105	3.4	18.7	68	4000	100	1400	272000	140000
105	3.4	18.7	68	4000	100	1400	272000	140000
105	3.4	18.7	68	4000	100	1400	272000	140000
52	3.4	18.7	34	4000	50.4	1400	136000	70560
						Total	952000	490560

Table 10.51 Heat Pump Power Option 1



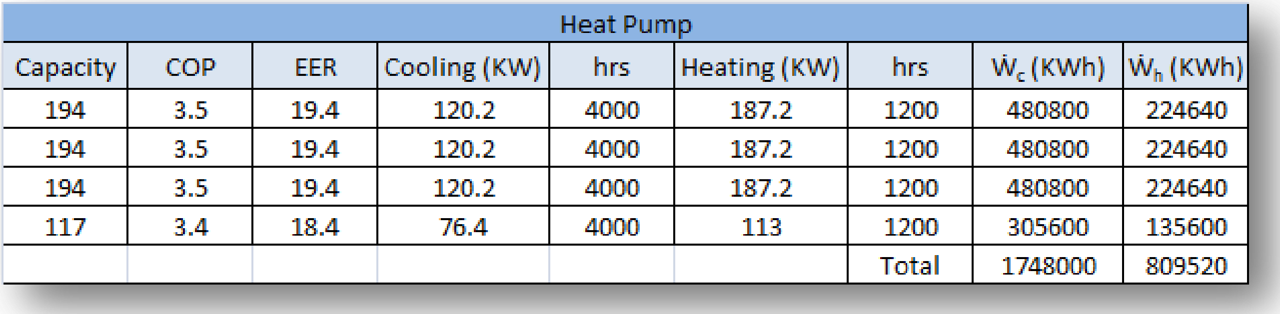
Heat Pump								
Capacity	COP	EER	Cooling (KW)	hrs	Heating (KW)	hrs	$\dot{W}_c$ (KWh)	$\dot{W}_h$ (KWh)
105	3.4	18.7	68	4000	100	1400	272000	140000
105	3.4	18.7	68	4000	100	1400	272000	140000
105	3.4	18.7	68	4000	100	1400	272000	140000
52	3.4	18.7	34	4000	50.4	1400	136000	70560
						Total	952000	490560

Table 10.52 Heat Pump Power Option 2



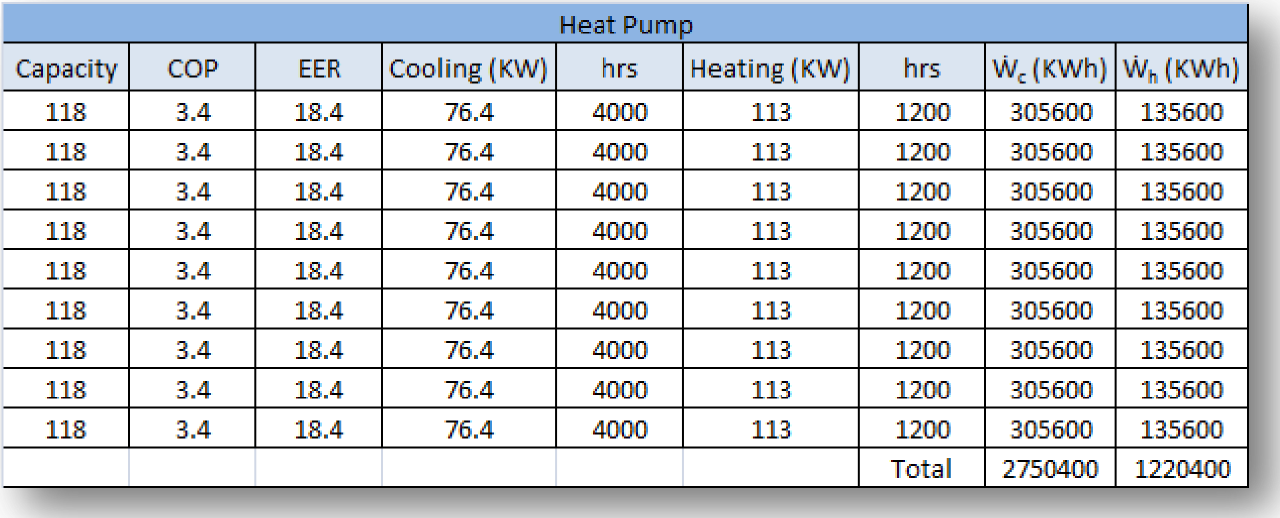
Heat Pump								
Capacity	COP	EER	Cooling (KW)	hrs	Heating (KW)	hrs	$\dot{W}_c$ (KWh)	$\dot{W}_h$ (KWh)
194	3.5	19.4	120.2	4000	187.2	1200	480800	224640
194	3.5	19.4	120.2	4000	187.2	1200	480800	224640
194	3.5	19.4	120.2	4000	187.2	1200	480800	224640
117	3.4	18.4	76.4	4000	113	1200	305600	135600
						Total	1748000	809520

Table 10.53 Heat Pump Power Option 3



Heat Pump								
Capacity	COP	EER	Cooling (KW)	hrs	Heating (KW)	hrs	$\dot{W}_c$ (KWh)	$\dot{W}_h$ (KWh)
194	3.5	19.4	120.2	4000	187.2	1200	480800	224640
194	3.5	19.4	120.2	4000	187.2	1200	480800	224640
194	3.5	19.4	120.2	4000	187.2	1200	480800	224640
117	3.4	18.4	76.4	4000	113	1200	305600	135600
						Total	1748000	809520

Table 10.54 Heat Pump Power Option 4



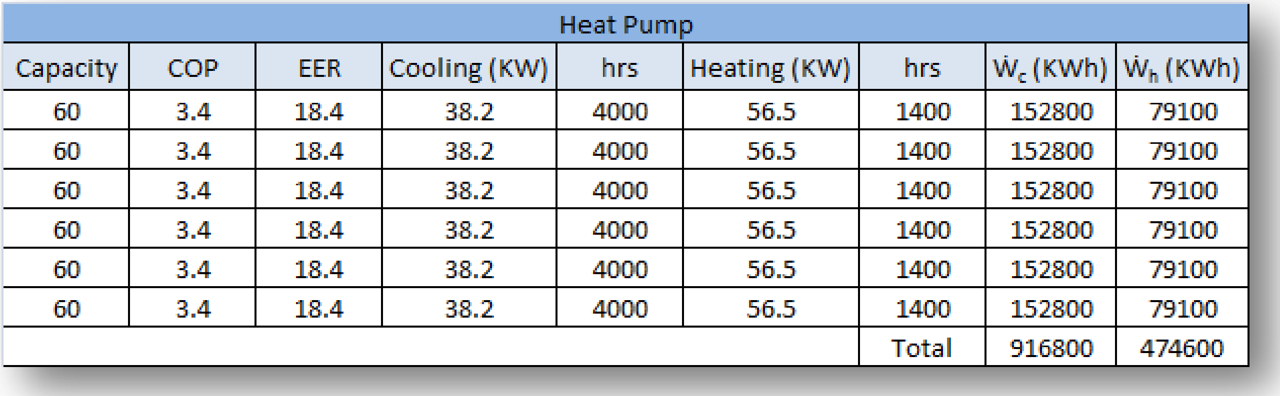
Heat Pump								
Capacity	COP	EER	Cooling (KW)	hrs	Heating (KW)	hrs	$\dot{W}_c$ (KWh)	$\dot{W}_h$ (KWh)
118	3.4	18.4	76.4	4000	113	1200	305600	135600
118	3.4	18.4	76.4	4000	113	1200	305600	135600
118	3.4	18.4	76.4	4000	113	1200	305600	135600
118	3.4	18.4	76.4	4000	113	1200	305600	135600
118	3.4	18.4	76.4	4000	113	1200	305600	135600
118	3.4	18.4	76.4	4000	113	1200	305600	135600
118	3.4	18.4	76.4	4000	113	1200	305600	135600
118	3.4	18.4	76.4	4000	113	1200	305600	135600
118	3.4	18.4	76.4	4000	113	1200	305600	135600
						Total	2750400	1220400

Table 10.55 Heat Pump Power Option 5

Option 5 is the only option that will not be designed by both methods. This is because the large size of the system will require a large amount of heat pumps anyway.

Method 2 Small Units

The tables for Method 2 are shown below. This was studied because the increased number of smaller heat pumps may reduce the amount of energy used for the whole system.



Heat Pump								
Capacity	COP	EER	Cooling (KW)	hrs	Heating (KW)	hrs	$\dot{W}_c$ (KWh)	$\dot{W}_h$ (KWh)
60	3.4	18.4	38.2	4000	56.5	1400	152800	79100
60	3.4	18.4	38.2	4000	56.5	1400	152800	79100
60	3.4	18.4	38.2	4000	56.5	1400	152800	79100
60	3.4	18.4	38.2	4000	56.5	1400	152800	79100
60	3.4	18.4	38.2	4000	56.5	1400	152800	79100
60	3.4	18.4	38.2	4000	56.5	1400	152800	79100
						Total	916800	474600

Table 10.56 Heat Pump Power Option 1

Heat Pump								
Capacity	COP	EER	Cooling (KW)	hrs	Heating (KW)	hrs	$\dot{W}_c$ (KWh)	$\dot{W}_h$ (KWh)
60	3.4	18.4	38.2	4000	56.5	1400	152800	79100
60	3.4	18.4	38.2	4000	56.5	1400	152800	79100
60	3.4	18.4	38.2	4000	56.5	1400	152800	79100
60	3.4	18.4	38.2	4000	56.5	1400	152800	79100
60	3.4	18.4	38.2	4000	56.5	1400	152800	79100
60	3.4	18.4	38.2	4000	56.5	1400	152800	79100
						Total	916800	474600

Table 10.57 Heat Pump Power Option 2

Heat Pump								
Capacity	COP	EER	Cooling (KW)	hrs	Heating (KW)	hrs	$\dot{W}_c$ (KWh)	$\dot{W}_h$ (KWh)
117	3.4	18.4	76.4	4000	113	1200	305600	135600
117	3.4	18.4	76.4	4000	113	1200	305600	135600
117	3.4	18.4	76.4	4000	113	1200	305600	135600
117	3.4	18.4	76.4	4000	113	1200	305600	135600
117	3.4	18.4	76.4	4000	113	1200	305600	135600
117	3.4	18.4	76.4	4000	113	1200	305600	135600
						Total	1833600	813600

Table 10.58 Heat Pump Power Option 3

Heat Pump								
Capacity	COP	EER	Cooling (KW)	hrs	Heating (KW)	hrs	$\dot{W}_c$ (KWh)	$\dot{W}_h$ (KWh)
117	3.4	18.4	76.4	4000	113	1200	305600	135600
117	3.4	18.4	76.4	4000	113	1200	305600	135600
117	3.4	18.4	76.4	4000	113	1200	305600	135600
117	3.4	18.4	76.4	4000	113	1200	305600	135600
117	3.4	18.4	76.4	4000	113	1200	305600	135600
117	3.4	18.4	76.4	4000	113	1200	305600	135600
						Total	1833600	813600

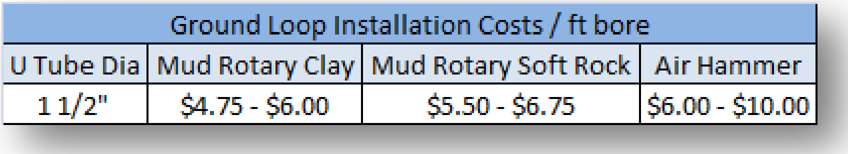
Table 10.59 Heat Pump Power Option 4

Looking at the final energy results, it is clear that Method 1 is better in terms of energy consumption for Options 3 and 4. Method 2 is better for Options 1 and 2. The total consumption for Options 1 and 2 were 1,442,560 KWh for Method 1 and 1,391,400 KWh for Method 2. This is about 52,000 KWh less than Method 1. For Options 3 and 4 Method 1 is better. The total consumption for Options 3 and 4 were 2,557,520 KWh for Method 1 and 2,647,200 for Method 2. Method 1 saves about 89,000 KWh annually. In total Method 2 saves Options 1 and 2 about $7,000 a year and Method 1 saves Options 3 and 4 about $12,000. While these numbers seem like a lot, they are still too small to rule out using the other method. This is because the first cost of the heat pumps can differ greatly. In the next section the first costs of the heat pumps will ultimately decide what method is used.

Cost

The final step for designing a ground source heat pump is to determine the final cost. The total cost will comprise of multiple different factors. The first is the cost of drilling and pipe. This is a very important factor because the cost of this can be very high, especially the farther you drill. Another cost is the first cost of all the equipment needed. This includes the piping, pumps, and heat pumps. The other major cost is the pump and heat pump energy. If is important to keep these values as low as possible to reduce cost, and get the most out of the geothermal heat pump.

The cost of drilling is the first factor considered. The depth of the borehole will increase the drilling price greatly the deeper you drill. To get through a shallow layer a mud rotary drill must be used. This is used when digging through soil or clay. When the soft rock is reached a mud rotary drill will still be used to break through. It will be more expensive though since it will need to larger. Finally to get through hard rock, an air hammer drill must be used to get through the rock. The price of the drilling types differs greatly. Table 10.60 shows the average cost for drilling per ft through different types of materials. It will be assumed that the first 100 ft drilled will be clay, the next 100 ft will be soft rock, and the rest will be hard rock.



Ground Loop Installation Costs / ft bore			
U Tube Dia	Mud Rotary Clay	Mud Rotary Soft Rock	Air Hammer
1 1/2"	$4.75 - $6.00	$5.50 - $6.75	$6.00 - $10.00

Table 10.60 Ground Loop Costs

The cost of pipe is determined by looking up manufacturer prices. This usually includes a certain percentage discount if you are ordering a large amount of piping. In this case, there is a 5% discount for 100 ft – 200 ft. Between 200 ft – 600 ft there is a 10% discount. For all lengths over 600 ft there is a 15% discount. These discounts help save money on first costs of pipe.

The specific pricing information for the heat pumps was not available. However, research was done on 12 heat pump prices in $/ton capacity. They ranged from $257/ton to $857/ton. The higher values will be used for this study since the heat pumps are large. $900/ton is what will be used to calculate the price of the heat pumps.

The final cost is the energy used for the pumps and heat pumps. The hospital uses Atlantic City Electric to provide electricity. Appendix D shows the rates used for the energy models, as well as calculating the cost for the pumps and heat pumps. The value used is $0.13 per KWh. Every option will be broken down to determine the final cost of installing and operating it. Maintenance and operating costs will not be included in this report, however, compared to that of a traditional HVAC system, a GSHP is significantly cheaper.

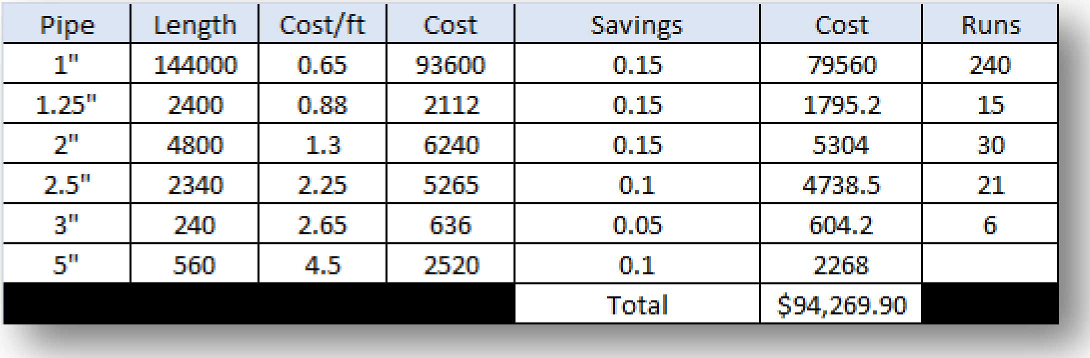
Option 1 AHU 1 300 ft

Table 10.61 shows the cost of drilling for Option 1.

	borehole length	# boreholes	clay	soft rock	hard rock	cost/ft clay	cost/ft soft rock	cost/ft hard rock	Total Cost/hole	Total Cost
AHU1	300	241	100	100	100	$5.00	$5.50	$7	$1,750.00	421750

Table 10.61 Drilling Cost

The cost of drilling is $462,000 to drill 120 boreholes at 600 ft each. This price is the cheapest of all the options because of the depth. This being the small system, it shows how much the first cost of drilling is.



Pipe	Length	Cost/ft	Cost	Savings	Cost	Runs
1"	144000	0.65	93600	0.15	79560	240
1.25"	2400	0.88	2112	0.15	1795.2	15
2"	4800	1.3	6240	0.15	5304	30
2.5"	2340	2.25	5265	0.1	4738.5	21
3"	240	2.65	636	0.05	604.2	6
5"	560	4.5	2520	0.1	2268	
				Total	$94,269.90	

Table 10.62 Pipe Cost

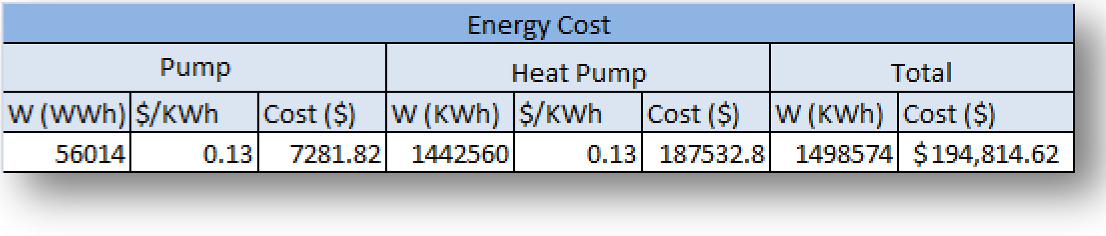
The pipe cost will also be a major contributor in the first cost. The total lengths for each size of pipe were totaled up over all 3 loops. As seen in the table above, Table 10.62, all the lengths quality for a discount. This helps keep the price down for the pipes.

There will be six Series 1531 – 3AC pumps being used in total for this system. With a manufacturer price of $2,233, the total price of the pumps will be $13,398. In addition to this first cost will be the first cost of the heat pumps used.

The heat pumps used for Method 1 are three 105 ton units, and one 52 ton unit. Using the $900/ton estimation, each 105 ton unit will cost $94,500. The 52 ton unit will cost $48,600. This gives a total first cost of $332,100. Method 2 will use six 60 ton units. At a cost of $54,000 per unit, the total first cost for Method 2 would be $324,000. Once again, both values are very close.

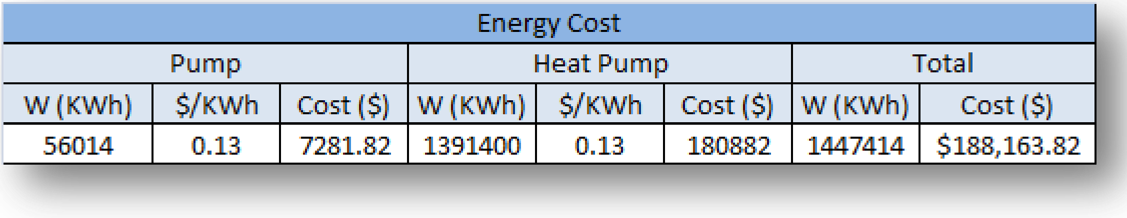
The total first cost for Method 1 will the drilling, pipes, pumps, and heat pumps from the first method of calculations. This total will end up being $861,550. The first cost for Method 2 will have the same factors except for the method 2 cost for the heat pumps. This is a total first cost of $853,450.

The cost of running the pumps and heat pumps annually is shown below in Table 10.63 for heat pump Method 1 and Table 10.64 for heat pump Method 2. These values will be compared to the annual energy cost to run the chillers and boilers in the current design.



Energy Cost							
Pump			Heat Pump			Total	
W (WWh)	$/KWh	Cost ($)	W (KWh)	$/KWh	Cost ($)	W (KWh)	Cost ($)
56014	0.13	7281.82	1442560	0.13	187532.8	1498574	$ 194,814.62

Table 10.63 Method 1 Energy Costs Option 1



Energy Cost							
Pump			Heat Pump			Total	
W (KWh)	$/KWh	Cost ($)	W (KWh)	$/KWh	Cost ($)	W (KWh)	Cost ($)
56014	0.13	7281.82	1391400	0.13	180882	1447414	$188,163.82

Table 10.64 Method 2 Energy Costs Option 1

Looking at the tables above, Method 2 is the cheapest system to operate. It also has the lower first cost compared to Method 1. Therefore, Method 2 will be used for Option 1, containing six 60 ton heat pumps.

The total annual energy use by the current chiller system is 11,911,880 KWh. This includes both the chillers and the cooling towers. The pumps for the current system were not included in this because they will be needed to pump the chilled water to the AHUs, and will remain in the redesigned system.

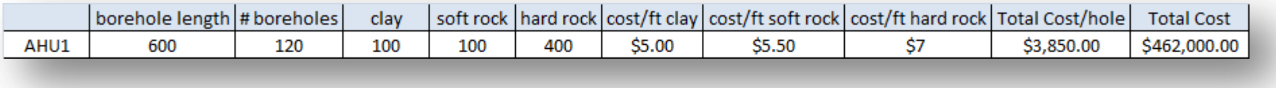
The annual cost for the chillers and cooling towers combined is just under $1.5 million. AHU 1 accounts for around 10% of the total chiller energy. The annual energy consumed for AHU 1 is therefore around 1,191,188 KWh, which is about $154,000.

For heating the annual cost is around 1,432,446 therms for the boilers themselves. This does not include pumps for pumping the hot water since they will not be replaced by the heat pump. AHU 1 accounts for 10% of the boilers as well, which is 143,244 therms, which is about $171,893.

So in total AHU 1 uses around $325,000 annually. Using the heat pumps nearly cuts the annual energy cost in half. The ground source heat pump will save the hospital $137,000 annually in operating costs. Compared to the $853,450 first cost, this leaves a simple payback period of 6 and a half years. The first cost does not include labor for laying out the pipe, as well as installing the pumps and heat pumps. This could increase the payback period. With a payback period of 6.5 years this could be a legitimate option for saving energy.

Option 2 AHU 1 600 ft

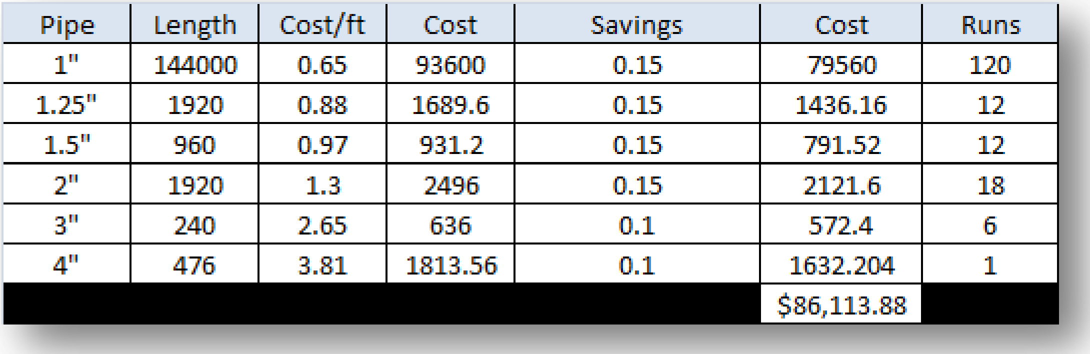
Table 10.65 shows the Drilling costs for Option 2



	borehole length	# boreholes	clay	soft rock	hard rock	cost/ft clay	cost/ft soft rock	cost/ft hard rock	Total Cost/hole	Total Cost
AHU1	600	120	100	100	400	$5.00	$5.50	$7	$3,850.00	$462,000.00

Table 10.65 Drilling Cost

The pipe cost is shown below in Table 10.66. Once again the lengths of pipe were summed up for each size pipe.



Pipe	Length	Cost/ft	Cost	Savings	Cost	Runs
1"	144000	0.65	93600	0.15	79560	120
1.25"	1920	0.88	1689.6	0.15	1436.16	12
1.5"	960	0.97	931.2	0.15	791.52	12
2"	1920	1.3	2496	0.15	2121.6	18
3"	240	2.65	636	0.1	572.4	6
4"	476	3.81	1813.56	0.1	1632.204	1
					$86,113.88	

Table 10.66 Pipe Cost

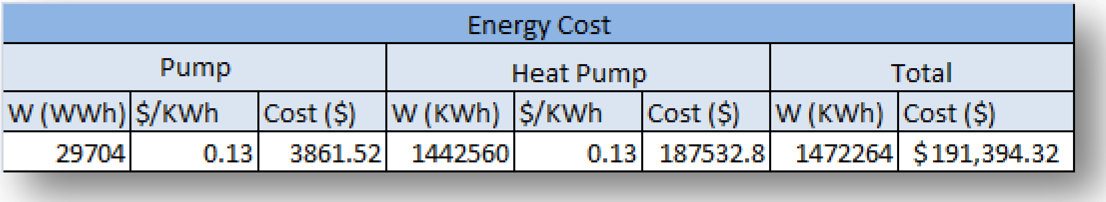
It is important to note that for the deeper bores the drilling price increased, however the pipe cost has decreased. However, Option 1 is still cheaper to install based on pipe price and drilling price combined.

The pumps used for Option 2 will be Series 1531 – ½ AC. There will be six pumps with each pump costing $2,000. The total for the six pumps will be $12,000. This is also cheaper than Option 1, but still doesn't beat the overall first cost price.

The heat pumps used for Method 1 are three 105 ton units, and one 52 ton unit. Using the $900/ton estimation, each 105 ton unit will cost $94,500. The 52 ton unit will cost $48,600. This gives a total first cost of $332,100. Method 2 will use six 60 ton units. At a cost of $54,000 per unit, the total first cost for Method 2 would be $324,000. Once again, both values are very close.

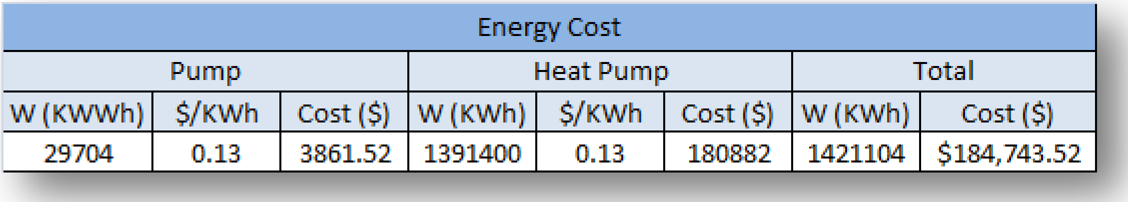
The total first cost for Method 1 will the drilling, pipes, pumps, and heat pumps from the first method of calculations. This total will end up being $892,000. The first cost for Method 2 will have the same factors except for the method 2 cost for the heat pumps. This is a total first cost of $884,450.

Option 2 is the same heat pump design as Option 1 since they are both AHU 1. Looking at Tables 10.67 for Method 1 and 10.68 for Method 2 shows the total energy used per year for Option 2.



Energy Cost							
Pump			Heat Pump			Total	
W (WWh)	$/KWh	Cost ($)	W (KWh)	$/KWh	Cost ($)	W (KWh)	Cost ($)
29704	0.13	3861.52	1442560	0.13	187532.8	1472264	$ 191,394.32

Table 10.67 Method 1 Energy Costs Option 2



Energy Cost							
Pump			Heat Pump			Total	
W (KWWh)	$/KWh	Cost ($)	W (KWh)	$/KWh	Cost ($)	W (KWh)	Cost ($)
29704	0.13	3861.52	1391400	0.13	180882	1421104	$184,743.52

Table 10.68 Method 2 Energy Costs Option 2

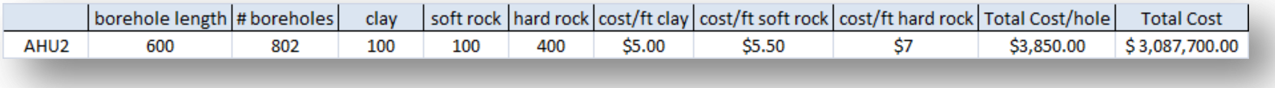
The cheapest operational costs are for the Method 2 layout. The cheaper first cost for this option is also Method 2. Once again the heat pump layout from Method 2 will be used, six 60 ton units. Once again this is a total first cost of $884,450.

Once again the current AHU 1 uses $325,000 annually in energy consumption. With a annual savings of $140,000 with the heat pump system, the simple payback period for Option 2 is also six and a half years. The payback period for Option 2 is slightly larger, but not enough to make a significant difference.

In terms of AHU 1, drilling the shorter boreholes seems to pay off a little better than deeper boreholes. Option 2 is only saves money on the pipes using a deeper borehole. However, this is not significant. This also does not affect the payback very much since the difference in the two options is so slim. If designing a ground source heat pump for AHU 1, I would choose to use Option 1, with the shorter boreholes. This is because the overall first cost is smaller than that of Option 2, but not by much. If the area of land for the boreholes was an issue, Option 2 might be a better choice.

Option 3 AHU 2 600 ft

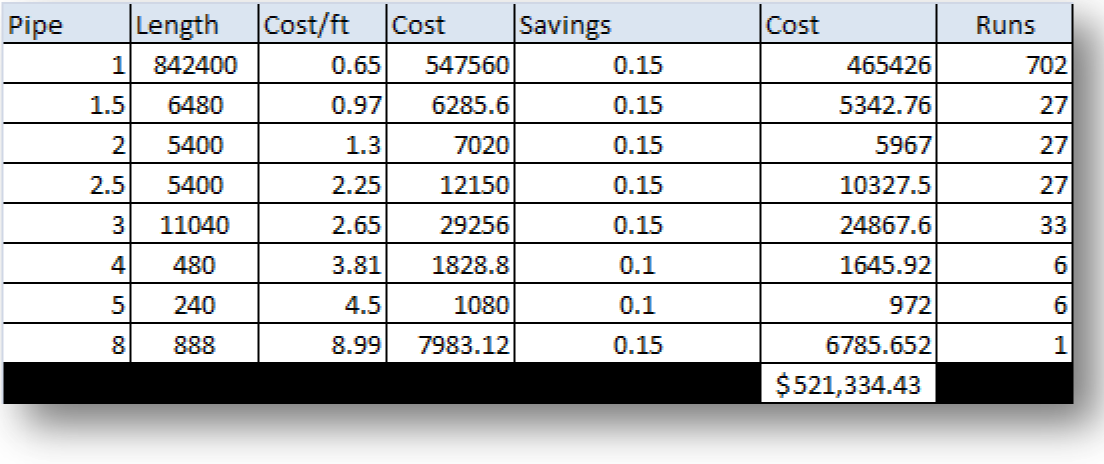
Table 10.69 shows the drilling cost for Option 3.



	borehole length	# boreholes	clay	soft rock	hard rock	cost/ft clay	cost/ft soft rock	cost/ft hard rock	Total Cost/hole	Total Cost
AHU2	600	802	100	100	400	$5.00	$5.50	$7	$3,850.00	$ 3,087,700.00

Table 10.69 Drilling Cost

As you can see the drilling cost increases significantly the deeper you drill. Table 10.70 below shows the pricing information for the pipes being used. The same process was followed as in the other two options.



Pipe	Length	Cost/ft	Cost	Savings	Cost	Runs
1	842400	0.65	547560	0.15	465426	702
1.5	6480	0.97	6285.6	0.15	5342.76	27
2	5400	1.3	7020	0.15	5967	27
2.5	5400	2.25	12150	0.15	10327.5	27
3	11040	2.65	29256	0.15	24867.6	33
4	480	3.81	1828.8	0.1	1645.92	6
5	240	4.5	1080	0.1	972	6
8	888	8.99	7983.12	0.15	6785.652	1
					$521,334.43	

Table 10.70 Pipe Cost

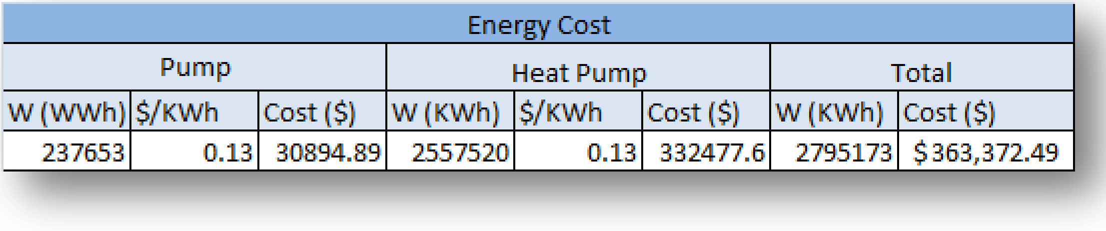
The pipe cost also increases significantly for the bigger system, but not as much as the drilling did.

The pumps used for Option 3 are Series 1510 – 4BC. The cost per pump is $2367, with a total of $14,202. Compare to the first two options, the pump prices increased due to the larger pumps, but not by much.

The heat pumps used for Method 1 are three 194 ton units, and one 117 ton unit. Using the $900/ton estimation, each 194 ton unit will cost $174,000. The 117 ton unit will cost $105,300. This gives a total first cost of $629,100. Method 2 will use six 117 ton units. At a cost of $105,300 per unit, the total first cost for Method 2 would be $631,800. Both values are very close.

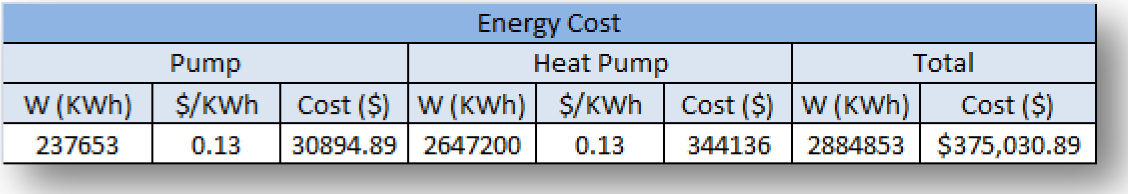
The total first cost for Method 1 will the drilling, pipes, pumps, and heat pumps from the first method of calculations. This total will end up being $4,252,302. The first cost for Method 2 will have the same factors except for the method 2 cost for the heat pumps. This is a total first cost of $4,249,602.

The cost of running the pumps and heat pumps annually is shown below in Table 10.71 for heat pump Method 1 and Table 10.72 for heat pump Method 2. These values will be compared to the annual energy cost to run the chillers and boilers in the current design.



Energy Cost							
Pump			Heat Pump			Total	
W (WWh)	$/KWh	Cost ($)	W (KWh)	$/KWh	Cost ($)	W (KWh)	Cost ($)
237653	0.13	30894.89	2557520	0.13	332477.6	2795173	$363,372.49

Table 10.71 Method 1 Energy Costs Option 3



Energy Cost							
Pump			Heat Pump			Total	
W (KWh)	$/KWh	Cost ($)	W (KWh)	$/KWh	Cost ($)	W (KWh)	Cost ($)
237653	0.13	30894.89	2647200	0.13	344136	2884853	$375,030.89

Table 10.72 Method 2 Energy Costs Option 3

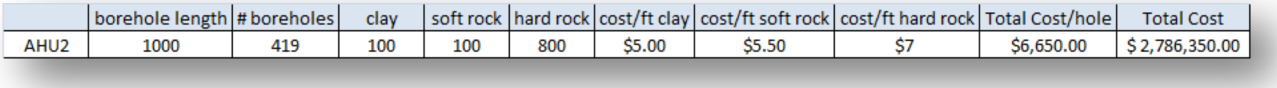
In this case, Method 1 is cheaper to operate than Method2 2. The first cost of the heat pumps is higher for Method 1 however, but not by much. The costs of running this option are significantly higher than the previous two. This is because AHU 2 is much larger than AHU 1.

AHU 2 consists of about 20% of the cooling and heating demand for the chiller and boiler systems. With the annual chiller consumption at 11,911,880 KWh, AHU 2 consumes 2,382,376 KWh. This equates to about $310,000 on cooling alone for the current system. The heating portion of AHU 2 consumes about 286,489 therms, at about $372,435.

This gives AHU 2 a total annual cost of $682,435 annually. The ground source heat pump for Option 3 uses roughly half the amount of energy used by the current system. The first cost for Method 1 is $4,252,302 with an annual savings of $319,000. This equates to simple payback period of a little over 13 years. Method 2 has a first cost of $4,249,602, and saves around $307,400 annually. This is a simple payback period of nearly 14 years. Due to the slightly better payback period, and the very close first costs, it is decided that the Method 1 layout for the heat pumps is better for Option 3.

Option 4 AHU 2 1000 ft

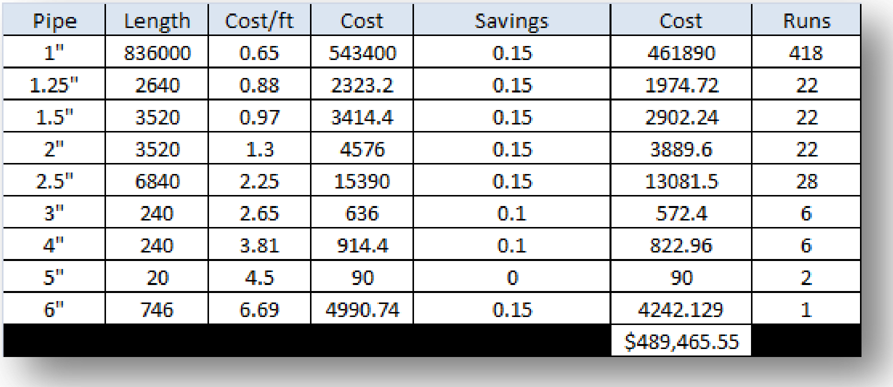
Table 10.73 shows the drilling costs for Option 4. The boreholes for this option are deeper.



	borehole length	# boreholes	clay	soft rock	hard rock	cost/ft clay	cost/ft soft rock	cost/ft hard rock	Total Cost/hole	Total Cost
AHU2	1000	419	100	100	800	$5.00	$5.50	$7	$6,650.00	$ 2,786,350.00

Table 10.73 Drilling Costs

The drilling costs for this option are much less than that of Option 3, which is at a shorter borehole length. This could be because the amount of boreholes needed decreased so dramatically, due to the longer borehole length. Table 10.74 below shows the pipe costs for Option 4.



Pipe	Length	Cost/ft	Cost	Savings	Cost	Runs
1"	836000	0.65	543400	0.15	461890	418
1.25"	2640	0.88	2323.2	0.15	1974.72	22
1.5"	3520	0.97	3414.4	0.15	2902.24	22
2"	3520	1.3	4576	0.15	3889.6	22
2.5"	6840	2.25	15390	0.15	13081.5	28
3"	240	2.65	636	0.1	572.4	6
4"	240	3.81	914.4	0.1	822.96	6
5"	20	4.5	90	0	90	2
6"	746	6.69	4990.74	0.15	4242.129	1
					$489,465.55	

Table 10.74 Pipe Costs

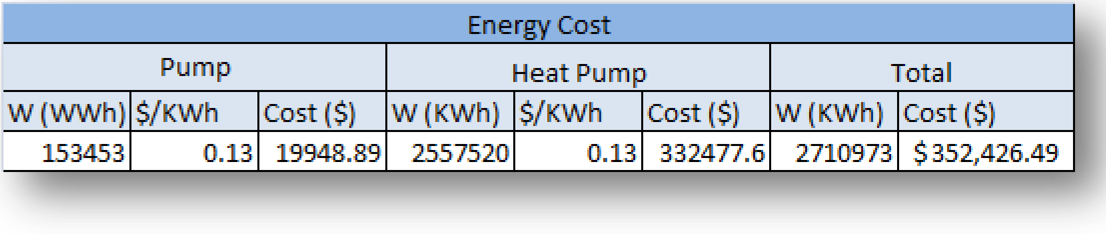
In the case of AHU 2, both the drilling price and pipe price decreased with the deeper boreholes. This is different than AHU 1, where the drilling price increased at the longer borehole length. This could be because at deeper depths it is better to drill deeper than have to drill more boreholes.

The pumps used for Option 4 are Series 1531 – 3BC at $2297 a pump. This makes a total of $13,782. This is once again cheaper than Option 3, even though the boreholes are deeper.

The heat pumps used for Method 1 are three 194 ton units, and one 117 ton unit. Using the $900/ton estimation, each 194 ton unit will cost $174,000. The 117 ton unit will cost $105,300. This gives a total first cost of $629,100. Method 2 will use six 117 ton units. At a cost of $105,300 per unit, the total first cost for Method 2 would be $631,800. Both values are very close.

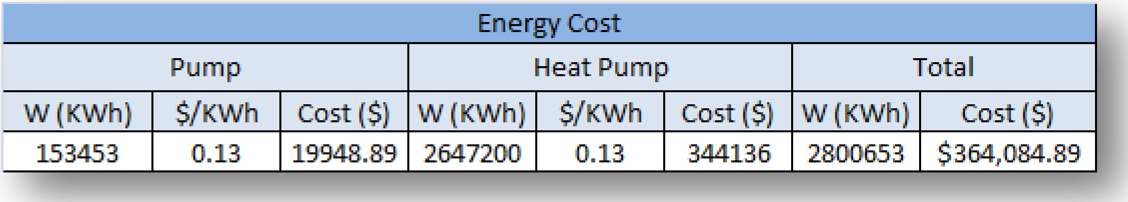
The total first cost for Method 1 will the drilling, pipes, pumps, and heat pumps from the first method of calculations. This total will end up being $3,918,700. The first cost for Method 2 will have the same factors except for the method 2 cost for the heat pumps. This is a total first cost of $3,916,000.

The cost of running the pumps and heat pumps annually is shown below in Table 10.75 for heat pump Method 1 and Table 10.76 for heat pump Method 2. These values will be compared to the annual energy cost to run the chillers and boilers in the current design.



Energy Cost							
Pump			Heat Pump			Total	
W (WWh)	$/KWh	Cost ($)	W (KWh)	$/KWh	Cost ($)	W (KWh)	Cost ($)
153453	0.13	19948.89	2557520	0.13	332477.6	2710973	$352,426.49

Table 10.75 Method 1 Energy Costs Option 4



Energy Cost							
Pump			Heat Pump			Total	
W (KWh)	$/KWh	Cost ($)	W (KWh)	$/KWh	Cost ($)	W (KWh)	Cost ($)
153453	0.13	19948.89	2647200	0.13	344136	2800653	$364,084.89

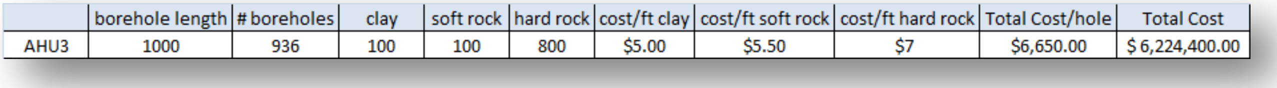
Table 10.76 Method 2 Energy Costs Option 4

Method 2 does use more energy than Method 1, but the first cost of the heat pumps are a bit lower.

With AHU 2 having an annual cost of $682,435, the operating costs of Option 4 are also roughly half of the current cost. With the first cost of Method 1 being $3,918,700 and the savings being $330,000 annually, the simple payback period is just under 12 years. The first cost for Method 2 is $3,918,000. The annual savings are $318,435. This equates to just over 12 years for a simple payback period. It seems that Method 1 is also the better method for this option. For both AHU 2 options method 1 has a smaller payback period. Option 4, with deeper boreholes, has an even better payback period than Option 3. This is because in this case the deeper boreholes ended up saving in the first cost of the pipe and drilling significantly.

Option 5 AHU 3 1000 ft

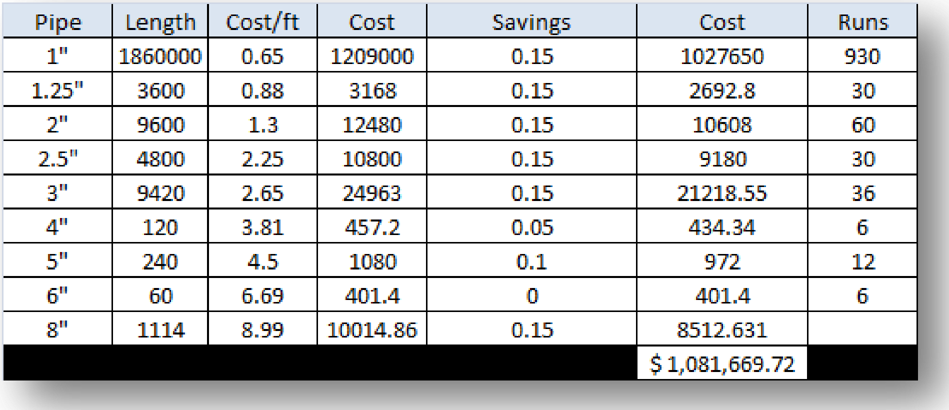
The drilling costs for Option 5 are shown in Table 10.77 below.



	borehole length	# boreholes	clay	soft rock	hard rock	cost/ft clay	cost/ft soft rock	cost/ft hard rock	Total Cost/hole	Total Cost
AHU3	1000	936	100	100	800	$5.00	$5.50	$7	$6,650.00	$ 6,224,400.00

Table 10.77 Drilling Costs

As seen in Table 1.77, the drilling costs for AHU 3 are very high. This is because not only of the large depth of the boreholes, but the amount of boreholes as well. The pipe pricing is shown in Table 10.78 below.



Pipe	Length	Cost/ft	Cost	Savings	Cost	Runs
1"	1860000	0.65	1209000	0.15	1027650	930
1.25"	3600	0.88	3168	0.15	2692.8	30
2"	9600	1.3	12480	0.15	10608	60
2.5"	4800	2.25	10800	0.15	9180	30
3"	9420	2.65	24963	0.15	21218.55	36
4"	120	3.81	457.2	0.05	434.34	6
5"	240	4.5	1080	0.1	972	12
6"	60	6.69	401.4	0	401.4	6
8"	1114	8.99	10014.86	0.15	8512.631	
					$ 1,081,669.72	

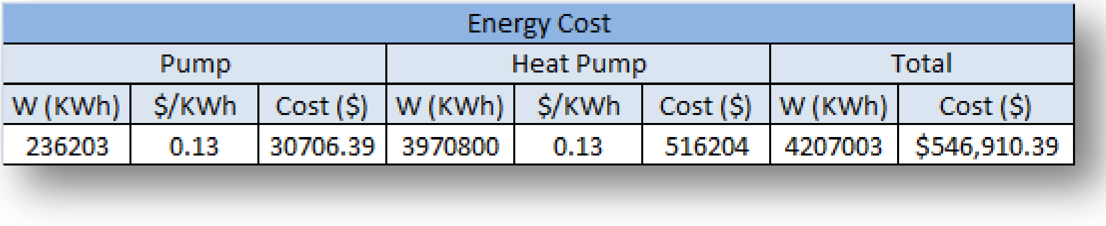
Table 10.78 Pipe Costs

Once again the price of the piping is much higher than the previous options, but this is because the immense size of AHU 3.

Option 5 will use six Series 1531 – 4 BC at $2367 a pump. This equates to $14,202 total for the pumps. This is similar to the pumps in the other options, even the size of the system is much larger.

The heat pumps used for will be nine 117 ton units. With a cost of $105,300 per pump, the total first cost for the heat pumps will be $947,700. The total first cost for Option 5 will the drilling, pipes, pumps, and heat pumps from the first method of calculations. This total will end up being $8,186,100.

The cost of running the pumps and heat pumps annually is shown below in Table 10.79. These values will be compared to the annual energy cost to run the chillers and boilers in the current design.



Energy Cost							
Pump			Heat Pump			Total	
W (KWh)	$/KWh	Cost ($)	W (KWh)	$/KWh	Cost ($)	W (KWh)	Cost ($)
236203	0.13	30706.39	3970800	0.13	516204	4207003	$546,910.39

Table 10.75 Energy Costs Option 5

The operational costs for Option 5 are the largest of the 5 options, but it has the potential for the most savings due to the amount of energy AHU 3 uses currently.

AHU 3 accounts for roughly 60-70% of the chiller and boiler energy. However, the ground source heat pump is only sized for half of this load due to the large amount of space the bores take up. This means that annually half of the AHU 3 system uses around 3,700,000 KWh, which is about $481,000 per year for cooling. The heating load on AHU 3 is 465,500 therms, which is around $558,600. In total half of AHU 3 costs just over $1 million.

The ground source heat pump saves $500,000 annually for AHU 3. With the addition of the nine heat pumps, one of the installed chillers can be taken away. This will save $150,000 in the first cost. With a total first cost of now $8,036,100, the simple payback period for this system will be just over 16 years. This option has the highest payback of any of the options, but it also saves the most annually. This could have huge potential over a lifecycle cost, which will be discussed in the conclusion of this section. This is also a very good example of how much the cost of drilling can be for ground source heat pump. In this example the drilling accounts for a substantial portion of the first costs.

Central Utility Plant Layout

Option Schematics

Now that final layouts are determined for each option, the layout in the central utility plant can be determined for each option.

Option 1 AHU 1 300 ft

Option 1 will contain 2 pumps, with a capacity of 72 gpm at 18 ft of head loss, and two 60 ton heat pumps per loop. Figure 10.33 shows the central utility plant schematic for one of the three loops. All three loops will be identical in this case.

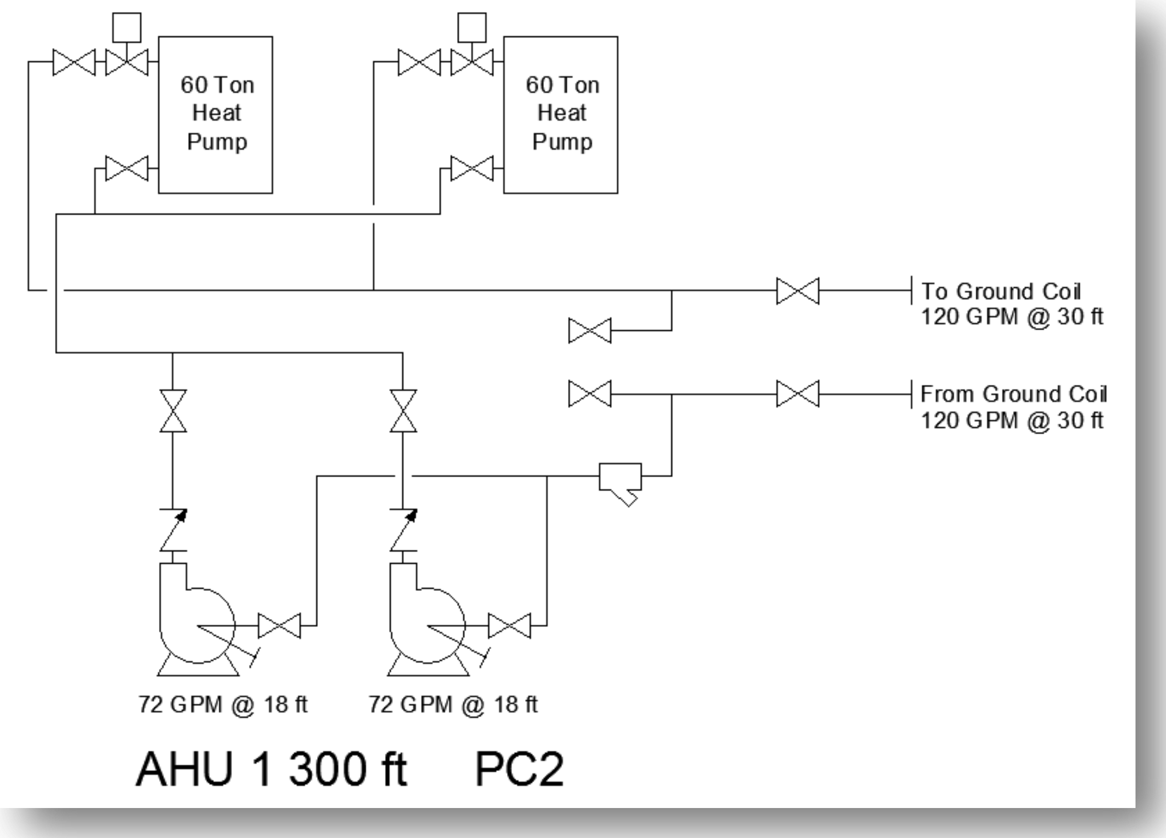


Figure 10.33 CPU Schematic Option 1

Each loop will be designed to this schematic. A head loss of 15 ft was assumed for this entire loop. This value was taken into account in the overall head loss for selecting the pumps. The main pipes will have an isolation valve, as well as a purge valve at the building entrance.

Option 2 AHU 1 600 ft

Option 2 will contain 2 pumps, with a capacity of 144 gpm at 21 ft of head loss, and two 60 ton heat pumps per loop. Figure 10.34 shows the central utility plant schematic for one of the three loops. All three loops will be identical in this case.

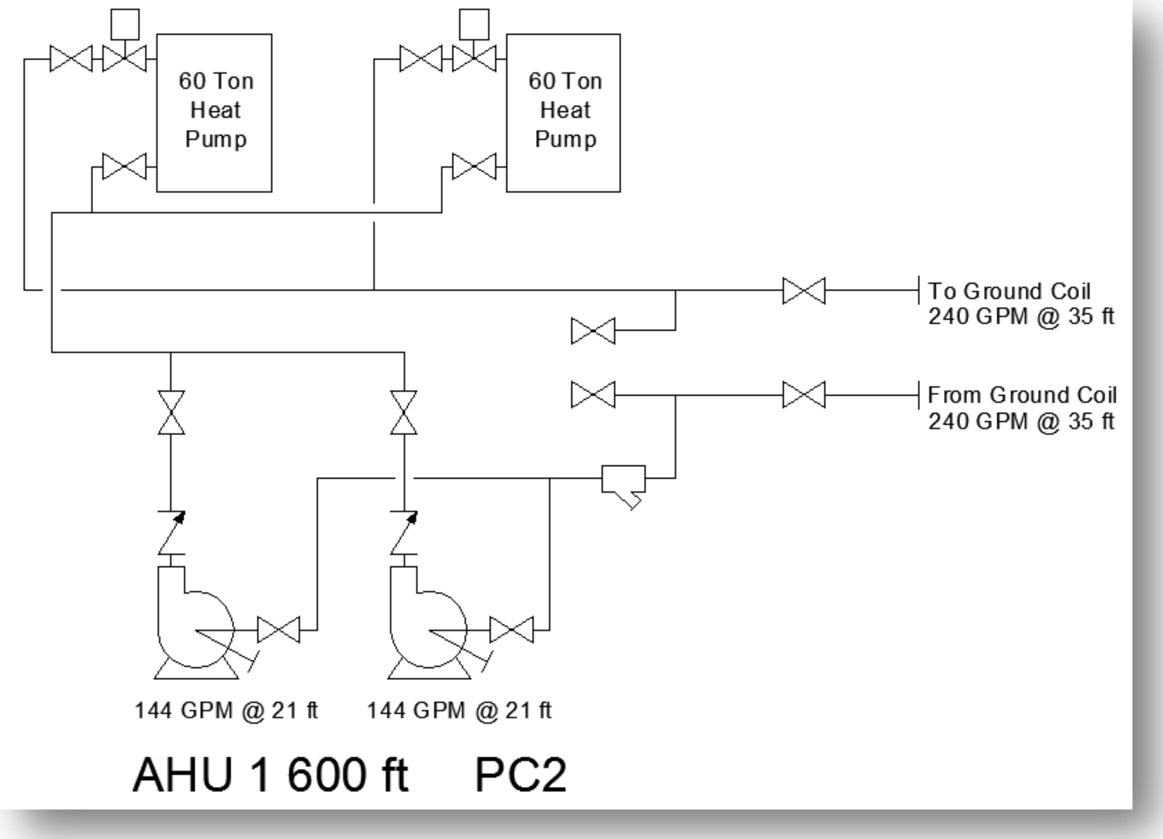


Figure 10.34 CPU Schematic Option 2

Each loop will be designed to this schematic. A head loss of 15 ft was assumed for this entire loop. This value was taken into account in the overall head loss for selecting the pumps. The main pipes will have an isolation valve, as well as a purge valve at the building entrance.

Option 3 AHU 2 600 ft

Option 3 will contain 2 pumps, with a capacity of 421 gpm at 28 ft of head loss, and two heat pumps. One heat pump will be exclusive to the loop, the 194 ton. The 117 ton heat pump will have all three loops feeding into it. Figure 10.35 shows the central utility plant schematic for one of the three loops. All three loops will be identical in this case.

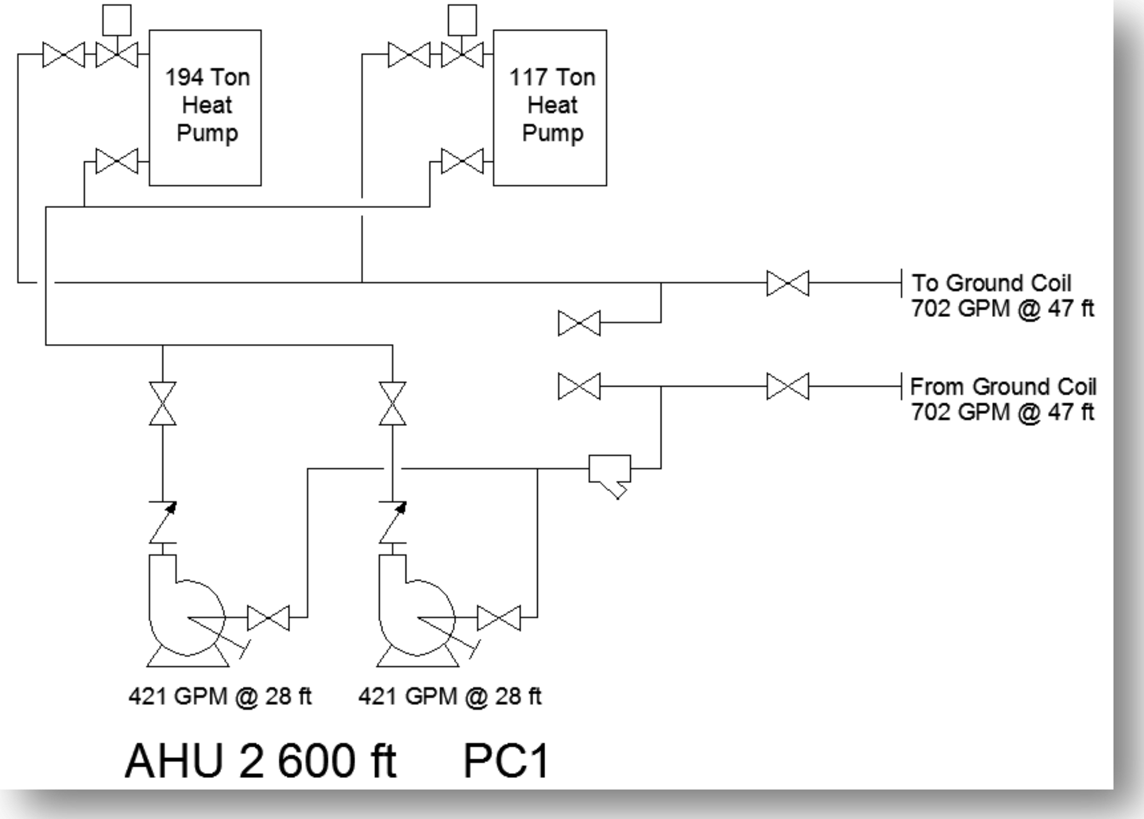


Figure 10.35 CPU Schematic Option 3

Each loop will be designed to this schematic. A head loss of 15 ft was assumed for this entire loop. This value was taken into account in the overall head loss for selecting the pumps. The main pipes will have an isolation valve, as well as a purge valve at the building entrance.

Option 4 AHU 2 1000 ft

Option 4 will contain 2 pumps, with a capacity of 240 gpm at 31 ft of head loss, and two heat pumps. One heat pump will be exclusive to the loop, the 194 ton. The 117 ton heat pump will have all three loops feeding into it. Figure 10.36 shows the central utility plant schematic for one of the three loops. Two of the three loops will be identical in this case. The third loop will have the same pumps and heat pumps, but the gpm required will be slightly more at 273 gpm per pump.

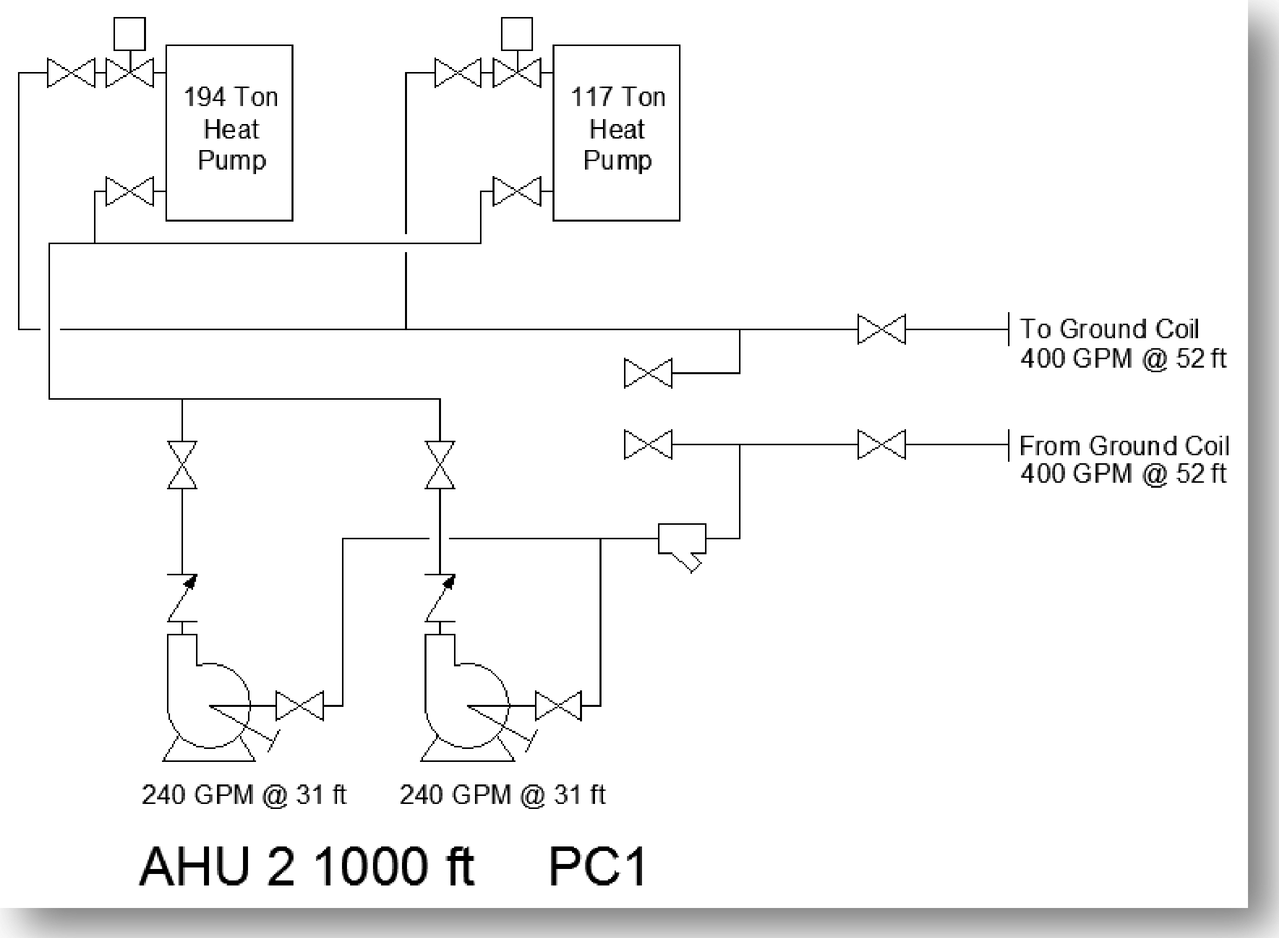


Figure 10.36 CPU Schematic Option 4

Each loop will be designed to this schematic, except for the third loop, which has 273 gpm per pump. A head loss of 15 ft was assumed for this entire loop. This value was taken into account in the overall head loss for selecting the pumps. The main pipes will have an isolation valve, as well as a purge valve at the building entrance.

Option 5 AHU 3 1000 ft

Option 2 will contain 2 pumps, with a capacity of 558 gpm at 28 ft of head loss, and three 118 ton heat pumps per loop. Figure 10.37 shows the central utility plant schematic for one of the three loops. All three loops will be identical in this case.

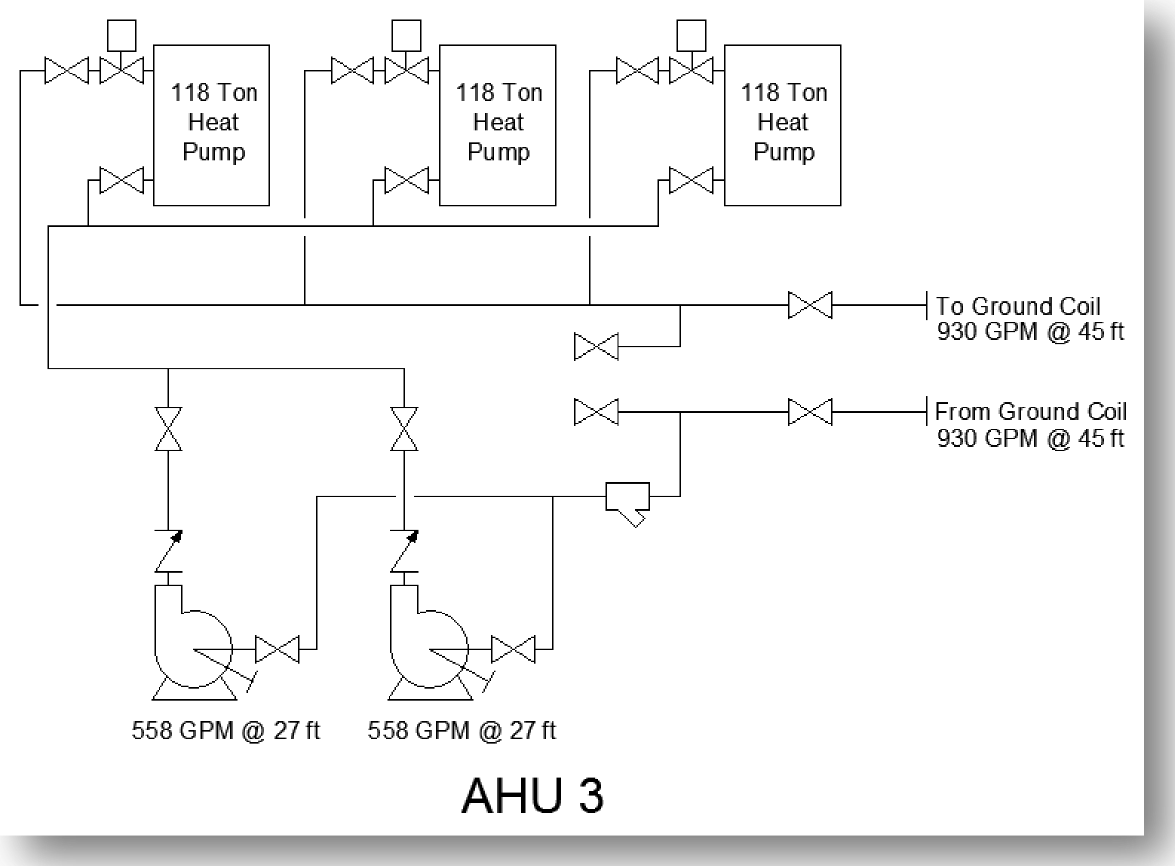


Figure 10.37 CPU Schematic Option 5

Each loop will be designed to this schematic. A head loss of 15 ft was assumed for this entire loop. This value was taken into account in the overall head loss for selecting the pumps. The main pipes will have an isolation valve, as well as a purge valve at the building entrance.

Mechanical Room Layout

It was important to analyze where all the equipment needed for the GSHP will fit in the central utility plant. The plant is quite large, and houses all the mechanical equipment. When the plant was designed it was given plenty of open space. This is because they wanted to allow room for future expansion. This space is perfect for housing all the new equipment. Figure 10.38 shows the overall layout for the mechanical room. The areas with cross hatching are the open space where the pumps and heat pumps can be located.

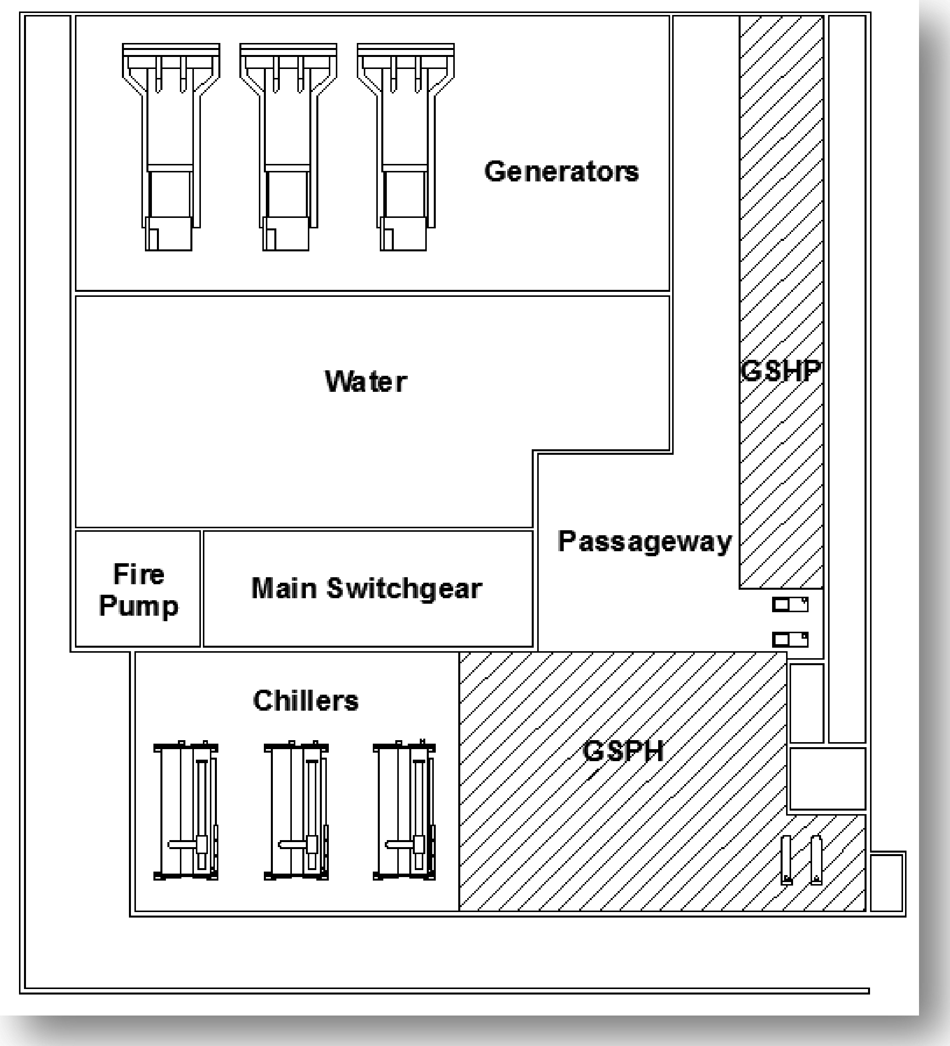


Figure 10.38 Mechanical Room Schematic

The total area of the hatched spaces is 3000 ft^2. The larger area next to the chillers is 2000 f^{t2} and the longer area near the generators is 1000 ft^2. The longer area is a perfect area to place the pumps and some of the heat pumps. The larger area by the chillers is perfect for heat pumps. It is also important to note that in Option 5, a chiller can be removed, creating even more space.

Outdoor Air Study

One other major potential for energy savings comes in the system design. The buildings ventilation rates were designed according to IMC 2003. While these standards are close to AHSRAEs, they are not the same. One specific area I noticed was the high amount of outdoor air that is entering the office areas. Many of the office spaces are conditioned to 100% outdoor air, or have more than the minimum required according to ASHRAE Standards. It was decided to redesign the outdoor air for the ASHRAE minimum to the office spaces to potentially save on energy. Appendix F shows the current flow rates, along with the new calculated flow rates as specified by ASHRAE. The information used was for a typical office space, with 5 cfm/person and .06 cfm/ft^2.

The analysis was done in Trane Trace energy modeling software. The AHUs affected will be AHU set 1 and AHU set 3, which serves most of the office spaces. The current building consumption is 22,212,000 KWh and 1,553,000 therms annually. With the redesigned airflow the new building energy consumption is 22,199,000 KWh, and 1,533,000 therms annually. As it turns out this is not a significant energy savings. The annual savings would be around $20,000.

This may not be worth it depending on the hospitals goal for air quality. While the offices are not located in the same area as operating rooms or any other room requiring high air quality, they may have wanted the overall air quality at the hospital to be higher than normal. The improved indoor air quality also makes the space more appealing. This could be the reason why they increased the air quality for the office spaces as well.

Conclusion

After studying the 5 different options, it seems Options 1 and 2 will have the shortest payback period. This is due to their small size compared to the other options. Options 2 and 3 were in the middle, with Option 5 having the longest payback period. It is also important to look at the life cycle cost of the system to determine which system to implement. First cost was including in determining the life cycle cost. Assuming the ground source heat pump has a life cycle of 30 years, Options 1 and 2 will each have an overall savings of $3,220,000. Option 3 will have a savings of $5,318,000 over 30 years. Option 4 will have a savings of nearly $6,000,000. Option 5 will have the largest savings at almost $7,000,000 over a 30 year period. If I had to choose one option, it would be Option 4. AHU 2 with a borehole depth of 1000 ft seems to be the most logical choice. It saves much more over a 30 year period than Options 1 and 2. It is also only $1,000,000 less in savings compared to Option 5. Option 5 was not chosen because of the overall high first cost of the system, especially the drilling.

There are several important design features to take away from the various design options that were performed in this report. The first is the price of drilling. The price of drilling can be a significant portion of the first cost of a system. Once the hard rock is penetrated, the cost of drilling will increase substantially. Options 1 and 2 did not have this problem since they were relatively shallow. Options 4 and 5, however, had a depth of 1000 ft. While this saved on number of boreholes, the cost of drilling became a large portion of the overall cost. This is not to say that the deeper drilling is not the better option though. In the case of Option 4, the price of drilling was less for the deeper bore than the shallower bore in Option 3. This is because while the bores were deeper, the amount of bores needed to be drilled was less. It is important to look at various design depths for the boreholes when designing a GSHP. The area of land that is available to work with is also a large factor in borehole length, since you may not have the space to have more boreholes.

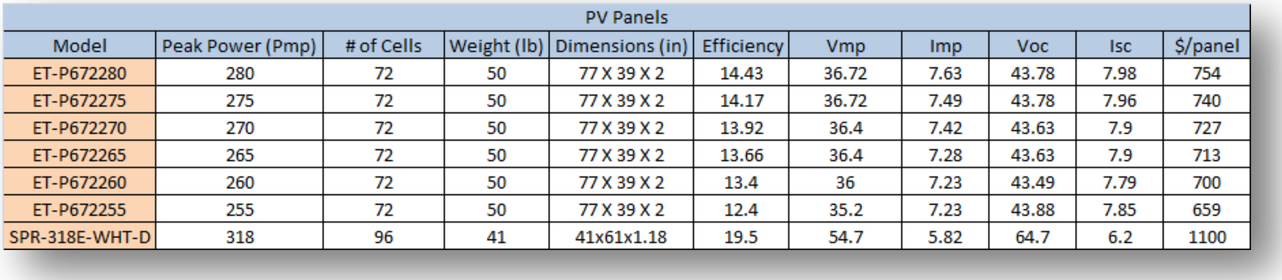
In terms of pumps, it seems that having to two pumps each sized to 50-60 % of the required head and gpm seems to be the better solution than one pump. It not only saves in energy costs, but offers a more reliable system. In the one pump system, if a pump fails that means one of the loops will not be running. The system will be running at 2/3 capacity. In a two pump system, if one of the pumps fails, there is still another pump running in that loop. This gives the system a 5/6 capacity if one pump fails.

Breadths

Electrical

The roof of the hospital is quite large and flat. This seemed like a perfect opportunity to incorporate solar panels into the design. The building is also very tall, and in the middle of a 120 acre site, which means there are absolutely no obstructions to block the sun. The panels being used will be PV panels, which will convert solar energy into electrical energy, which will then tie into the buildings grid system.

The first step taken was to select the solar panels being used. It was decided to go with larger, more efficient panels since this could provide a lot of electrical energy. Table 11.1 shows the various panels that were selected for analysis.



PV Panels										
Model	Peak Power (Pmp)	# of Cells	Weight (lb)	Dimensions (in)	Efficiency	Vmp	Imp	Voc	Isc	$/panel
ET-P672280	280	72	50	77 X 39 X 2	14.43	36.72	7.63	43.78	7.98	754
ET-P672275	275	72	50	77 X 39 X 2	14.17	36.72	7.49	43.78	7.96	740
ET-P672270	270	72	50	77 X 39 X 2	13.92	36.4	7.42	43.63	7.9	727
ET-P672265	265	72	50	77 X 39 X 2	13.66	36.4	7.28	43.63	7.9	713
ET-P672260	260	72	50	77 X 39 X 2	13.4	36	7.23	43.49	7.79	700
ET-P672255	255	72	50	77 X 39 X 2	12.4	35.2	7.23	43.88	7.85	659
SPR-318E-WHT-D	318	96	41	41x61x1.18	19.5	54.7	5.82	64.7	6.2	1100

Table 11.1 Panel Selection

Figures 11.1 and 11.2 show the electrical characteristics of the panels and the different layers. The panels have polycrystalline cells, which are the most efficient. They are also the most expensive however. The average panel's peak power is 270 W, as shown in the figure below.

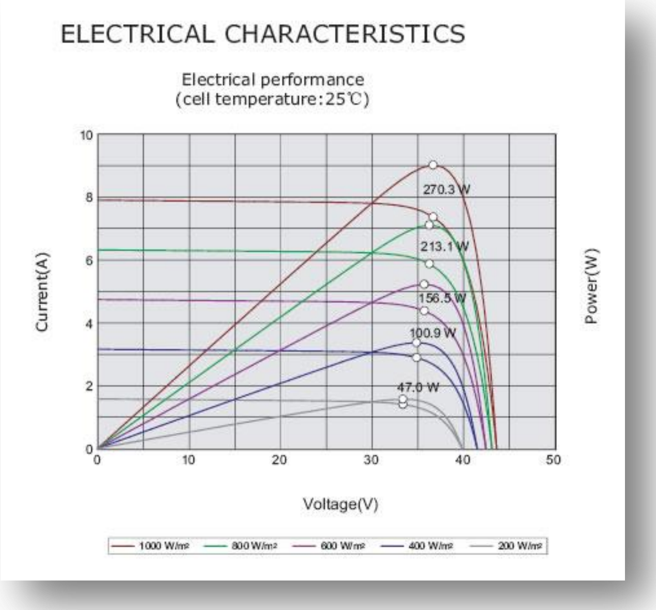


Figure 11.1 Electrical Characteristics

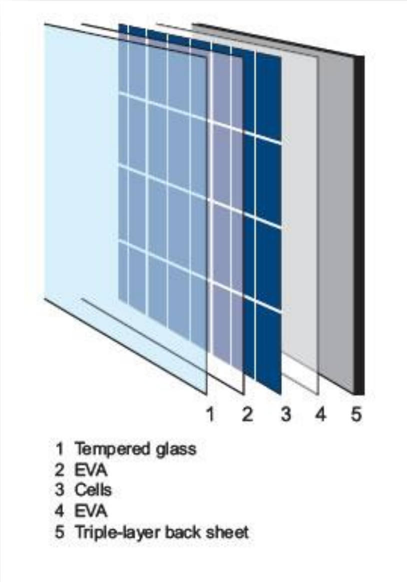


Figure 11.2 Panel Construction

All panels are the same dimensions except for the last one. The last panel is a high power and high efficiency panel. However, it is relatively new so the cost per panel is very high. The dimensions of the panels will help determine the layout for the panels on the roof. Figure 11.3 below shows the proposed areas for the placement of the panels on the roof. The front façade of the building faces directly north. So the panels will be facing directly south. The reason for the panels not being placed in the area where the east and west wings join the center spine is because the shadow of the higher spine section will cover the panels for half the day. A further study of this is done below during the shadow analysis.

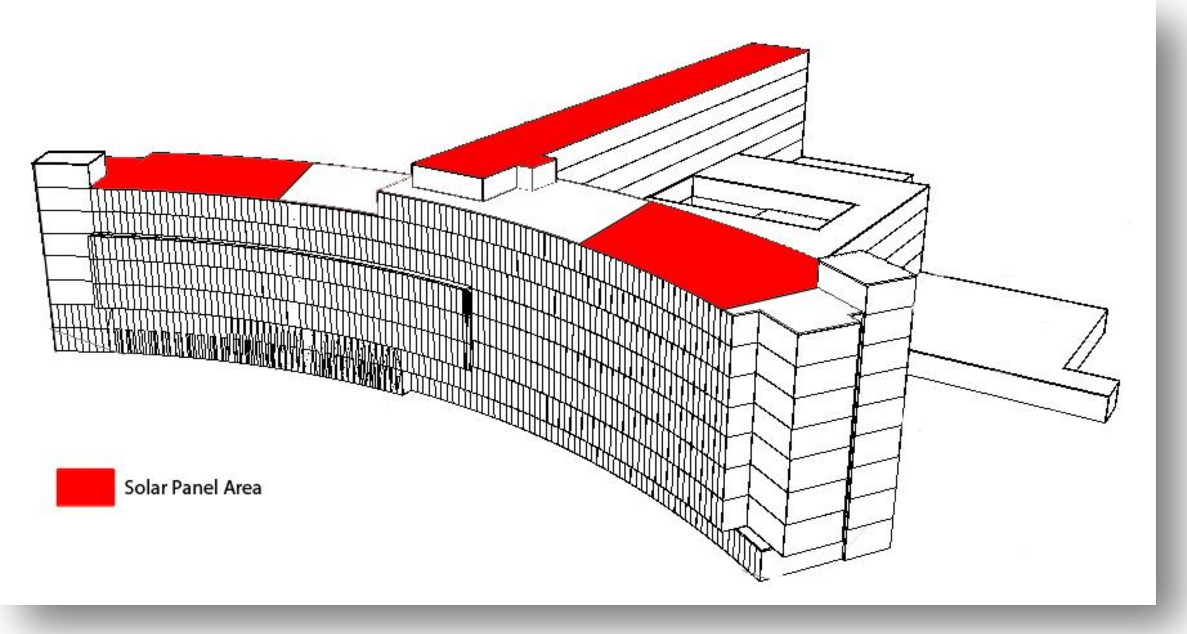


Figure 11.3 Panel Area

The total area that a panel takes up must first be calculated. The panels will adjust in the North-South direction monthly based on the solar angle. The lowest of this angle is 26°. This is important in the design because you do not want the shadow of one panel hitting the panel behind it. Figure 11.4 shows the min length the panels need to be apart from each other so that the shadows do not hit other panels.

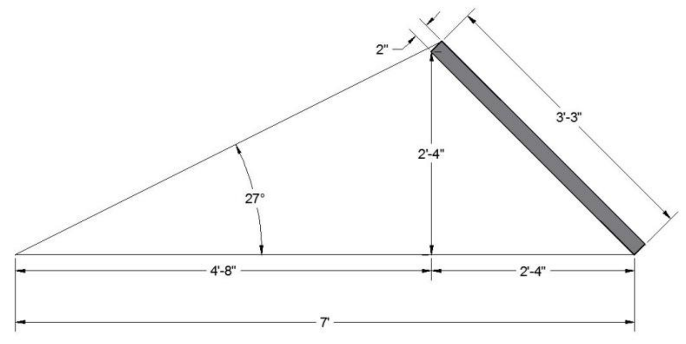


Figure 11.4 Panel Spacing

The panels must be spaced at least 7 ft away from the others for the shadows not to interfere. It was also decided that the panels will be 4.5 away from the edge of the roof so that there can be ample room for maintenance of the panels. The panels will be strung together in rows, 7 feet away from each row. Figure 11.5 shows this arrangement.

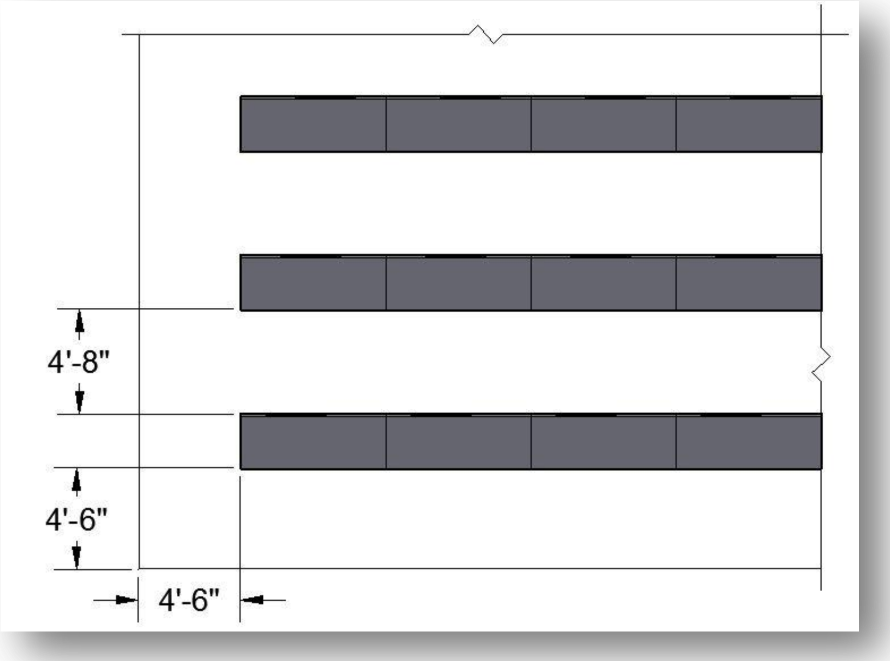


Figure 11.5 Panel Layout

Now the Layout is determined, it is necessary to study the shading on the panels. This was done through EcoTech. The building was analyzed for the winter solstice at 9 am, noon, and 4 pm. The winter solstice was chosen because this is when the sun is the lowest, and the shadows will therefore be the most extreme. If the shadows do not obstruct panels in this case, then they will not obstruct the panels in any other ones. Figure 11.6 shows the shadow analysis for 9 am. Figure 11.7 shows the shadow analysis for noon. Figure 11.8 shows the shadow analysis for 4 pm. It is important to notice that the shadows do not obstruct the panels, either from the panels themselves or the center spine of the building. These images also show why panels were not placed closer to the spine of the building, due to the shadow it casts. Appendix G shows the images for the Summer Solstice and the Equinox. The times analyzed were 9 am, noon, and 4 pm as well.

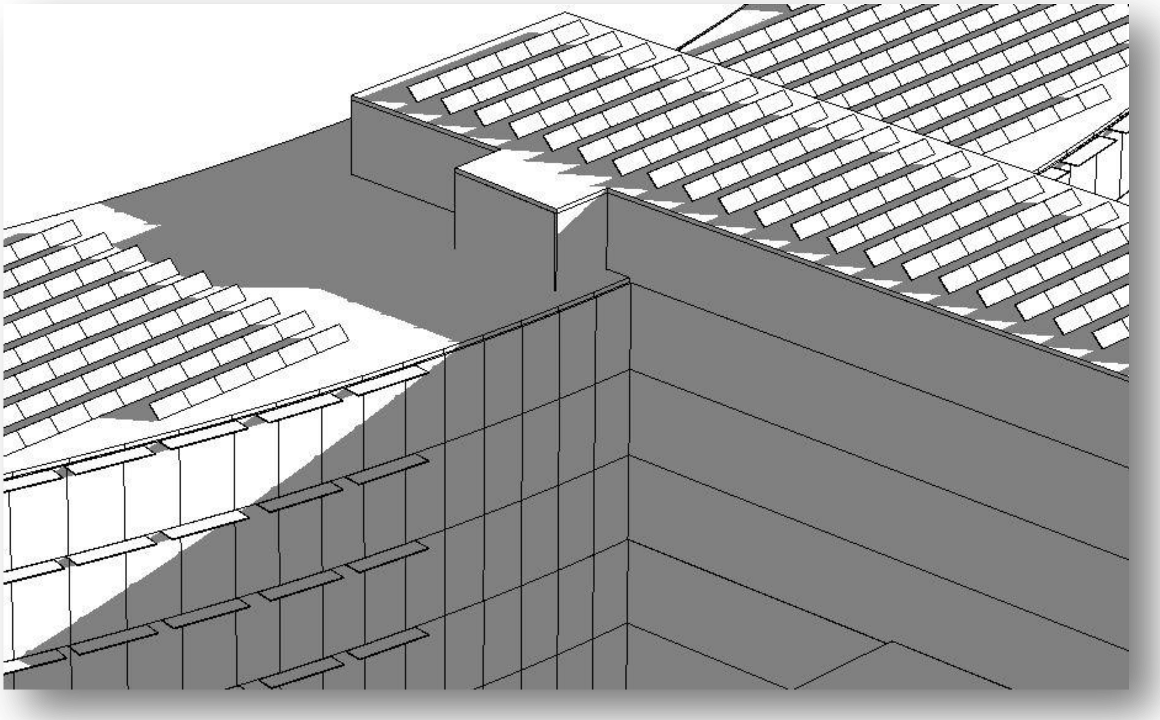


Figure 11.6 Winter Solstice 9 am

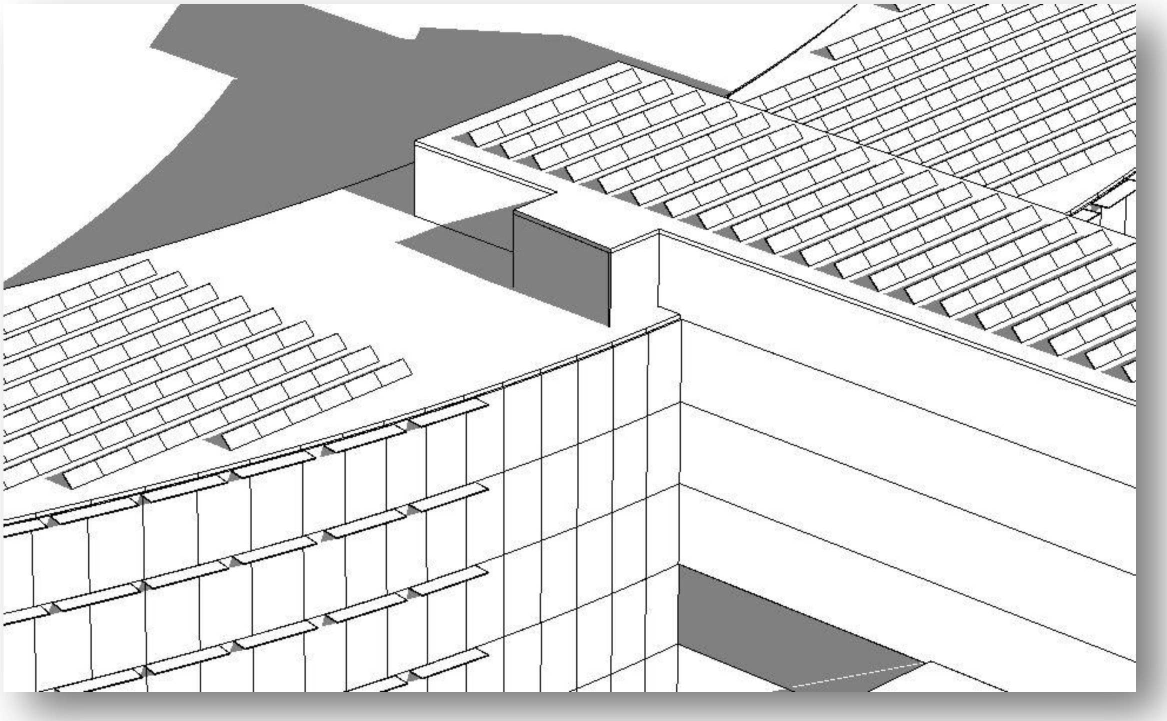


Figure 11.7 Winter Solstice Noon

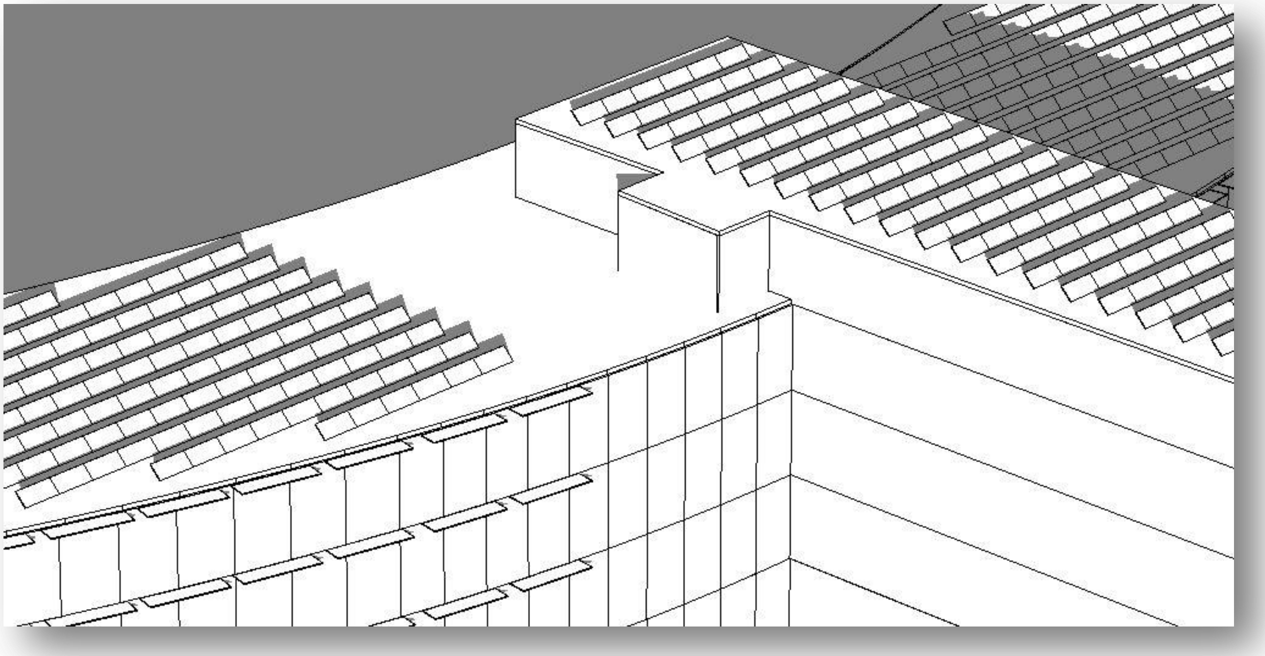


Figure 11.8 Winter Solstice 4 pm

The shadow of the spine does hit the panels on the west wing just before sunset as shown in Figure 11.8. However, the layout was not changed because this would only occur for a very small amount of time and only around the Winter Solstice.

The final layout is shown in Figure 11.9. Figures 11.10, 11.12, and 11.13show up close the layout for the center spine, the east wing, and the west wing, respectively. The center spine consists of 6 panels in a row, with 59 rows. This equates to 354 panels for the center spine. The east wing contains 251 total panels. The panels all end 4 ½' from the edge of the roof. This allows for room to walk around them. The west wing contains 279 panels. There are more panels on the west side than the east because the east side has a stair tower at the south corner, whereas the west side does not.

All 3 areas are located on different floors. The center spine panels are located on the roof of the 8th floor. The east wing panels are located on the roof of the 7th floor. The west wing panels are located on the roof of the 6th floor. There are also panels located on the façade of the building that can be seen in Figures 11.10 -11.13. These are included in the totals mentioned above, and will provide shading for the patient rooms that they are on top of. The shading impact and daylight were not studied in this report.

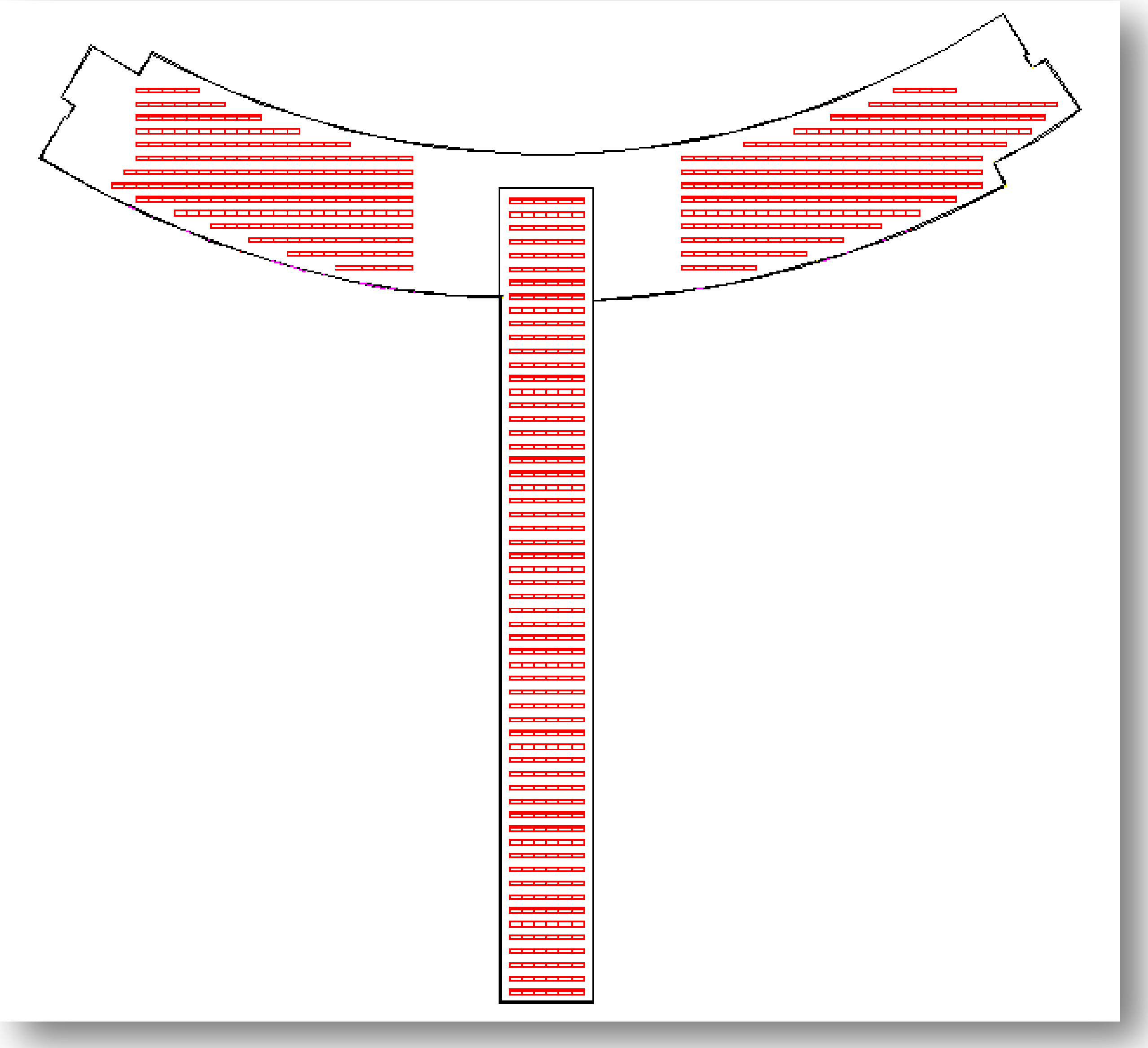


Figure 11.9 Solar Panel Layout Entire Roof

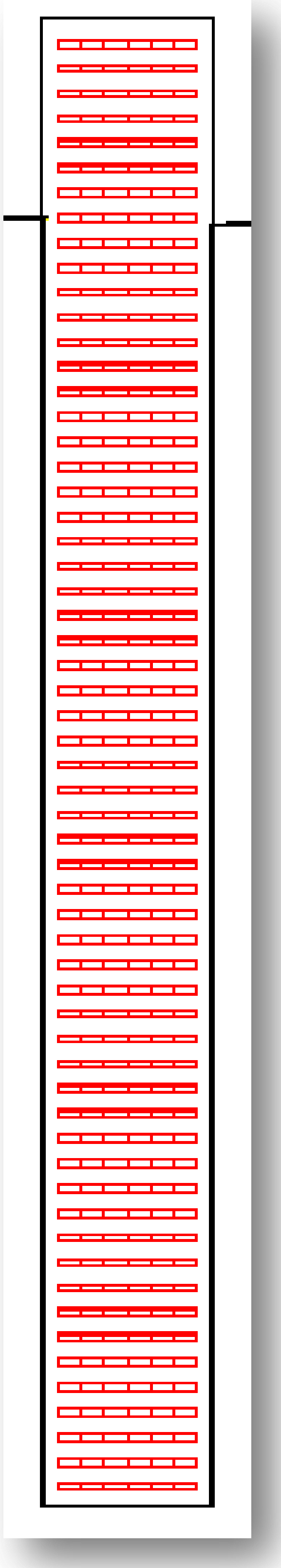


Figure 11.10 Center Spine Panel Layout

Figure 11.11 East Wing Panel Layout

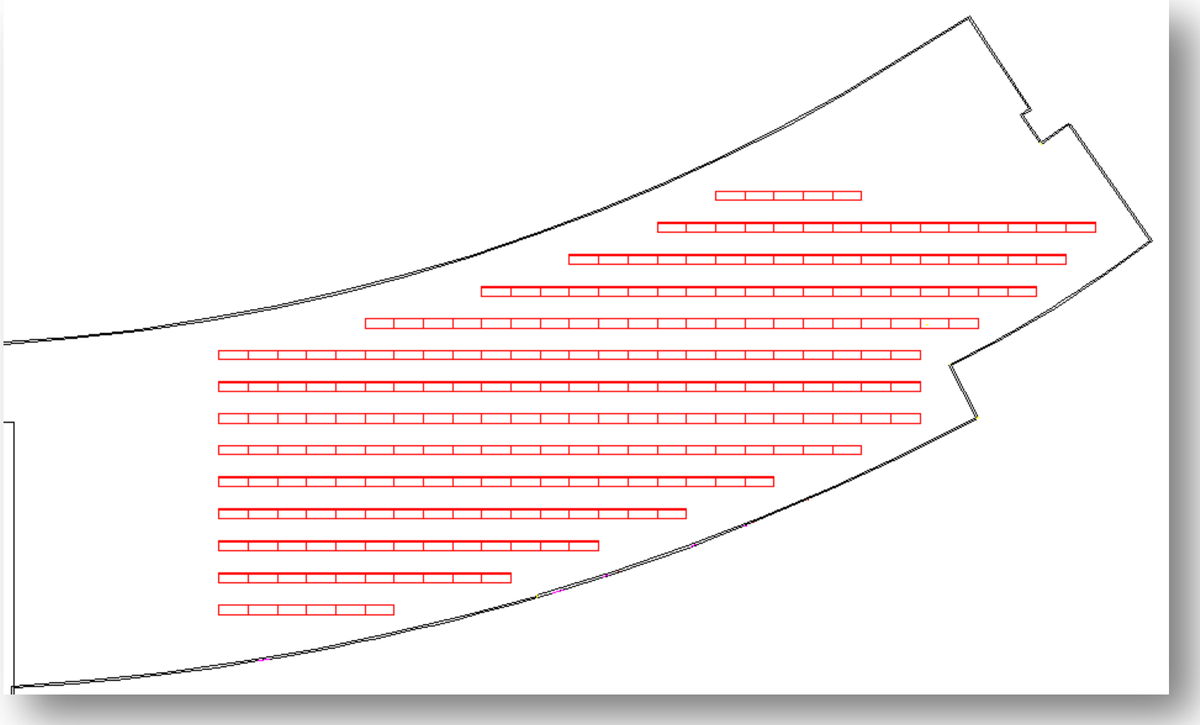


Figure 11.12 West Wing Panel Layout

The mounting system for the panels is also an important factor to consider. The panels will be lined up rows, so a simple bracing system is designed to hold them up in a row. Figure 11.13below shows the back of the panels and how the framing works.

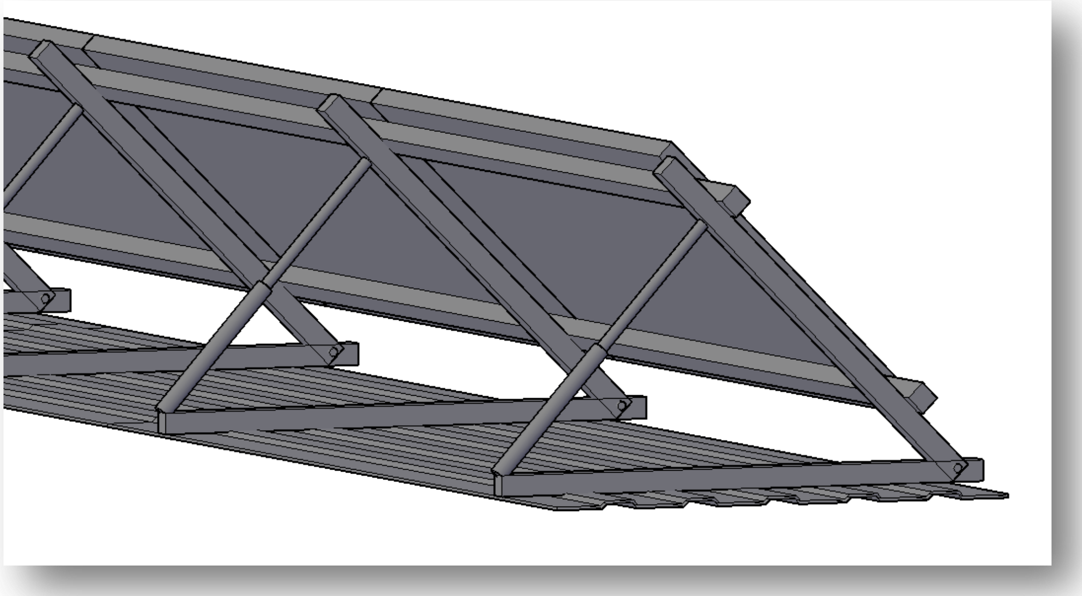


Figure 11.13 Panel Framing System

The framing system will be mounted to the steel decking in the roof. A motor will adjust the angle of the panels so they can adjust to the angle of the sun. The panels will adjust monthly in order to achieve maximum solar collection. Figure 11.14 shows the hinge and motor system, as well as the framing connecting to the steel deck.

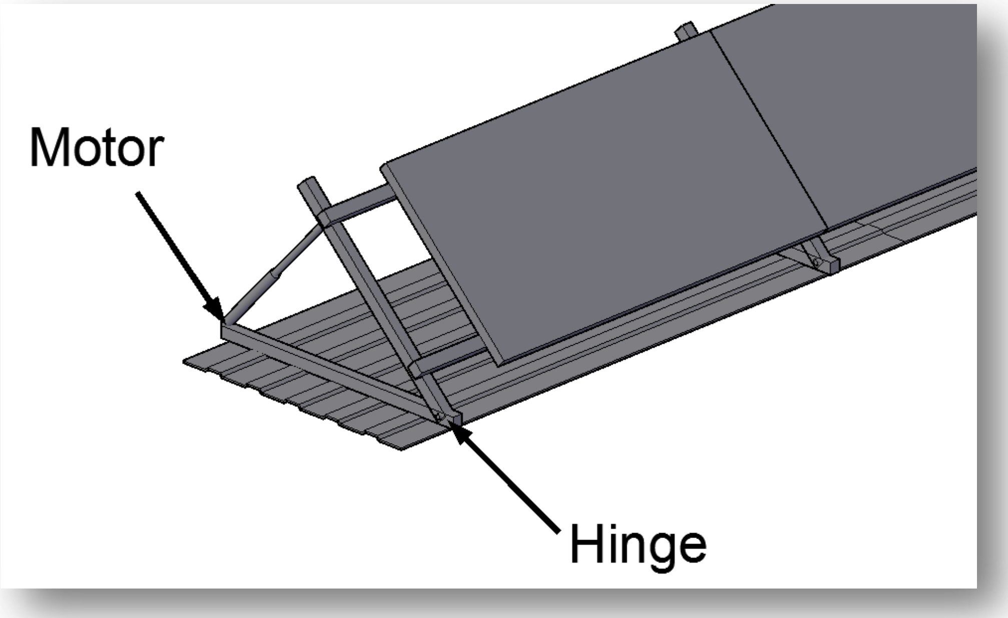
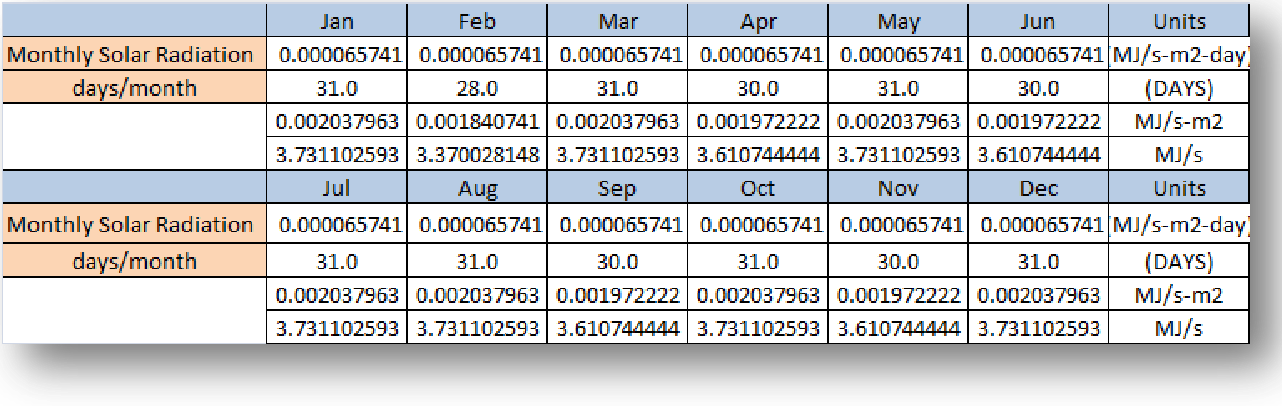


Figure 11.14 Mounting System

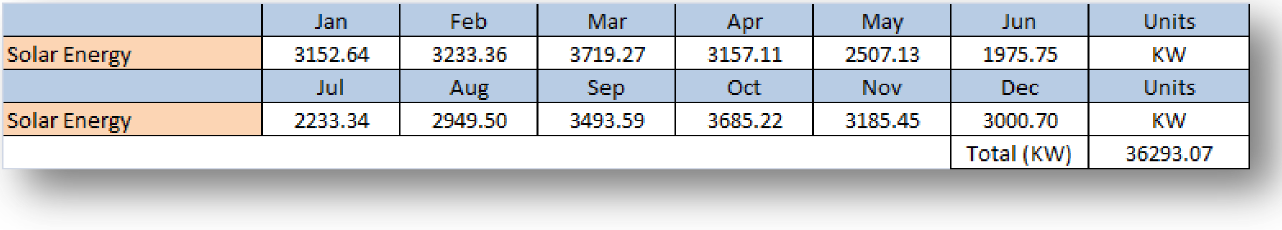
The next step was to determine the amount of solar energy that will be collected by the panels. The monthly solar radiation was obtained. These values were given in MJ/s-m^2. This number was multiplied by the days of each month as wells as the total collective area of the panels on the roof to give the final solar energy in MJ/s. This process can be seen in Table 11.2 below.



	Jan	Feb	Mar	Apr	May	Jun	Units
Monthly Solar Radiation	0.000065741	0.000065741	0.000065741	0.000065741	0.000065741	0.000065741	MJ/s-m2-day
days/month	31.0	28.0	31.0	30.0	31.0	30.0	(DAYS)
	0.002037963	0.001840741	0.002037963	0.001972222	0.002037963	0.001972222	MJ/s-m2
	3.731102593	3.370028148	3.731102593	3.610744444	3.731102593	3.610744444	MJ/s
	Jul	Aug	Sep	Oct	Nov	Dec	Units
Monthly Solar Radiation	0.000065741	0.000065741	0.000065741	0.000065741	0.000065741	0.000065741	MJ/s-m2-day
days/month	31.0	31.0	30.0	31.0	30.0	31.0	(DAYS)
	0.002037963	0.002037963	0.001972222	0.002037963	0.001972222	0.002037963	MJ/s-m2
	3.731102593	3.731102593	3.610744444	3.731102593	3.610744444	3.731102593	MJ/s

Table 11.2 Monthly Solar Radiation Values

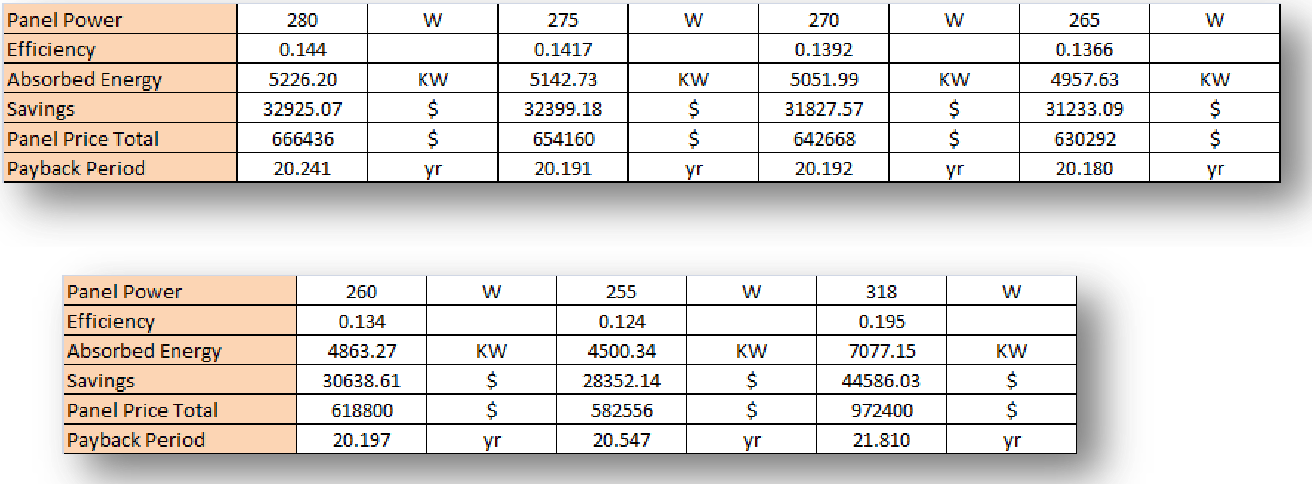
To determine the amount of solar energy that would be absorbed by the panels, the incident angle first had to be found using the orientation of the panels. The panels are facing directly south, and they will be sloped so that they are perpendicular to the sun. This will ensure maximum solar collection. Once the incidence angle was found the solar energy hitting the panels can be calculated (G). The final value is given in KW. The final values are shown below in Table 11.3.



	Jan	Feb	Mar	Apr	May	Jun	Units
Solar Energy	3152.64	3233.36	3719.27	3157.11	2507.13	1975.75	KW
	Jul	Aug	Sep	Oct	Nov	Dec	Units
Solar Energy	2233.34	2949.50	3493.59	3685.22	3185.45	3000.70	KW
						Total (KW)	36293.07

Table 11.3 Monthly Solar Values on Panels.

The equations and in depth calculations for the above table can be seen in Appendix H. The total area of the panels is 1830.8 m^2. The values seen in the table above were then multiplied by the efficiency of the panel module. This is the amount of electrical energy the panels are able to convert from the solar energy hitting the panels. Table 11.4 shows a breakdown of the different size panels under consideration, along with a simple payback period to determine which panel will be used.



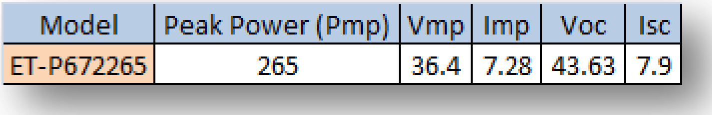
Panel Power	280	W	275	W	270	W	265	W
Efficiency	0.144		0.1417		0.1392		0.1366	
Absorbed Energy	5226.20	KW	5142.73	KW	5051.99	KW	4957.63	KW
Savings	32925.07	$	32399.18	$	31827.57	$	31233.09	$
Panel Price Total	666436	$	654160	$	642668	$	630292	$
Payback Period	20.241	yr	20.191	yr	20.192	yr	20.180	yr

Panel Power	260	W	255	W	318	W
Efficiency	0.134		0.124		0.195	
Absorbed Energy	4863.27	KW	4500.34	KW	7077.15	KW
Savings	30638.61	$	28352.14	$	44586.03	$
Panel Price Total	618800	$	582556	$	972400	$
Payback Period	20.197	yr	20.547	yr	21.810	yr

Table 11.4 Panel Analysis

Although all the payback periods are very close, the panel with the least payback period is the 265W ET panel. Notice the more powerful panel with a higher efficiency had the highest payback. This is because of the large first cost for this type of panel.

Knowing what panel to design for is the first step in determining the electrical characteristics of the system. The factors that need to be known are the voltage and current of the panels in order to size the wiring, and ultimately the inverters. The electrical data for the chosen panel is shown in Table 11.5



Model	Peak Power (Pmp)	Vmp	Imp	Voc	Isc
ET-P672265	265	36.4	7.28	43.63	7.9

Table 11.5 Electrical Data

The system is to be designed of the short circuit voltage (V_{oc}) and current (I_{sc}). This is because the wires will have to be able to handle these values if the system short circuits. The goal for designing the layout is keeping the wire sizes smaller (cheaper). When the panels are placed in series the voltages will be added up, this will keep the current down. When the panels are placed in parallel the currents will be added up. The advantage to a parallel current is that if one panel goes out, then the rest of the panels will not go out, as opposed to a series connection. The inverters selected have a max voltage of 600 V. It was decided to put as many panels in series until the summation of voltages reached 600 V. Then the panels in series will be connected in parallel. This will help keep the current down. The basic design of this is shown in Figure 11.15.

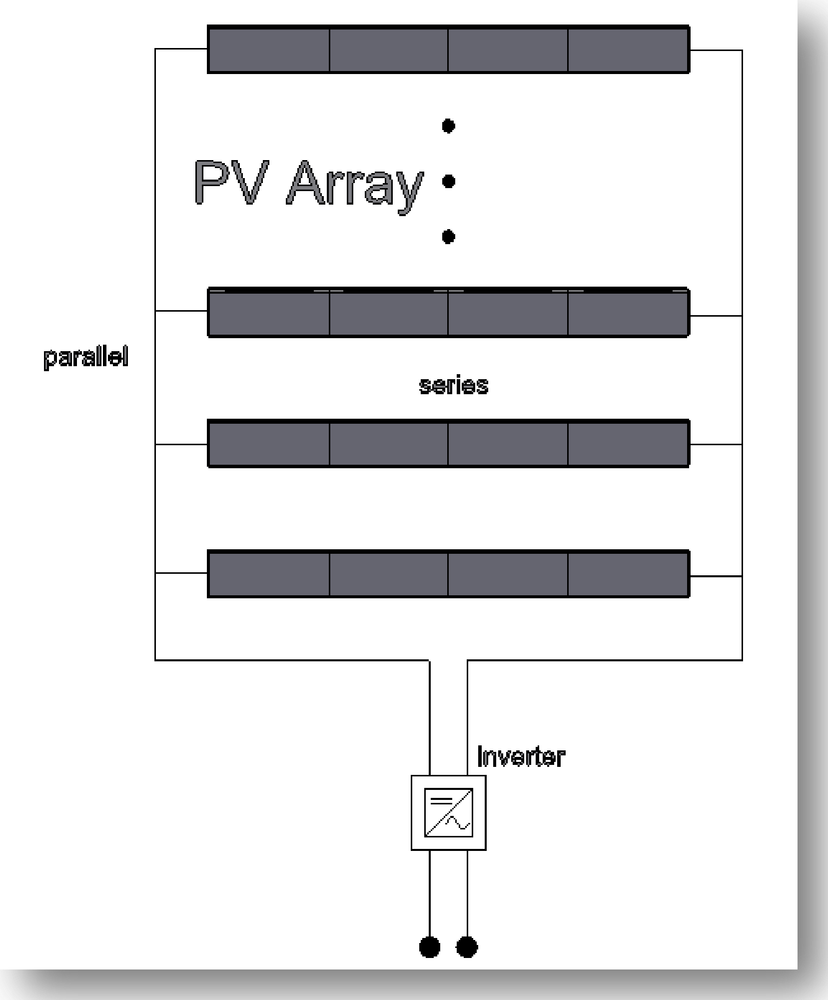


Figure 11.15 Basic Layout of Panel System

Various arrangements were considered for area to determine the max voltage and current. Table 11.6 shows the various arrangements considered for the main spine.

Main Spine	354 Panels					
Panel Properties			Arrangement		Max Conditions	
Voc	Isc	Adjusted Voc	Series	Parallel	Voltage (V)	Current (A)
43.63	7.9	49.7	12	29	597	229
43.63	7.9	49.7	6	59	298	466
43.63	7.9	49.7	10	36	497	284

Table 11.6 Main Spine Panel Arrangements

The design highlighted in yellow shows what will be used. 2 rows (12 total panels) will be connected in series giving a total of 597 V < 600 V. This will then be connected in parallel to all the other rows in series, making the total current 229 A. This must be checked against the manufacturer data so that the amperage does not go over what the equipment can handle.

The inverter selected in this case the Satcon 100 KW Inverter. This has a voltage range of 315 – 600 V and a max current of 331 A. An advantage to this inverter is that its output voltage can be 480 V. This is important because the main transformers for the hospital step the supply power down to 480 V before going into the switchgear. This means that the panels can tie directly into the power system for the building at 480 V. Figure 11.16 shows the wiring layout for the main spine panels.

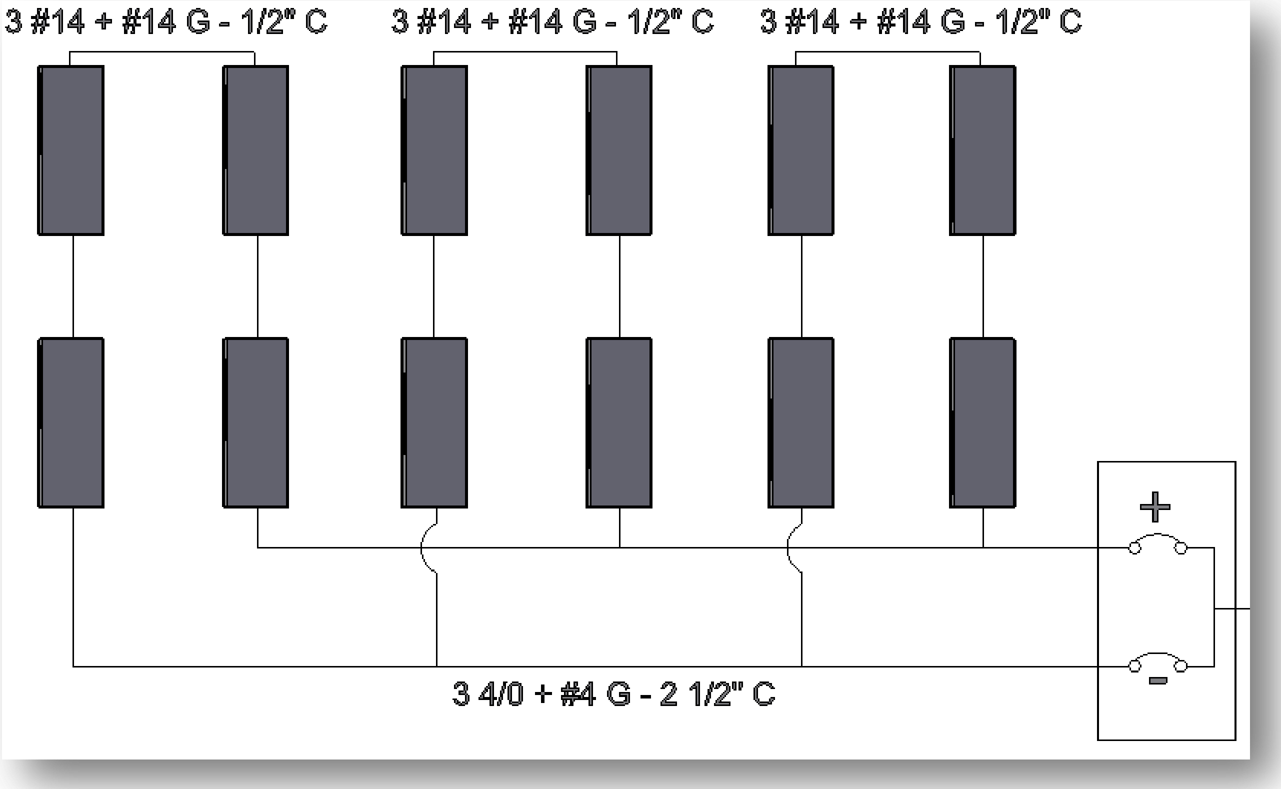


Figure 11.16 Wiring Layout

The wire sizes were determined based on NEC 2008 standards. The wire size for the panels in series is simply the short circuit current for a panel. The wire size selected was the smallest available that could handle that current. All the wires for the panels will connect into a junction box also shown in the above image. The ground wire was also sized base on the current of the system. The size of conduit depends on the amount of current conducting wires and their size. All values were determined based on NEC 2008 standards.

Figure 11.17 shows the layout from the junction box through the inverter. There is a main disconnect switch on each side of the inverter in case the current needs to be shut off.

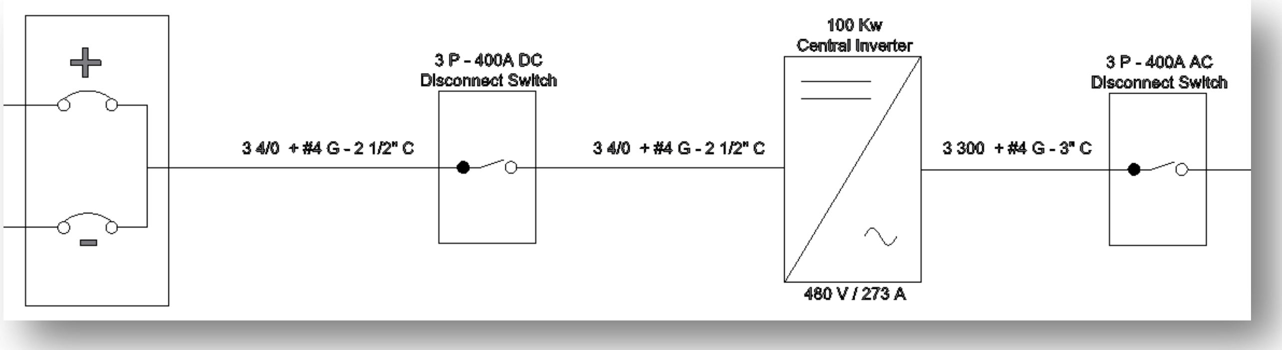
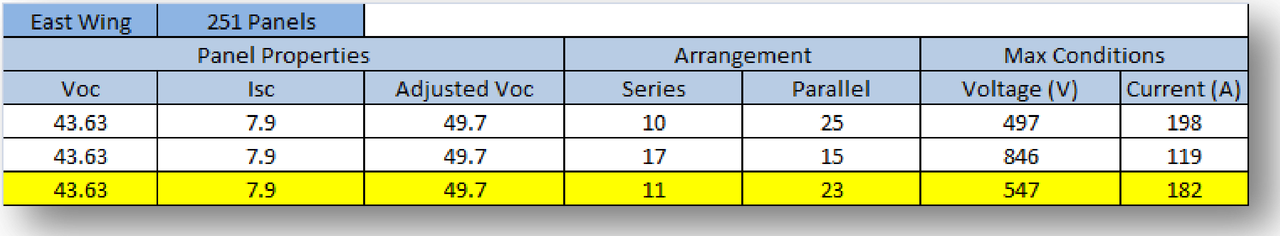


Figure 11.17 Wiring Layout

The wire sizing before the inverter is based on the 229 A of the total system. The DC disconnect switch was also sized on this amperage. The inverter will drop the voltage to 480 V as well as switch it to AC current. The wire size on this was based on the total power before the inverter (V=597 I= 229, P=136W). This was then multiplied by the inverter efficiency (.96) to get the power coming out of the inverter, which is 131W. This was then divided by the 480 V to obtain the current, which would be 273 A. The wire and disconnect switch on the AC were sized on this current. After the AC disconnect switch the panel system will tie into the 480 V switchboards for the hospital.

Table 11.7 shows the various arrangements for the east wing of the hospital. Since there are less panels on this system a smaller inverter could be used. The requirements for the smaller inverters were 305 - 600 V and 192 A.



East Wing	251 Panels					
Panel Properties			Arrangement		Max Conditions	
Voc	Isc	Adjusted Voc	Series	Parallel	Voltage (V)	Current (A)
43.63	7.9	49.7	10	25	497	198
43.63	7.9	49.7	17	15	846	119
43.63	7.9	49.7	11	23	547	182

Table 11.7 East Wing Panel Arrangements

The arrangement chosen for the east wing is 11 panels in series, with 23 rows in parallel. Once again this reaches the max voltage of the inverters at 547 V for each row, and has a max current of 182 A. Figure 11.18 shows the wiring layout for the panels.

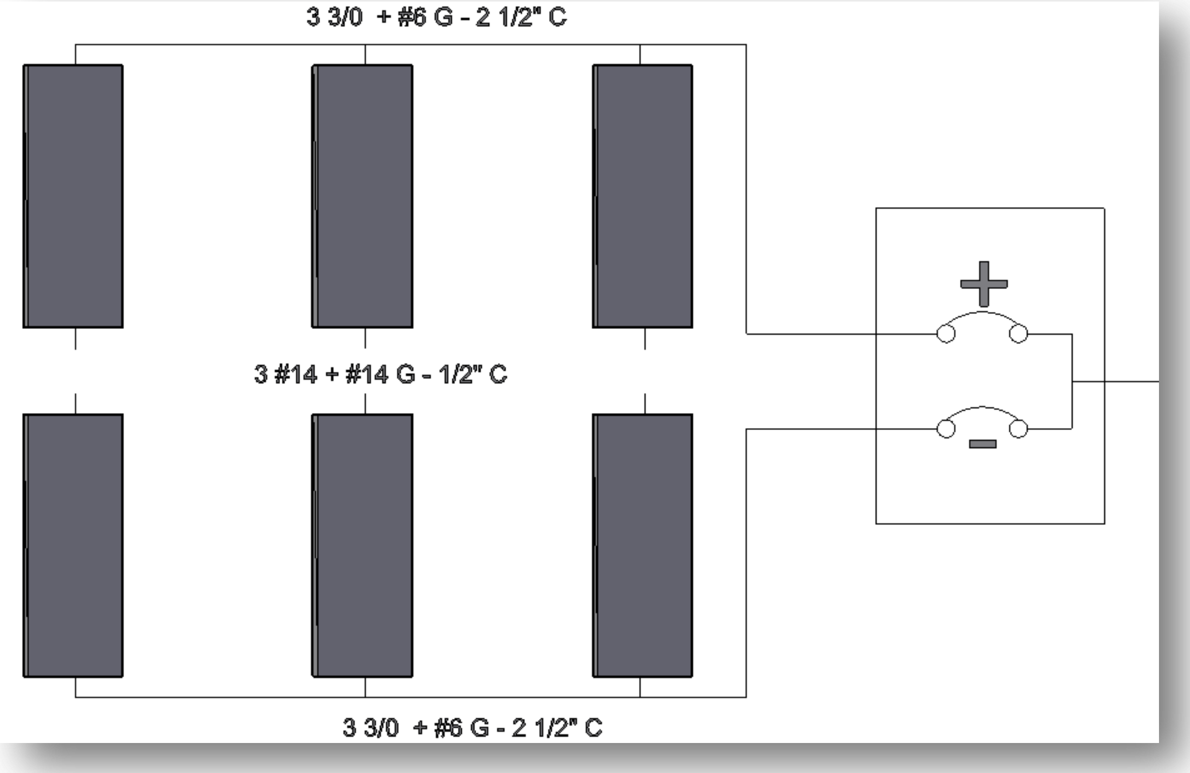


Figure 11.18 Wiring Layout

The wire sizes were based on the panel current at 7.9 A. The wire sizes for all the panels in parallel was based on the 182 A for the total circuit. Once again these values were determined from NEC 2008. Figure 11.19 shows the wiring diagram from the junction box through the inverter.

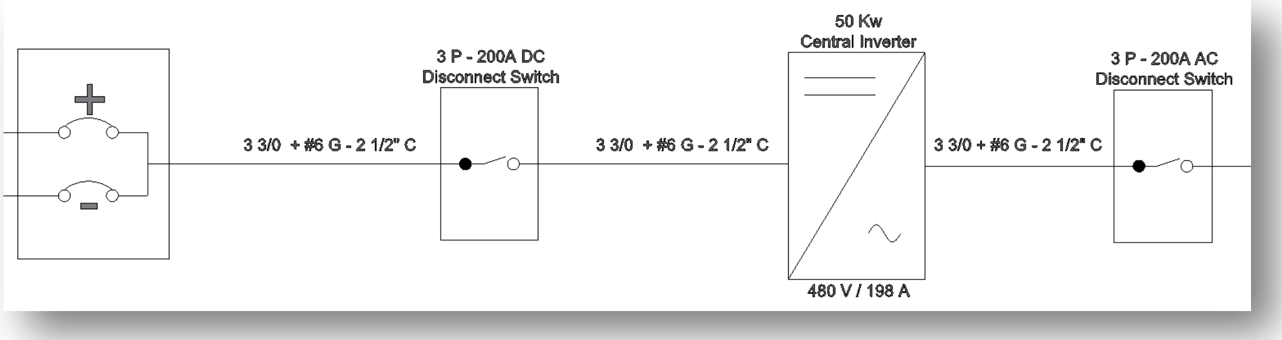
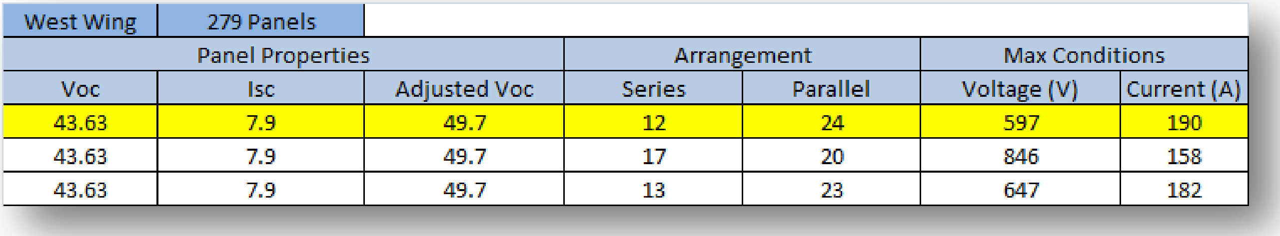


Figure 11.19 Wiring Layout

The wire size before the inverter will be the same as the panels in parallel, 182A. The wire size after the inverter is also the same because its max current will be 198 A, and the 3/0 wire has a max current of 200 A. The inverter being used is a Satcon 50 KW with efficiency of .955. The power (P=IV) entering the inverter was multiplied by this efficiency to determine the power coming out of the inverter.

Table 11.8 shows the various arrangements for the west wing panels.



West Wing	279 Panels					
Panel Properties			Arrangement		Max Conditions	
Voc	Isc	Adjusted Voc	Series	Parallel	Voltage (V)	Current (A)
43.63	7.9	49.7	12	24	597	190
43.63	7.9	49.7	17	20	846	158
43.63	7.9	49.7	13	23	647	182

Table 11.8 West Wing Panels

The same inverter will be used for the west wing as the east wing. This means the requirements must be 305-600 V and 192 A. The west wing panels come very close to both these values. Figure 11.20 below shows the wiring layout for the west wing.

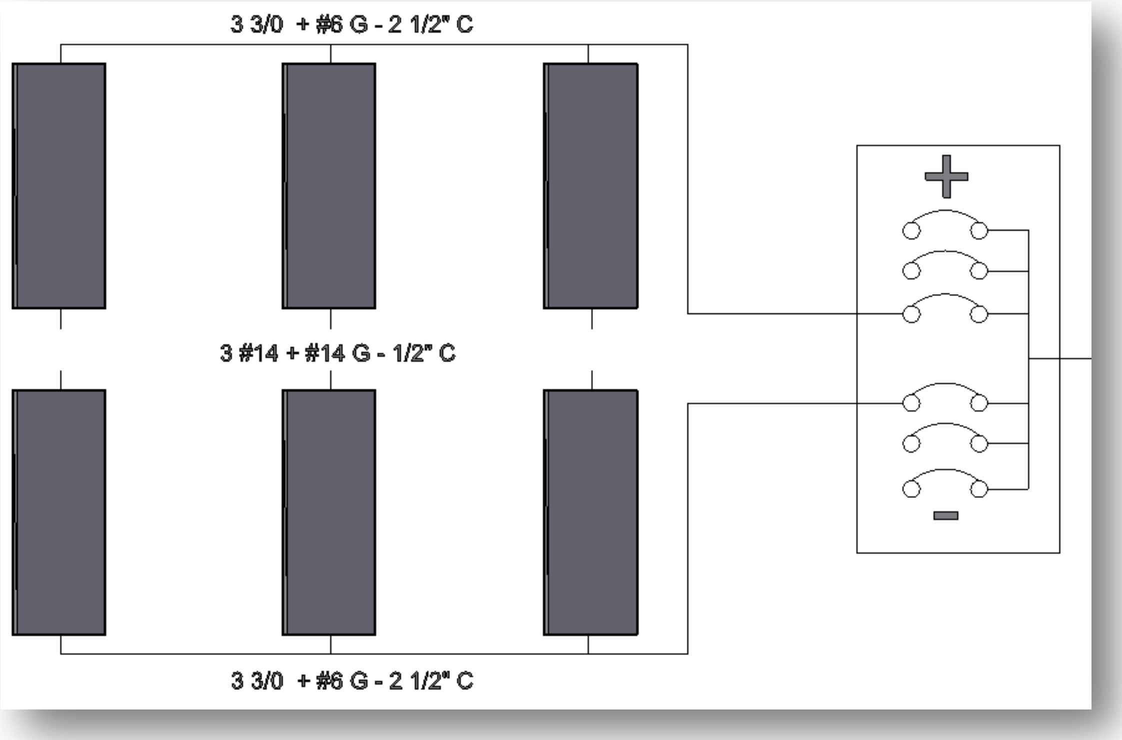


Figure 11.20 Wiring Layout

The west wing will have the same wire sizes as the east wing because the currents do not differ by much in the panel circuit. Figure 11.21 shows the wiring diagram from the junction box through the inverter.

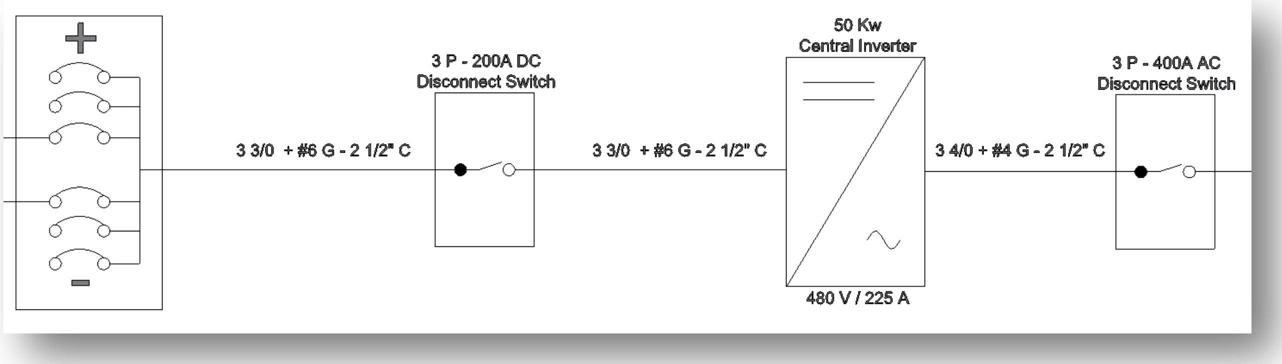


Figure 11.21 Wiring Diagram

The current leading the inverter will be 225 A based on the efficiency of the inverter and the power entering it. The wire size after the inverter was based on this current. Once again this was based on the NEC 2008.

The cost for each panel is $713 per panel. With a total of 884 panels this means the price of the panels alone is $630,292. The price for the 100 KW Satcon inverter is $41,100. The price for the 50 KW Satcon inverter is $26,000 each, with there being 2 this equates to $52,000. This means there is a total first cost of $750,000 included wiring and smaller items. The panels in total will produce around 5000 W in total, which is an annual savings of nearly $32,000. This would equate to a nearly 24 year simple payback period. However, there are government incentives that help on the first cost of the system. The US Department of Treasury has a Renewable Energy Grant that will pay 30% of the first cost for the PV panel system. This will take $225,000 of the first. There is no max limit on this grant. There is also a Solar Energy Sales Tax Exemption which requires no sales tax on the panels being purchased. The new total first cost will be $525,000, making the simple payback period a little under 17 years.

With a payback period of 17 years this system may be worth installing. The panels themselves have a warranty up to 30 years, and the system requires very little maintenance. There may also be a discount on the price of the panels since so many are being purchased. This would also help reduce the first cost.

Structural

Due to the large amount of panels on the roof it was important to see if they had any structural impact on the building. Since the original design criteria was not known for the structural plans in the construction documents, the columns were redesigned with no panels on the roof. They were then redesigned with panels on the roof to see if they had any impact.

Various loads were used to determine the overall load on each column. The dead loads that would be included on the columns will be the steel decking and concrete, misc. loads, superimposed loads, beams, exterior wall, roof, and floor loads. The live loads will be the snow, misc. loads, and petitions. The loads are as followed:

Dead:

Decking = 50 psf
Misc. = 8 psf
Slab = 75 psf
Super Imposed Roof = 5psf
Super Imposed Floor = 10 psf
Beams = 5 psf
Exterior Wall = 25 psf
Curtain Wall = 10 psf

Roof Total = Decking + Super Imposed Roof + Misc. = 50 + 5 + 8 = 63 psf

Floor Total = Slab + Beams + Super Imposed Floor = 90 psf

Live:

Snow = 30 psf
Misc. = 60 psf
Partition = 20 psf

Roof = Snow = 30 psf

Floor = Misc. + Partition = 60 + 20 = 80 psf

Factored Loads:

Roof
1.2D + .5S = 1.2*(63) + .5*(30) = 90.6 psf

The floor loads over an area of greater than 400 ft^2 had the Live Reduction Equation applied:

$$LLR = LL\ x\ (\frac{15}{\sqrt{4\ x\ Area}})$$

This was applied to all live loads that covered the appropriate area.

The wall load was determined by multiplying the exterior wall or curtain wall load (psf) by the area of wall that the specific column covered. This value is shown in the tables is in lbs. The total kips were added up and the column was selected based on the lightest column that could support the load. This was done to ensure the cheapest column is used.

Figure 12.1 shows a diagram of the column layout for the building.

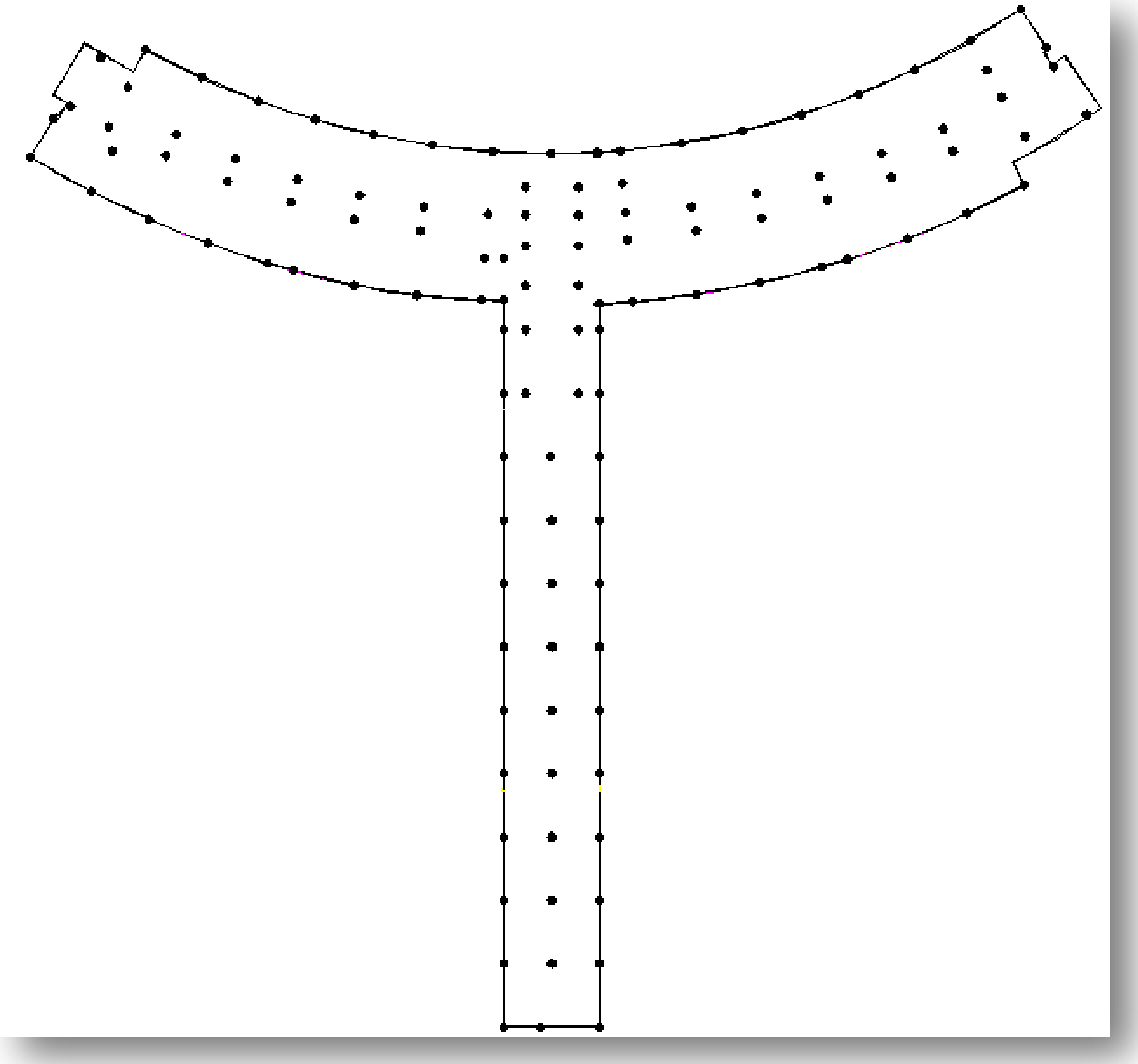


Figure 12.1 Column Layout

A more detailed view of the column layout for the spine is seen in Figures 12.2 and 12.3. These columns are numbered. The column numbers synch with the column numbers in the load calculations seen later in this section.

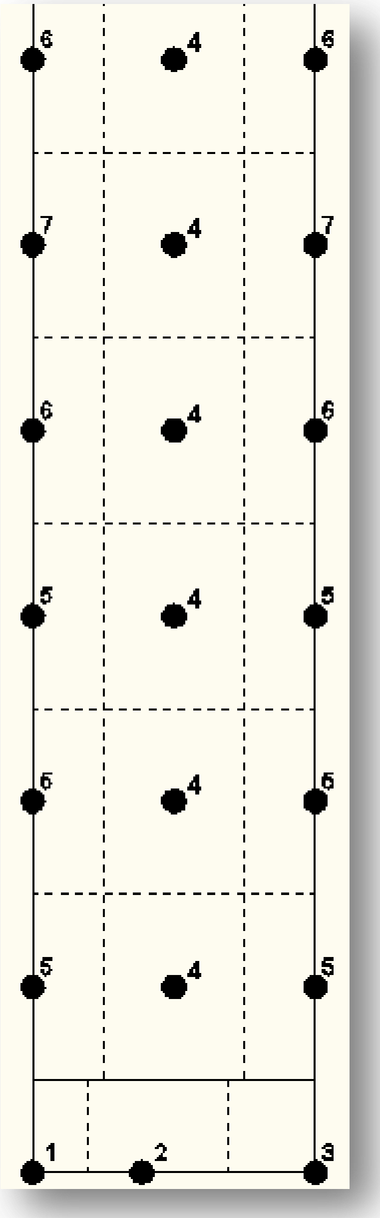


Figure 12.2 Center Spine Column Layout Bottom Half

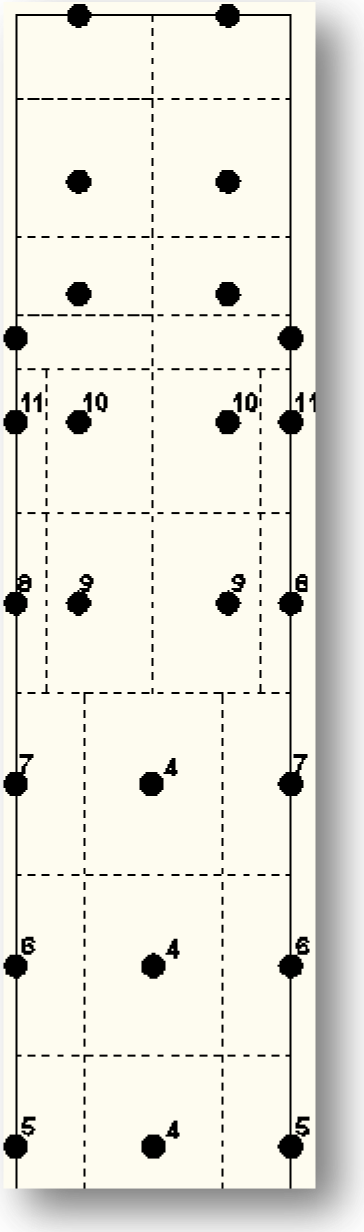


Figure 12.3 Center Spine Column Layout Top Half

Figure 12.4 shows the column layout for the east wing. The west wing columns will not be redesigned since they will be the same as the east wing.

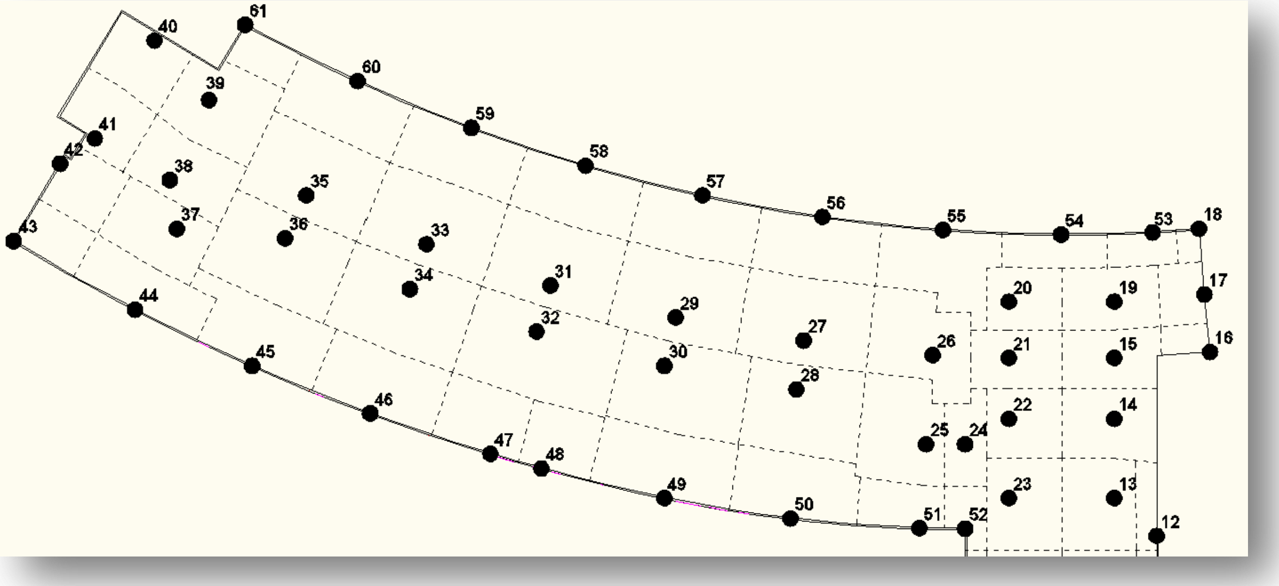
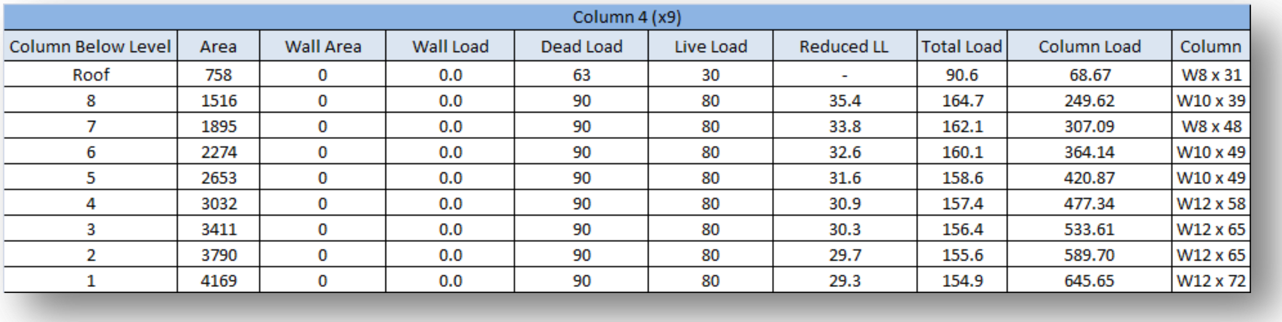


Figure 12.4 East Wing Column Layout

The dotted lines in the figures above indicate the areas that are assigned to each column. These areas are what is multiplied by the load (psf) to determine the final load on each column. Only roof loads were placed on the columns supporting the roof, however, this load will be carried through the rest of the floors. Exterior walls loads were also only applied to exterior walls. Table 12.1 shows an example of the column calculations done. This example is for Column 4 located at the center of the spine.

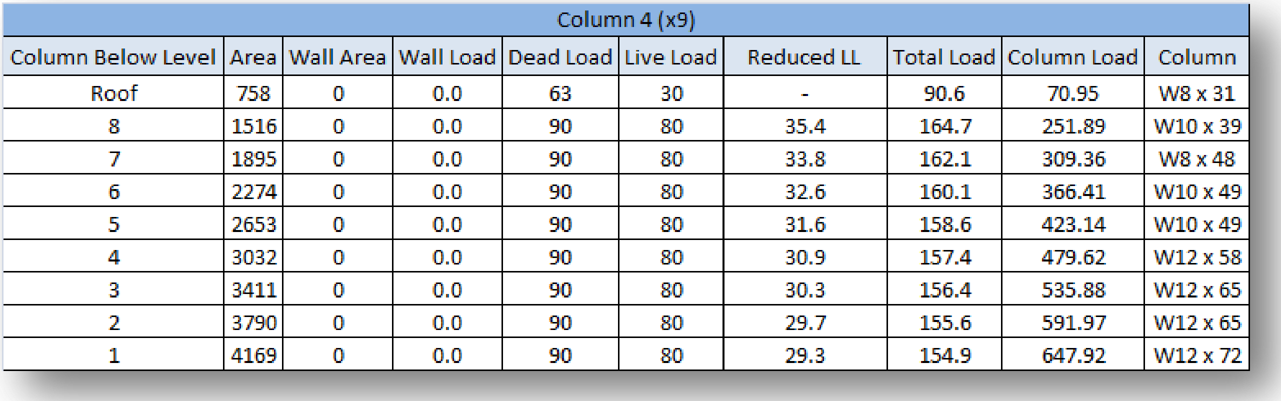


Column 4 (x9)									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	758	0	0.0	63	30	-	90.6	68.67	W8 x 31
8	1516	0	0.0	90	80	35.4	164.7	249.62	W10 x 39
7	1895	0	0.0	90	80	33.8	162.1	307.09	W8 x 48
6	2274	0	0.0	90	80	32.6	160.1	364.14	W10 x 49
5	2653	0	0.0	90	80	31.6	158.6	420.87	W10 x 49
4	3032	0	0.0	90	80	30.9	157.4	477.34	W12 x 58
3	3411	0	0.0	90	80	30.3	156.4	533.61	W12 x 65
2	3790	0	0.0	90	80	29.7	155.6	589.70	W12 x 65
1	4169	0	0.0	90	80	29.3	154.9	645.65	W12 x 72

Table 12.1 Column 4 Calculations

The additional load for the panels and equipment for the center spine will be 2 psf. Each panel weighs 50 lbs. The total amount of panels on the center spine is 354. This equates to a total weight of 17700 lbs. The area of the roof of the main spine is 17512 ft^2. This means there is 1.01 psf for the spine. An additional 1 psf was added to account for the framing system and other equipment. The total 2 psf value was multiplied by the column area on the roof and added to the column load.

The redesign of Column 4 with the panel loads on it is shown below in Table 12.2.



Column 4 (x9)									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	758	0	0.0	63	30	-	90.6	70.95	W8 x 31
8	1516	0	0.0	90	80	35.4	164.7	251.89	W10 x 39
7	1895	0	0.0	90	80	33.8	162.1	309.36	W8 x 48
6	2274	0	0.0	90	80	32.6	160.1	366.41	W10 x 49
5	2653	0	0.0	90	80	31.6	158.6	423.14	W10 x 49
4	3032	0	0.0	90	80	30.9	157.4	479.62	W12 x 58
3	3411	0	0.0	90	80	30.3	156.4	535.88	W12 x 65
2	3790	0	0.0	90	80	29.7	155.6	591.97	W12 x 65
1	4169	0	0.0	90	80	29.3	154.9	647.92	W12 x 72

Table 12.2 Column 4 Calculations with Panels

As seen by looking at the total column load, the panels add 2 kips on this column. This is not nearly enough to change the structure of the building. After recalculating all the loads on the columns affected by the panels, none of the columns needed to be changed because of the additional load. The loads already in place account for such a significant portion of the loads and additional load from the panels does not make much of a difference. The columns that are affected by the solar panels can be seen in Appendix I. Both the calculations before and after the panels were added are displayed to show that the additional load does not affect any of the columns.

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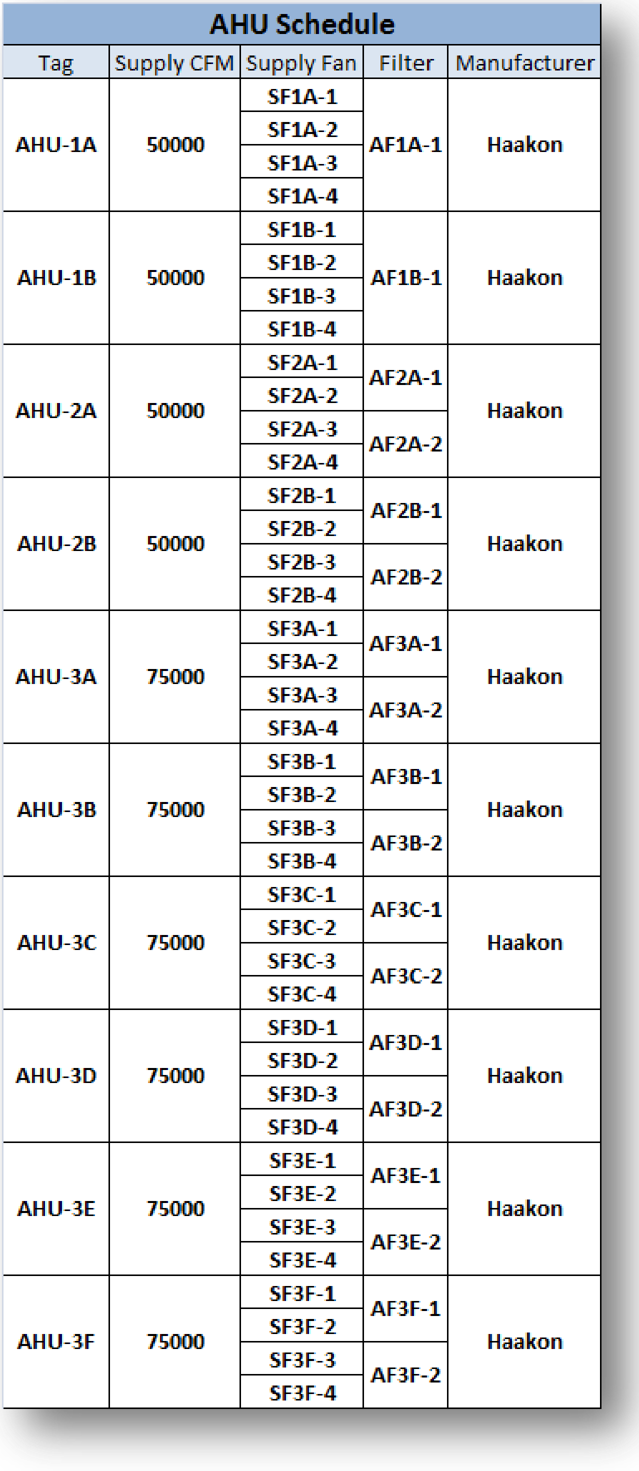
Scott Lindvall – HGA Architects & Engineering

Dr. Stephen Treado – Penn State Thesis Advisor

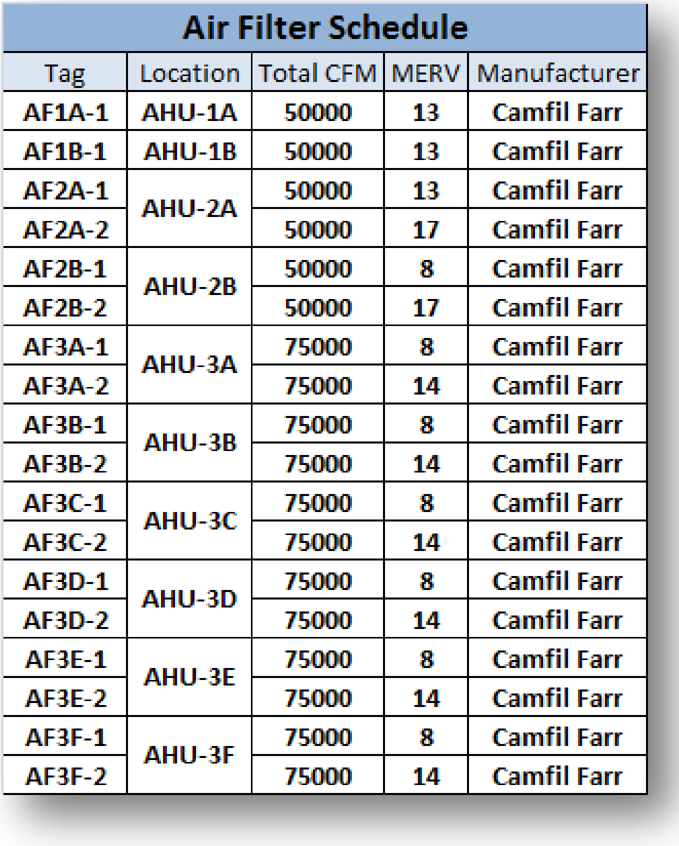
Appendix A



AHU Schedule

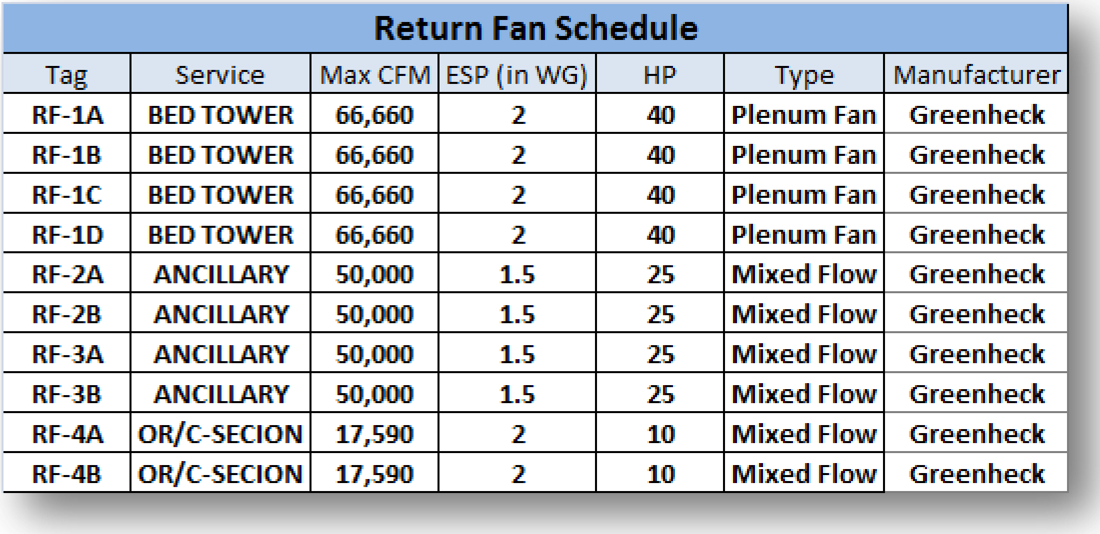
Tag	Supply CFM	Supply Fan	Filter	Manufacturer
AHU-1A	50000	SF1A-1	AF1A-1	Haakon
		SF1A-2		
		SF1A-3		
		SF1A-4		
AHU-1B	50000	SF1B-1	AF1B-1	Haakon
		SF1B-2		
		SF1B-3		
		SF1B-4		
AHU-2A	50000	SF2A-1	AF2A-1	Haakon
		SF2A-2		
		SF2A-3	AF2A-2	
		SF2A-4		
AHU-2B	50000	SF2B-1	AF2B-1	Haakon
		SF2B-2		
		SF2B-3	AF2B-2	
		SF2B-4		
AHU-3A	75000	SF3A-1	AF3A-1	Haakon
		SF3A-2		
		SF3A-3	AF3A-2	
		SF3A-4		
AHU-3B	75000	SF3B-1	AF3B-1	Haakon
		SF3B-2		
		SF3B-3	AF3B-2	
		SF3B-4		
AHU-3C	75000	SF3C-1	AF3C-1	Haakon
		SF3C-2		
		SF3C-3	AF3C-2	
		SF3C-4		
AHU-3D	75000	SF3D-1	AF3D-1	Haakon
		SF3D-2		
		SF3D-3	AF3D-2	
		SF3D-4		
AHU-3E	75000	SF3E-1	AF3E-1	Haakon
		SF3E-2		
		SF3E-3	AF3E-2	
		SF3E-4		
AHU-3F	75000	SF3F-1	AF3F-1	Haakon
		SF3F-2		
		SF3F-3	AF3F-2	
		SF3F-4		

Air Handling Unit Schedule



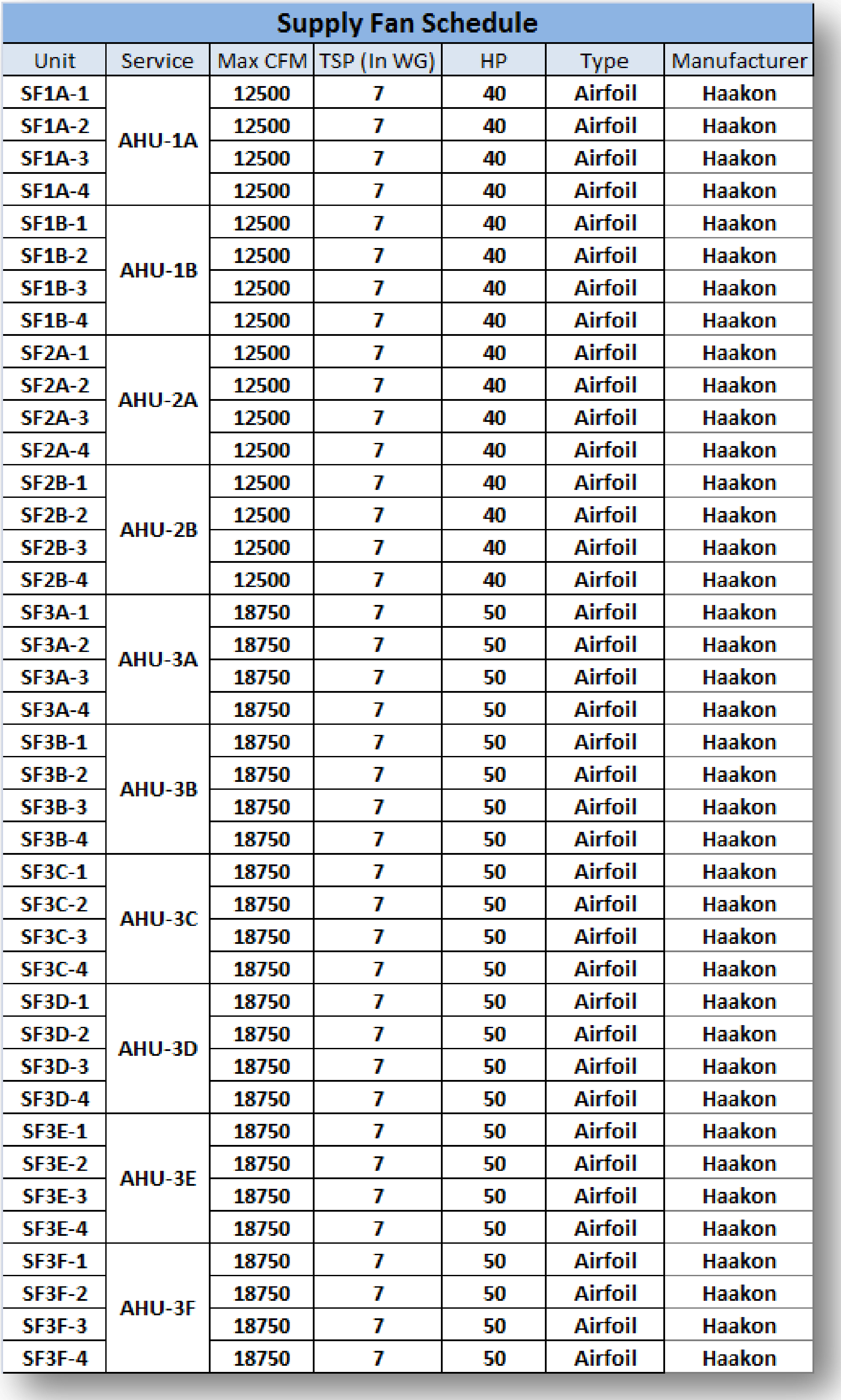
Air Filter Schedule				
Tag	Location	Total CFM	MERV	Manufacturer
AF1A-1	AHU-1A	50000	13	Camfil Farr
AF1B-1	AHU-1B	50000	13	Camfil Farr
AF2A-1	AHU-2A	50000	13	Camfil Farr
AF2A-2		50000	17	Camfil Farr
AF2B-1	AHU-2B	50000	8	Camfil Farr
AF2B-2		50000	17	Camfil Farr
AF3A-1	AHU-3A	75000	8	Camfil Farr
AF3A-2		75000	14	Camfil Farr
AF3B-1	AHU-3B	75000	8	Camfil Farr
AF3B-2		75000	14	Camfil Farr
AF3C-1	AHU-3C	75000	8	Camfil Farr
AF3C-2		75000	14	Camfil Farr
AF3D-1	AHU-3D	75000	8	Camfil Farr
AF3D-2		75000	14	Camfil Farr
AF3E-1	AHU-3E	75000	8	Camfil Farr
AF3E-2		75000	14	Camfil Farr
AF3F-1	AHU-3F	75000	8	Camfil Farr
AF3F-2		75000	14	Camfil Farr

Air Filter Schedule



Return Fan Schedule						
Tag	Service	Max CFM	ESP (in WG)	HP	Type	Manufacturer
RF-1A	BED TOWER	66,660	2	40	Plenum Fan	Greenheck
RF-1B	BED TOWER	66,660	2	40	Plenum Fan	Greenheck
RF-1C	BED TOWER	66,660	2	40	Plenum Fan	Greenheck
RF-1D	BED TOWER	66,660	2	40	Plenum Fan	Greenheck
RF-2A	ANCILLARY	50,000	1.5	25	Mixed Flow	Greenheck
RF-2B	ANCILLARY	50,000	1.5	25	Mixed Flow	Greenheck
RF-3A	ANCILLARY	50,000	1.5	25	Mixed Flow	Greenheck
RF-3B	ANCILLARY	50,000	1.5	25	Mixed Flow	Greenheck
RF-4A	OR/C-SECION	17,590	2	10	Mixed Flow	Greenheck
RF-4B	OR/C-SECION	17,590	2	10	Mixed Flow	Greenheck

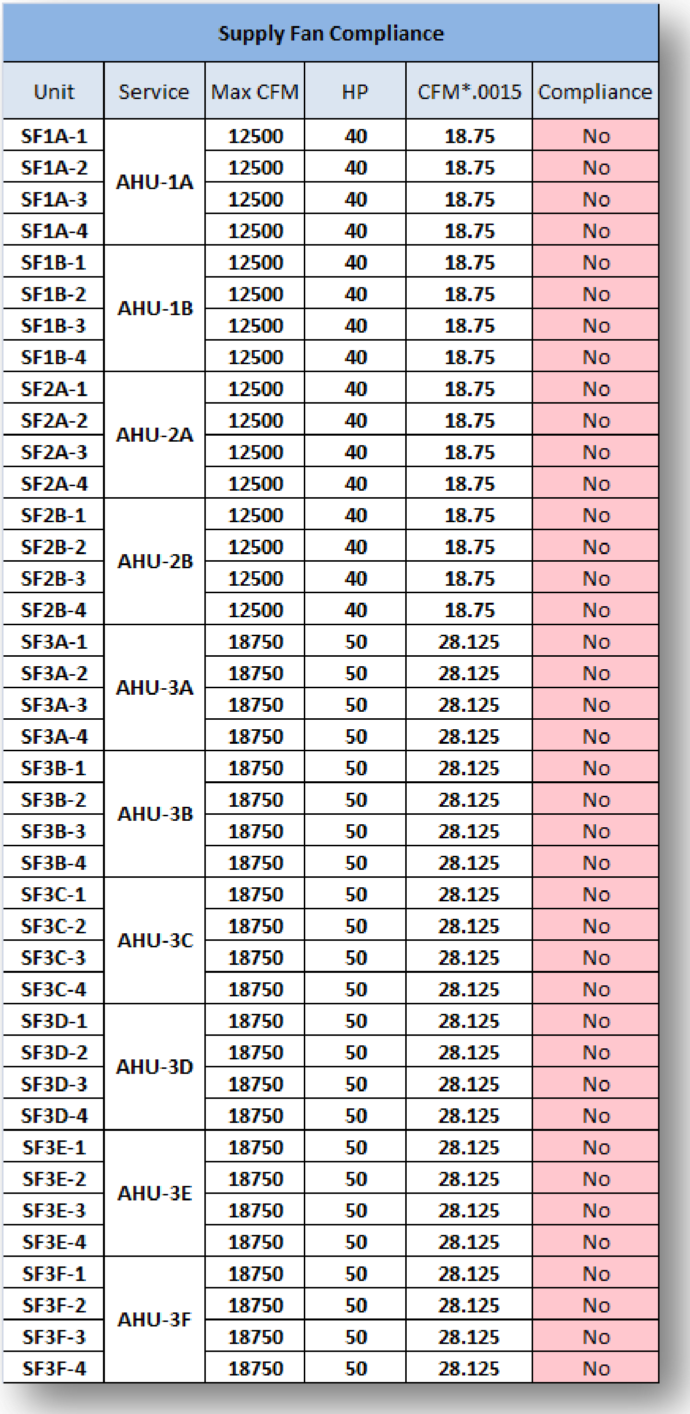
Return Fan Schedule



Supply Fan Schedule						
Unit	Service	Max CFM	TSP (In WG)	HP	Type	Manufacturer
SF1A-1	AHU-1A	12500	7	40	Airfoil	Haakon
SF1A-2		12500	7	40	Airfoil	Haakon
SF1A-3		12500	7	40	Airfoil	Haakon
SF1A-4		12500	7	40	Airfoil	Haakon
SF1B-1	AHU-1B	12500	7	40	Airfoil	Haakon
SF1B-2		12500	7	40	Airfoil	Haakon
SF1B-3		12500	7	40	Airfoil	Haakon
SF1B-4		12500	7	40	Airfoil	Haakon
SF2A-1	AHU-2A	12500	7	40	Airfoil	Haakon
SF2A-2		12500	7	40	Airfoil	Haakon
SF2A-3		12500	7	40	Airfoil	Haakon
SF2A-4		12500	7	40	Airfoil	Haakon
SF2B-1	AHU-2B	12500	7	40	Airfoil	Haakon
SF2B-2		12500	7	40	Airfoil	Haakon
SF2B-3		12500	7	40	Airfoil	Haakon
SF2B-4		12500	7	40	Airfoil	Haakon
SF3A-1	AHU-3A	18750	7	50	Airfoil	Haakon
SF3A-2		18750	7	50	Airfoil	Haakon
SF3A-3		18750	7	50	Airfoil	Haakon
SF3A-4		18750	7	50	Airfoil	Haakon
SF3B-1	AHU-3B	18750	7	50	Airfoil	Haakon
SF3B-2		18750	7	50	Airfoil	Haakon
SF3B-3		18750	7	50	Airfoil	Haakon
SF3B-4		18750	7	50	Airfoil	Haakon
SF3C-1	AHU-3C	18750	7	50	Airfoil	Haakon
SF3C-2		18750	7	50	Airfoil	Haakon
SF3C-3		18750	7	50	Airfoil	Haakon
SF3C-4		18750	7	50	Airfoil	Haakon
SF3D-1	AHU-3D	18750	7	50	Airfoil	Haakon
SF3D-2		18750	7	50	Airfoil	Haakon
SF3D-3		18750	7	50	Airfoil	Haakon
SF3D-4		18750	7	50	Airfoil	Haakon
SF3E-1	AHU-3E	18750	7	50	Airfoil	Haakon
SF3E-2		18750	7	50	Airfoil	Haakon
SF3E-3		18750	7	50	Airfoil	Haakon
SF3E-4		18750	7	50	Airfoil	Haakon
SF3F-1	AHU-3F	18750	7	50	Airfoil	Haakon
SF3F-2		18750	7	50	Airfoil	Haakon
SF3F-3		18750	7	50	Airfoil	Haakon
SF3F-4		18750	7	50	Airfoil	Haakon

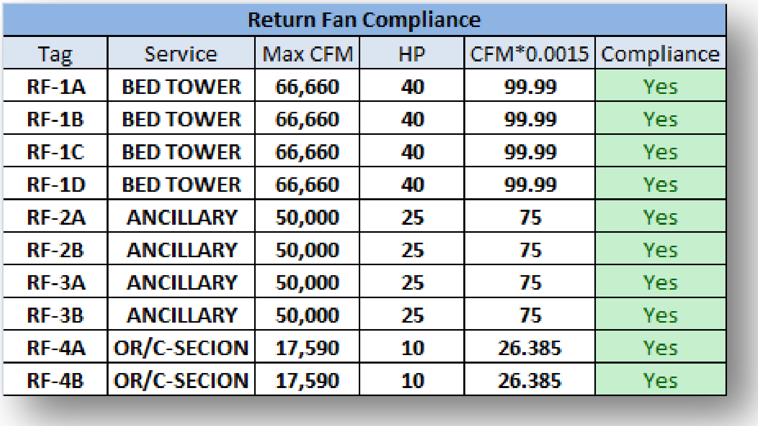
Supply Fan Schedule

Appendix B



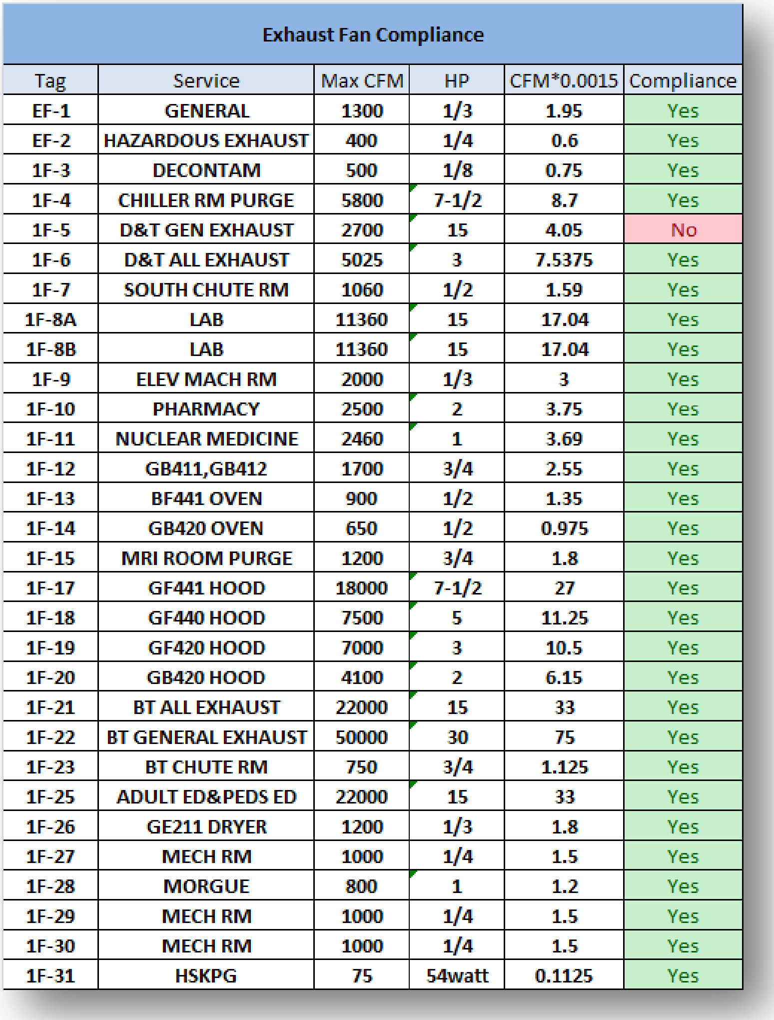
Supply Fan Compliance					
Unit	Service	Max CFM	HP	CFM*.0015	Compliance
SF1A-1	AHU-1A	12500	40	18.75	No
SF1A-2		12500	40	18.75	No
SF1A-3		12500	40	18.75	No
SF1A-4		12500	40	18.75	No
SF1B-1	AHU-1B	12500	40	18.75	No
SF1B-2		12500	40	18.75	No
SF1B-3		12500	40	18.75	No
SF1B-4		12500	40	18.75	No
SF2A-1	AHU-2A	12500	40	18.75	No
SF2A-2		12500	40	18.75	No
SF2A-3		12500	40	18.75	No
SF2A-4		12500	40	18.75	No
SF2B-1	AHU-2B	12500	40	18.75	No
SF2B-2		12500	40	18.75	No
SF2B-3		12500	40	18.75	No
SF2B-4		12500	40	18.75	No
SF3A-1	AHU-3A	18750	50	28.125	No
SF3A-2		18750	50	28.125	No
SF3A-3		18750	50	28.125	No
SF3A-4		18750	50	28.125	No
SF3B-1	AHU-3B	18750	50	28.125	No
SF3B-2		18750	50	28.125	No
SF3B-3		18750	50	28.125	No
SF3B-4		18750	50	28.125	No
SF3C-1	AHU-3C	18750	50	28.125	No
SF3C-2		18750	50	28.125	No
SF3C-3		18750	50	28.125	No
SF3C-4		18750	50	28.125	No
SF3D-1	AHU-3D	18750	50	28.125	No
SF3D-2		18750	50	28.125	No
SF3D-3		18750	50	28.125	No
SF3D-4		18750	50	28.125	No
SF3E-1	AHU-3E	18750	50	28.125	No
SF3E-2		18750	50	28.125	No
SF3E-3		18750	50	28.125	No
SF3E-4		18750	50	28.125	No
SF3F-1	AHU-3F	18750	50	28.125	No
SF3F-2		18750	50	28.125	No
SF3F-3		18750	50	28.125	No
SF3F-4		18750	50	28.125	No

Supply Fan Compliance



Return Fan Compliance					
Tag	Service	Max CFM	HP	CFM*0.0015	Compliance
RF-1A	BED TOWER	66,660	40	99.99	Yes
RF-1B	BED TOWER	66,660	40	99.99	Yes
RF-1C	BED TOWER	66,660	40	99.99	Yes
RF-1D	BED TOWER	66,660	40	99.99	Yes
RF-2A	ANCILLARY	50,000	25	75	Yes
RF-2B	ANCILLARY	50,000	25	75	Yes
RF-3A	ANCILLARY	50,000	25	75	Yes
RF-3B	ANCILLARY	50,000	25	75	Yes
RF-4A	OR/C-SECION	17,590	10	26.385	Yes
RF-4B	OR/C-SECION	17,590	10	26.385	Yes

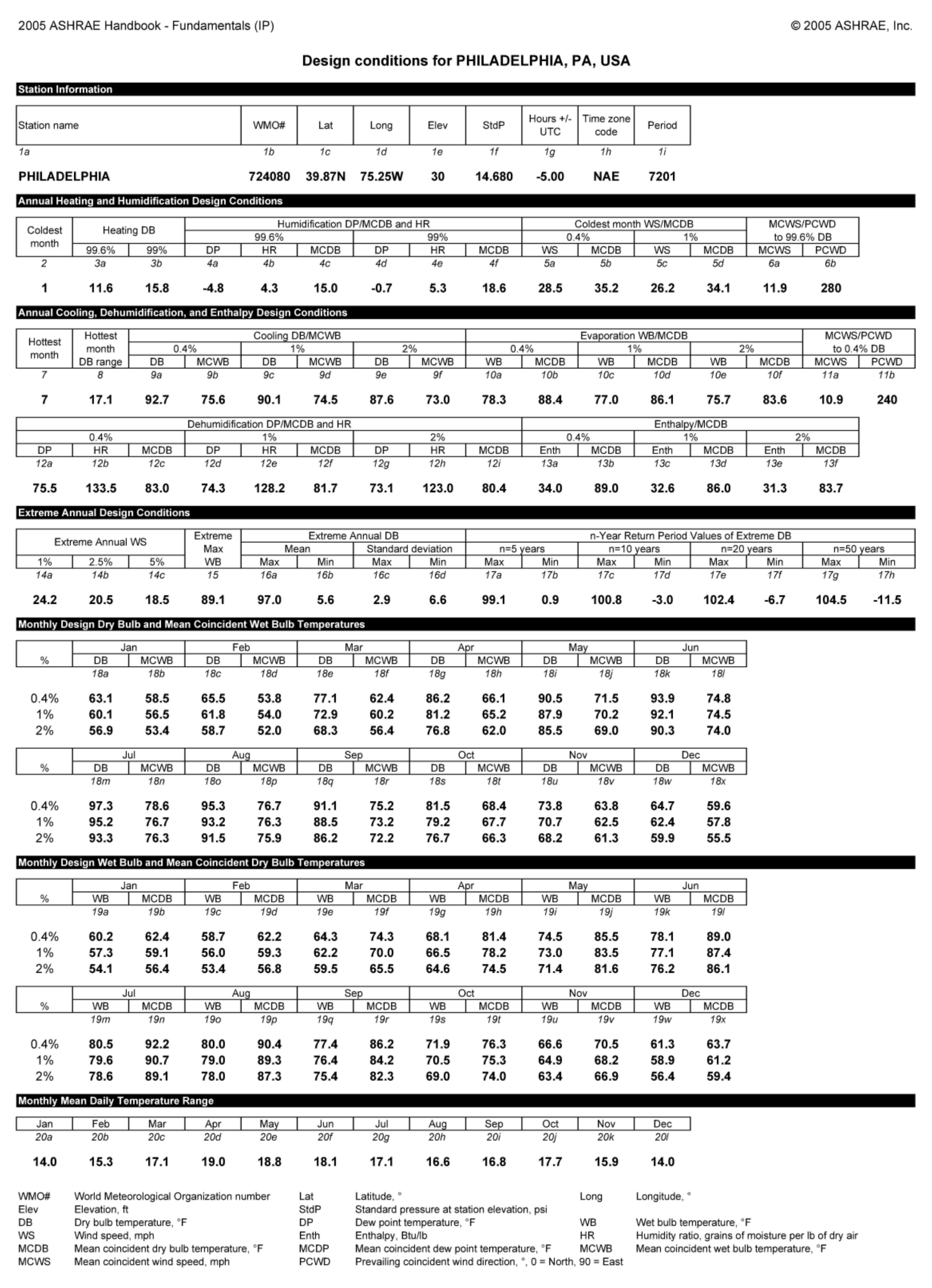
Return Fan Compliance



Exhaust Fan Compliance					
Tag	Service	Max CFM	HP	CFM*0.0015	Compliance
EF-1	GENERAL	1300	1/3	1.95	Yes
EF-2	HAZARDOUS EXHAUST	400	1/4	0.6	Yes
1F-3	DECONTAM	500	1/8	0.75	Yes
1F-4	CHILLER RM PURGE	5800	7-1/2	8.7	Yes
1F-5	D&T GEN EXHAUST	2700	15	4.05	No
1F-6	D&T ALL EXHAUST	5025	3	7.5375	Yes
1F-7	SOUTH CHUTE RM	1060	1/2	1.59	Yes
1F-8A	LAB	11360	15	17.04	Yes
1F-8B	LAB	11360	15	17.04	Yes
1F-9	ELEV MACH RM	2000	1/3	3	Yes
1F-10	PHARMACY	2500	2	3.75	Yes
1F-11	NUCLEAR MEDICINE	2460	1	3.69	Yes
1F-12	GB411,GB412	1700	3/4	2.55	Yes
1F-13	BF441 OVEN	900	1/2	1.35	Yes
1F-14	GB420 OVEN	650	1/2	0.975	Yes
1F-15	MRI ROOM PURGE	1200	3/4	1.8	Yes
1F-17	GF441 HOOD	18000	7-1/2	27	Yes
1F-18	GF440 HOOD	7500	5	11.25	Yes
1F-19	GF420 HOOD	7000	3	10.5	Yes
1F-20	GB420 HOOD	4100	2	6.15	Yes
1F-21	BT ALL EXHAUST	22000	15	33	Yes
1F-22	BT GENERAL EXHAUST	50000	30	75	Yes
1F-23	BT CHUTE RM	750	3/4	1.125	Yes
1F-25	ADULT ED&PEDS ED	22000	15	33	Yes
1F-26	GE211 DRYER	1200	1/3	1.8	Yes
1F-27	MECH RM	1000	1/4	1.5	Yes
1F-28	MORGUE	800	1	1.2	Yes
1F-29	MECH RM	1000	1/4	1.5	Yes
1F-30	MECH RM	1000	1/4	1.5	Yes
1F-31	HSKPG	75	54watt	0.1125	Yes

Exhaust Fan Compliance

Appendix C



2005 ASHRAE Handbook - Fundamentals (IP)

Design conditions for PHILADELPHIA, PA, USA

Station Information

Station name	WMO#	Lat	Long	Elev	StdP	Hours +/- UTC	Time zone code	Period
1a	*1b*	*1c*	*1d*	*1e*	*1f*	*1g*	*1h*	*1i*
PHILADELPHIA	**724080**	**39.87N**	**75.25W**	**30**	**14.680**	**-5.00**	**NAE**	**7201**

Annual Heating and Humidification Design Conditions

Coldest month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB	
			99.6%			99%			0.4%		1%			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
2	*3a*	*3b*	*4a*	*4b*	*4c*	*4d*	*4e*	*4f*	*5a*	*5b*	*5c*	*5d*	*6a*	*6b*
1	**11.6**	**15.8**	**-4.8**	**4.3**	**15.0**	**-0.7**	**5.3**	**18.6**	**28.5**	**35.2**	**26.2**	**34.1**	**11.9**	**280**

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest month	Hottest month DB range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	*8*	*9a*	*9b*	*9c*	*9d*	*9e*	*9f*	*10a*	*10b*	*10c*	*10d*	*10e*	*10f*	*11a*	*11b*
7	**17.1**	**92.7**	**75.6**	**90.1**	**74.5**	**87.6**	**73.0**	**78.3**	**88.4**	**77.0**	**86.1**	**75.7**	**83.6**	**10.9**	**240**

Dehumidification DP/MCDB and HR									Enthalpy/MCDB					
0.4%			1%			2%			0.4%		1%		2%	
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB
12a	*12b*	*12c*	*12d*	*12e*	*12f*	*12g*	*12h*	*12i*	*13a*	*13b*	*13c*	*13d*	*13e*	*13f*
75.5	**133.5**	**83.0**	**74.3**	**128.2**	**81.7**	**73.1**	**123.0**	**80.4**	**34.0**	**89.0**	**32.6**	**86.0**	**31.3**	**83.7**

Extreme Annual Design Conditions

Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
14a	*14b*	*14c*	*15*	*16a*	*16b*	*16c*	*16d*	*17a*	*17b*	*17c*	*17d*	*17e*	*17f*	*17g*	*17h*
24.2	**20.5**	**18.5**	**89.1**	**97.0**	**5.6**	**2.9**	**6.6**	**99.1**	**0.9**	**100.8**	**-3.0**	**102.4**	**-6.7**	**104.5**	**-11.5**

Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18a	*18b*	*18c*	*18d*	*18e*	*18f*	*18g*	*18h*	*18i*	*18j*	*18k*	*18l*
0.4%	**63.1**	**58.5**	**65.5**	**53.8**	**77.1**	**62.4**	**86.2**	**66.1**	**90.5**	**71.5**	**93.9**	**74.8**
1%	**60.1**	**56.5**	**61.8**	**54.0**	**72.9**	**60.2**	**81.2**	**65.2**	**87.9**	**70.2**	**92.1**	**74.5**
2%	**56.9**	**53.4**	**58.7**	**52.0**	**68.3**	**56.4**	**76.8**	**62.0**	**85.5**	**69.0**	**90.3**	**74.0**

%	Jul		Aug		Sep		Oct		Nov		Dec	
	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB	DB	MCWB
	18m	*18n*	*18o*	*18p*	*18q*	*18r*	*18s*	*18t*	*18u*	*18v*	*18w*	*18x*
0.4%	**97.3**	**78.6**	**95.3**	**76.7**	**91.1**	**75.2**	**81.5**	**68.4**	**73.8**	**63.8**	**64.7**	**59.6**
1%	**95.2**	**76.7**	**93.2**	**76.3**	**88.5**	**73.2**	**79.2**	**67.7**	**70.7**	**62.5**	**62.4**	**57.8**
2%	**93.3**	**76.3**	**91.5**	**75.9**	**86.2**	**72.2**	**76.7**	**66.3**	**68.2**	**61.3**	**59.9**	**55.5**

Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures

%	Jan		Feb		Mar		Apr		May		Jun	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19a	*19b*	*19c*	*19d*	*19e*	*19f*	*19g*	*19h*	*19i*	*19j*	*19k*	*19l*
0.4%	**60.2**	**62.4**	**58.7**	**62.2**	**64.3**	**74.3**	**68.1**	**81.4**	**74.5**	**85.5**	**78.1**	**89.0**
1%	**57.3**	**59.1**	**56.0**	**59.3**	**62.2**	**70.0**	**66.5**	**78.2**	**73.0**	**83.5**	**77.1**	**87.4**
2%	**54.1**	**56.4**	**53.4**	**56.8**	**59.5**	**65.5**	**64.6**	**74.5**	**71.4**	**81.6**	**76.2**	**86.1**

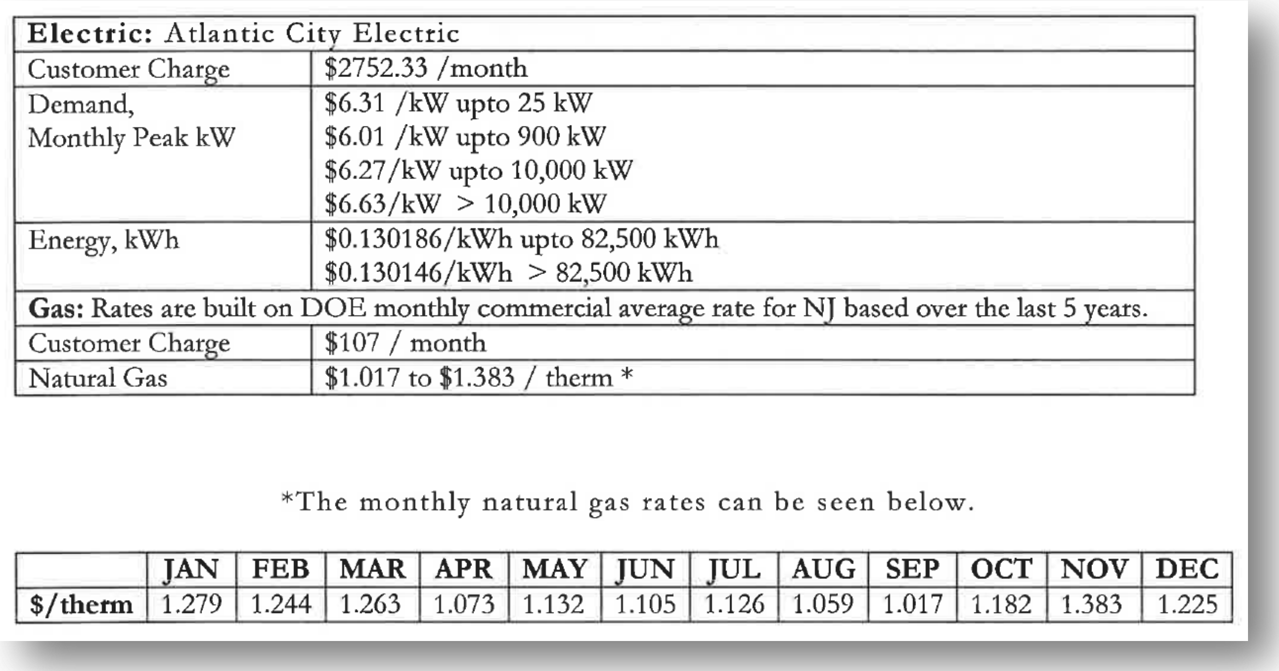
%	Jul		Aug		Sep		Oct		Nov		Dec	
	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB	WB	MCDB
	19m	*19n*	*19o*	*19p*	*19q*	*19r*	*19s*	*19t*	*19u*	*19v*	*19w*	*19x*
0.4%	**80.5**	**92.2**	**80.0**	**90.4**	**77.4**	**86.2**	**71.9**	**76.3**	**66.6**	**70.5**	**61.3**	**63.7**
1%	**79.6**	**90.7**	**79.0**	**89.3**	**76.4**	**84.2**	**70.5**	**75.3**	**64.9**	**68.2**	**58.9**	**61.2**
2%	**78.6**	**89.1**	**78.0**	**87.3**	**75.4**	**82.3**	**69.0**	**74.0**	**63.4**	**66.9**	**56.4**	**59.4**

Monthly Mean Daily Temperature Range

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
20a	*20b*	*20c*	*20d*	*20e*	*20f*	*20g*	*20h*	*20i*	*20j*	*20k*	*20l*
14.0	**15.3**	**17.1**	**19.0**	**18.8**	**18.1**	**17.1**	**16.6**	**16.8**	**17.7**	**15.9**	**14.0**

WMO#	World Meteorological Organization number	Lat	Latitude, °	Long	Longitude, °
Elev	Elevation, ft	StdP	Standard pressure at station elevation, psi		
DB	Dry bulb temperature, °F	DP	Dew point temperature, °F	WB	Wet bulb temperature, °F
WS	Wind speed, mph	Enth	Enthalpy, Btu/lb	HR	Humidity ratio, grains of moisture per lb of dry air
MCDB	Mean coincident dry bulb temperature, °F	MCDP	Mean coincident dew point temperature, °F	MCWB	Mean coincident wet bulb temperature, °F
MCWS	Mean coincident wind speed, mph	PCWD	Prevailing coincident wind direction, °, 0 = North, 90 = East		

Appendix D



Electric: Atlantic City Electric	
Customer Charge	$2752.33 /month
Demand, Monthly Peak kW	$6.31 /kW upto 25 kW $6.01 /kW upto 900 kW $6.27/kW upto 10,000 kW $6.63/kW > 10,000 kW
Energy, kWh	$0.130186/kWh upto 82,500 kWh $0.130146/kWh > 82,500 kWh
Gas: Rates are built on DOE monthly commercial average rate for NJ based over the last 5 years.	
Customer Charge	$107 / month
Natural Gas	$1.017 to $1.383 / therm *

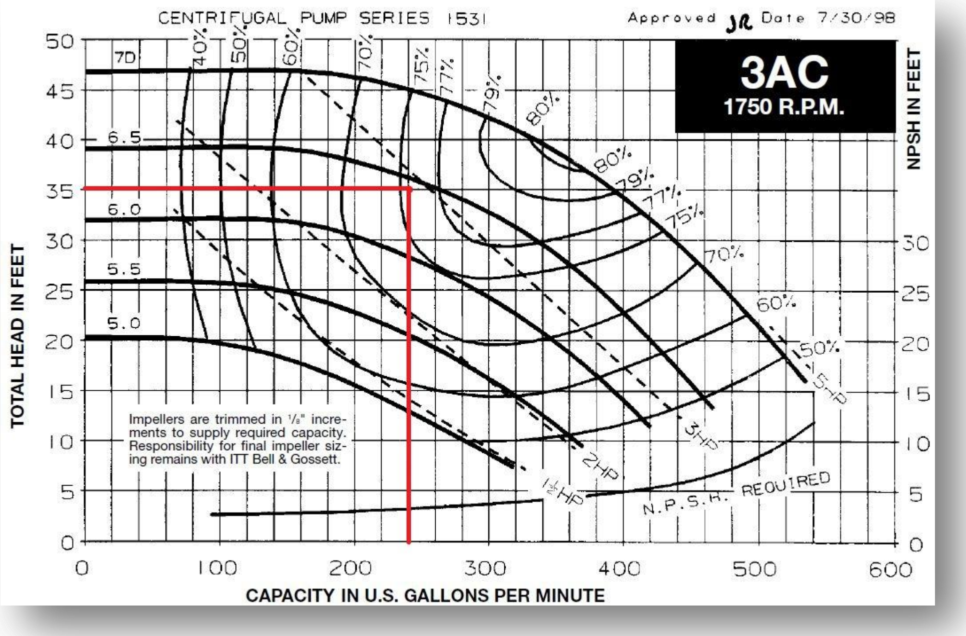
*The monthly natural gas rates can be seen below.

	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
$/therm	1.279	1.244	1.263	1.073	1.132	1.105	1.126	1.059	1.017	1.182	1.383	1.225

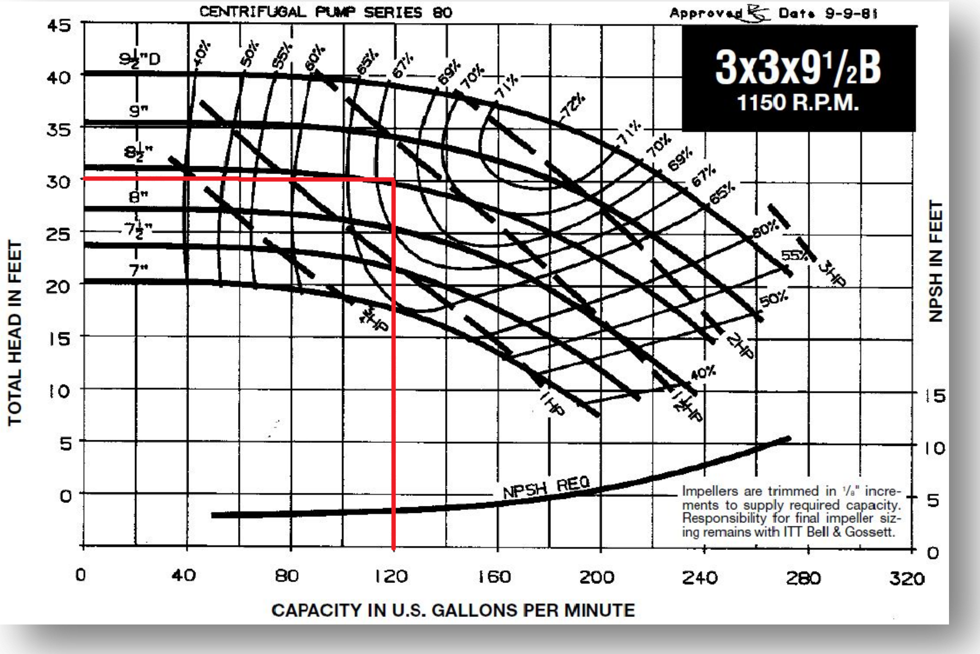
Appendix E

Method 1

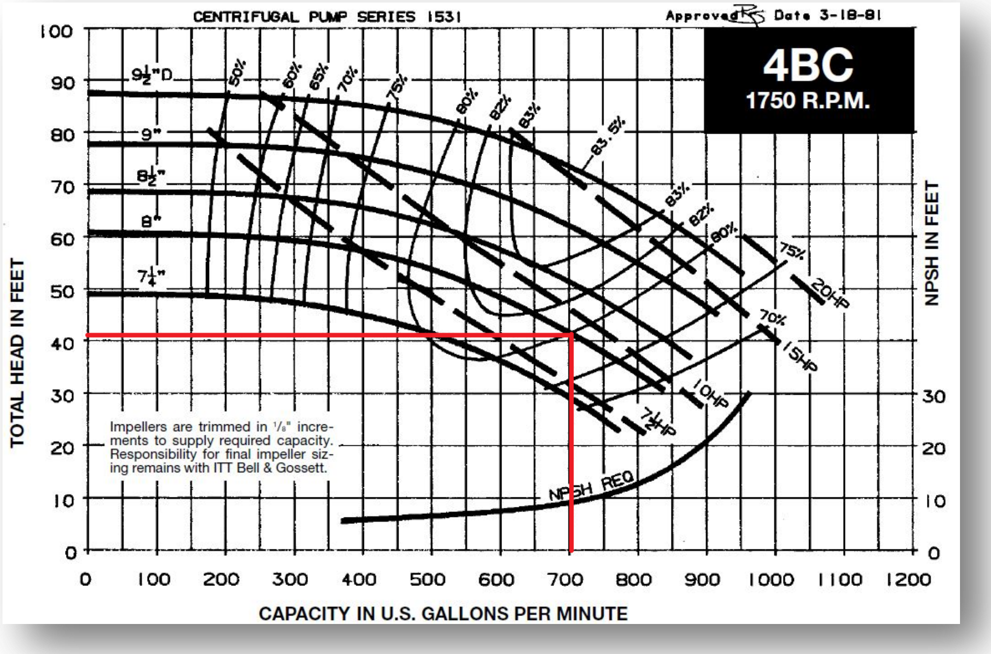
Option 1 AHU 1 300 ft



Option 2 AHU 1 600 ft

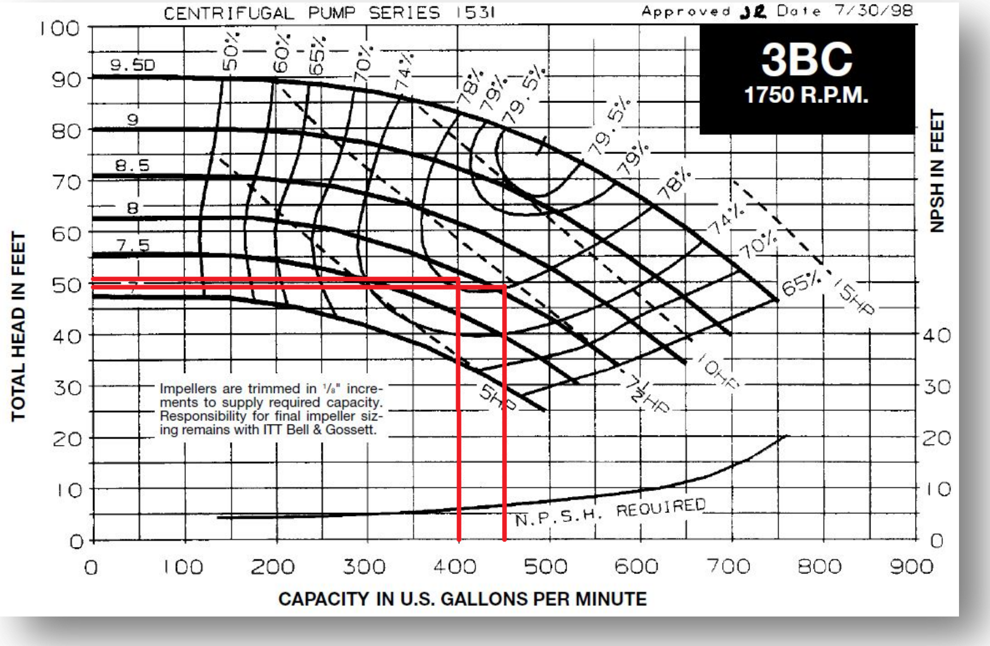


Option 3 AHU 2 600 ft



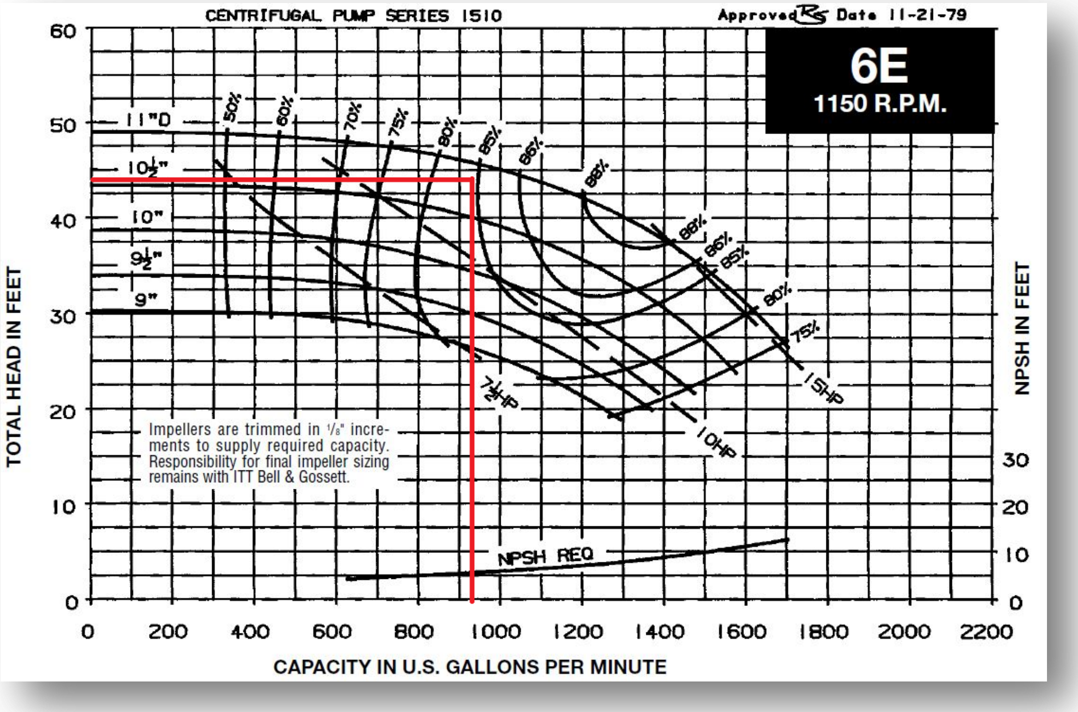
Impellers are trimmed in ⅛" increments to supply required capacity. Responsibility for final impeller sizing remains with ITT Bell & Gossett.

Option 4 AHU 2 1000 ft

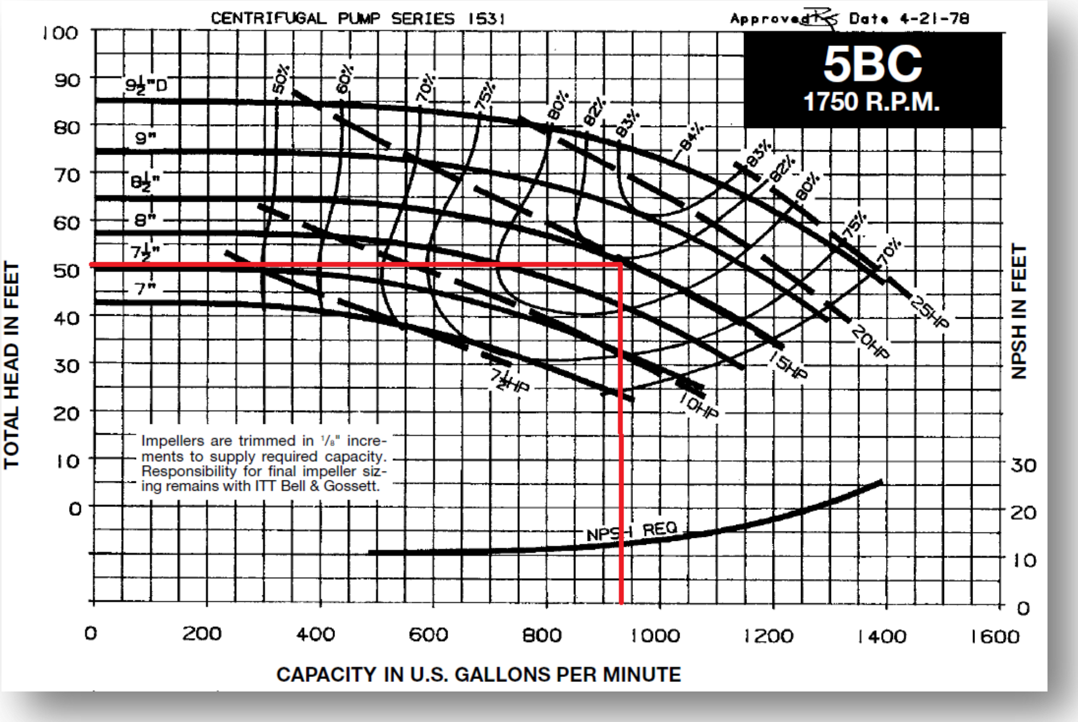


Impellers are trimmed in ⅛" increments to supply required capacity. Responsibility for final impeller sizing remains with ITT Bell & Gossett.

Option 5 AHU 3 1000 ft



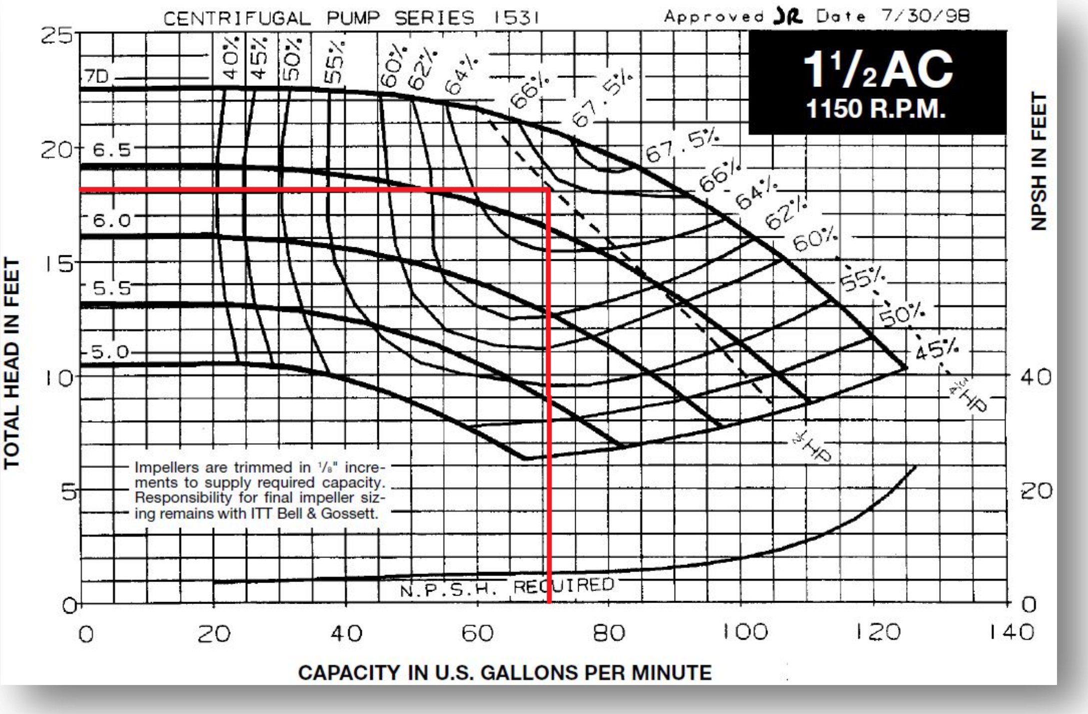
Impellers are trimmed in ⅛" increments to supply required capacity. Responsibility for final impeller sizing remains with ITT Bell & Gossett.



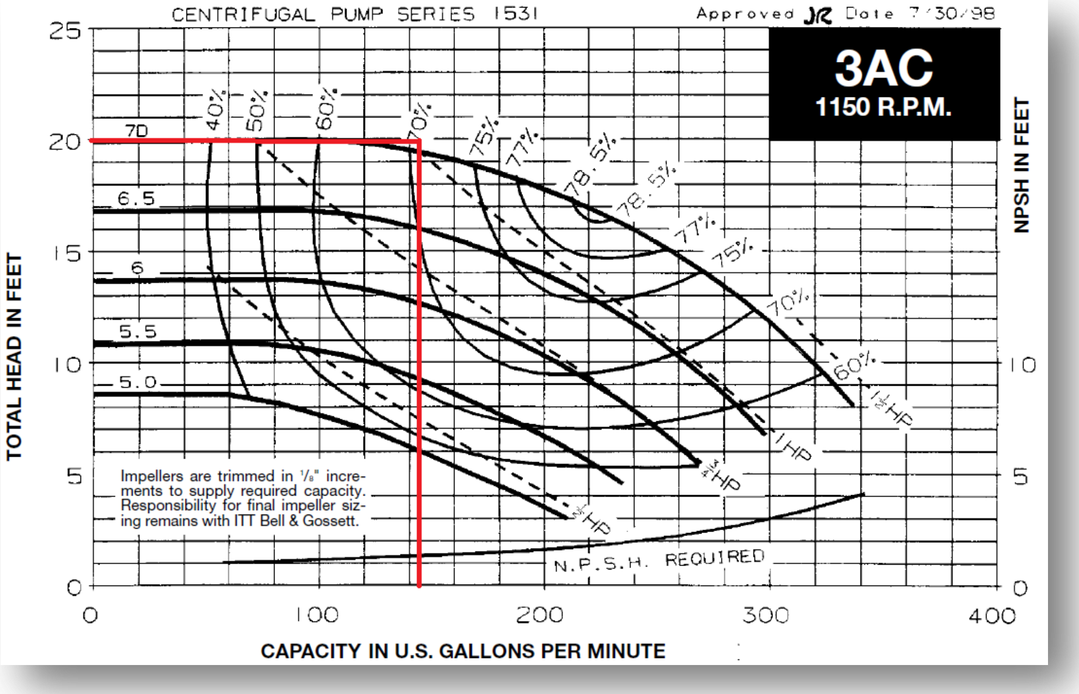
Impellers are trimmed in ⅛" increments to supply required capacity. Responsibility for final impeller sizing remains with ITT Bell & Gossett.

Method 2

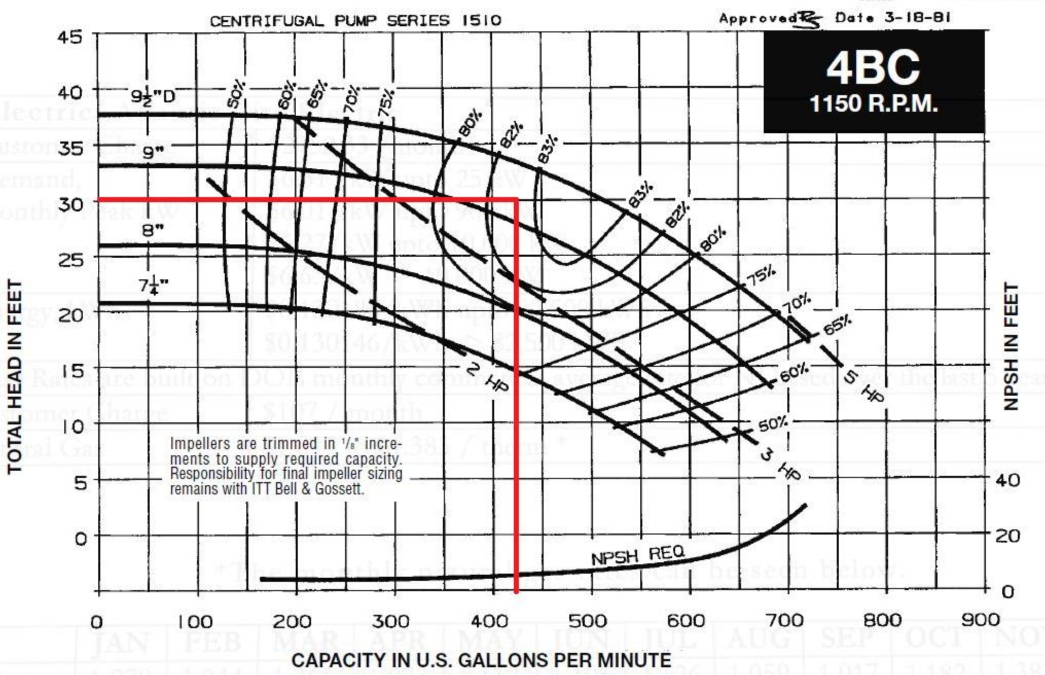
Option 1 AHU 1 300 ft



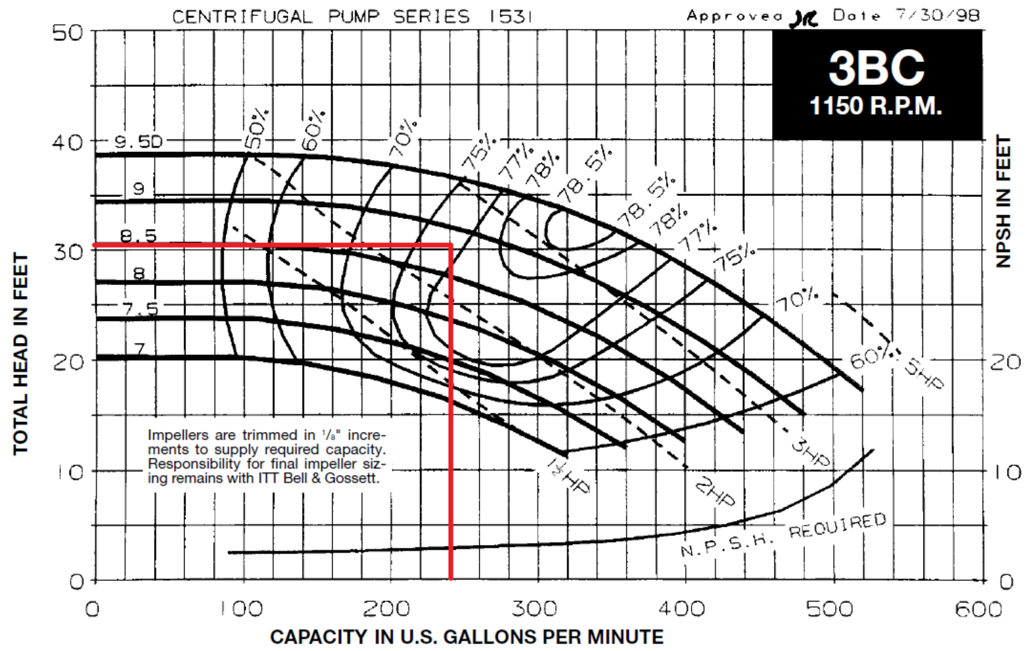
Option 2 AHU 1 600ft



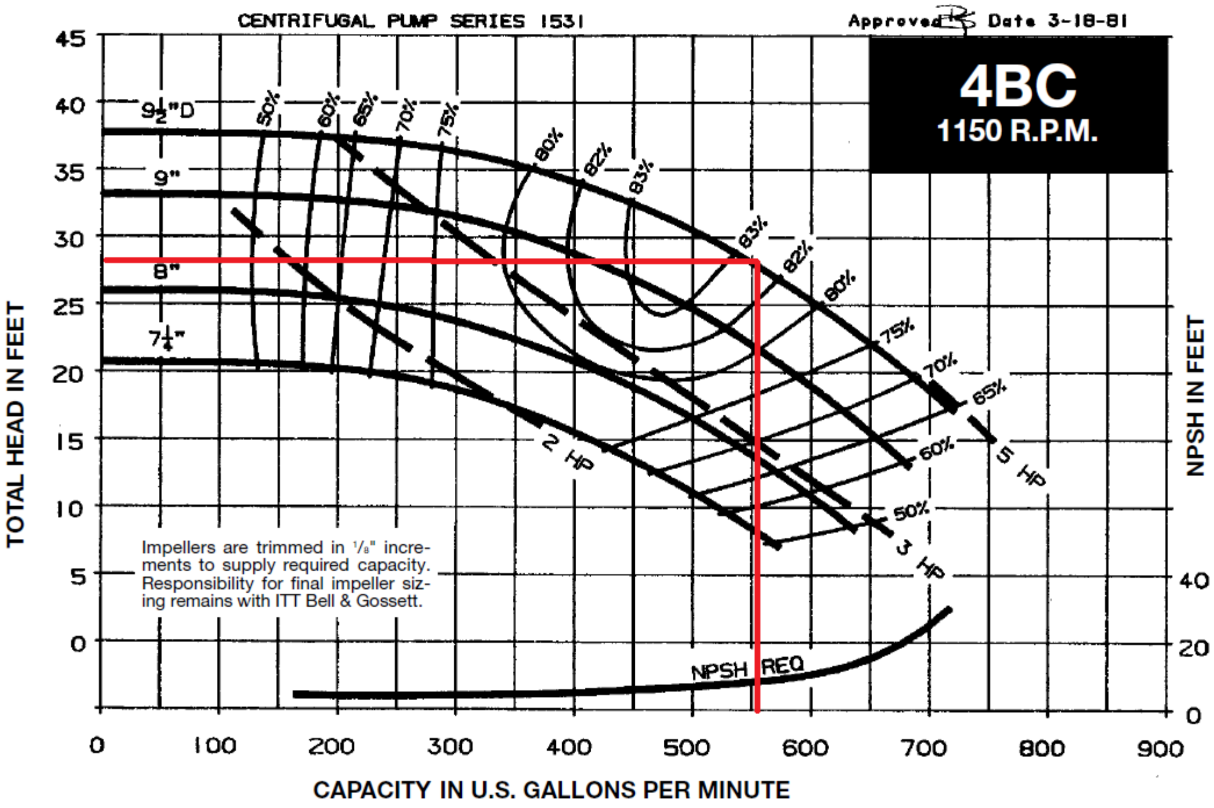
Option 3 AHU 2 600 ft



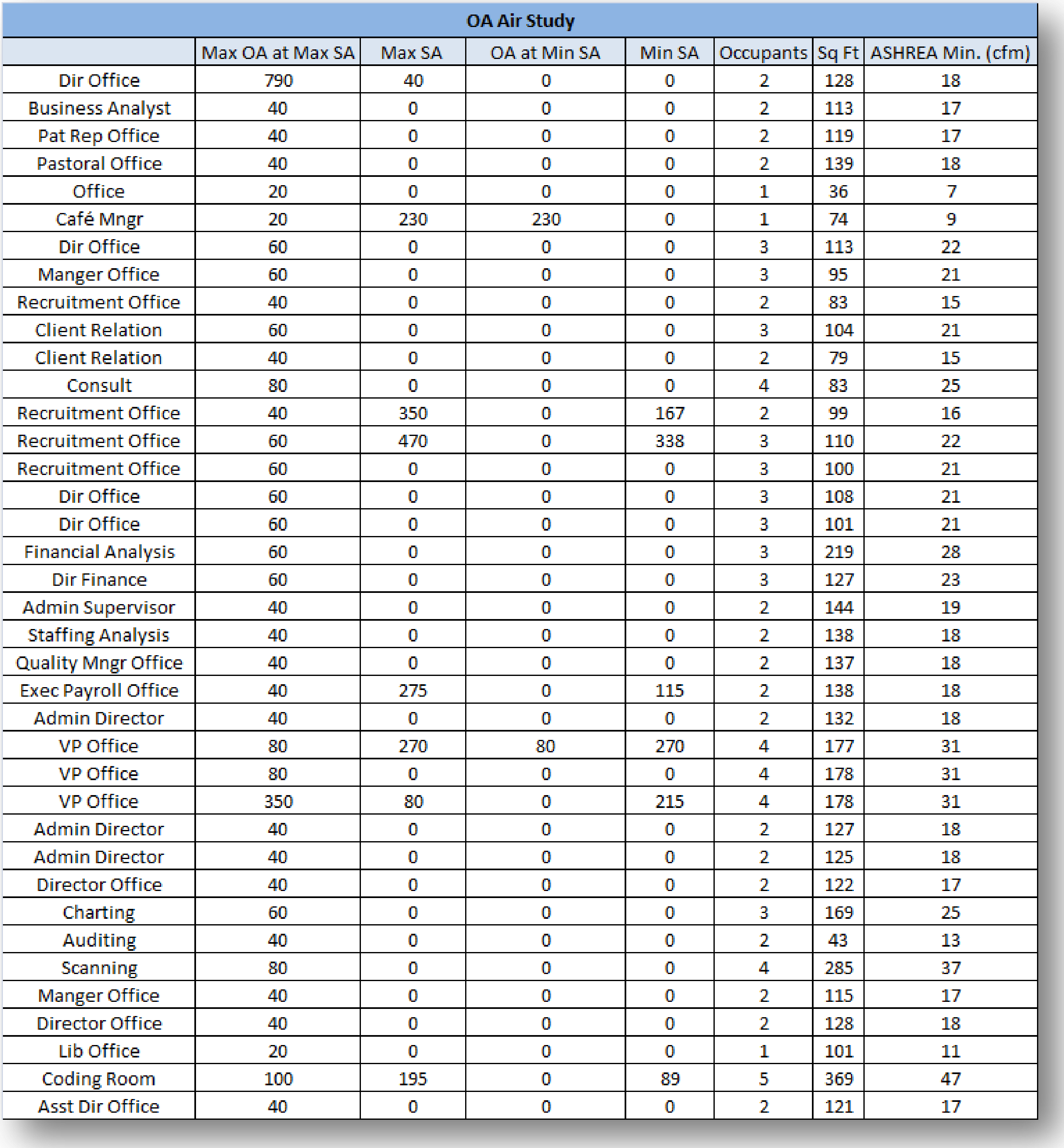
Option 4 AHU 2 1000 ft



Option 5 AHU 3 1000 ft



Appendix F



OA Air Study							
	Max OA at Max SA	Max SA	OA at Min SA	Min SA	Occupants	Sq Ft	ASHREA Min. (cfm)
Dir Office	790	40	0	0	2	128	18
Business Analyst	40	0	0	0	2	113	17
Pat Rep Office	40	0	0	0	2	119	17
Pastoral Office	40	0	0	0	2	139	18
Office	20	0	0	0	1	36	7
Café Mngr	20	230	230	0	1	74	9
Dir Office	60	0	0	0	3	113	22
Manger Office	60	0	0	0	3	95	21
Recruitment Office	40	0	0	0	2	83	15
Client Relation	60	0	0	0	3	104	21
Client Relation	40	0	0	0	2	79	15
Consult	80	0	0	0	4	83	25
Recruitment Office	40	350	0	167	2	99	16
Recruitment Office	60	470	0	338	3	110	22
Recruitment Office	60	0	0	0	3	100	21
Dir Office	60	0	0	0	3	108	21
Dir Office	60	0	0	0	3	101	21
Financial Analysis	60	0	0	0	3	219	28
Dir Finance	60	0	0	0	3	127	23
Admin Supervisor	40	0	0	0	2	144	19
Staffing Analysis	40	0	0	0	2	138	18
Quality Mngr Office	40	0	0	0	2	137	18
Exec Payroll Office	40	275	0	115	2	138	18
Admin Director	40	0	0	0	2	132	18
VP Office	80	270	80	270	4	177	31
VP Office	80	0	0	0	4	178	31
VP Office	350	80	0	215	4	178	31
Admin Director	40	0	0	0	2	127	18
Admin Director	40	0	0	0	2	125	18
Director Office	40	0	0	0	2	122	17
Charting	60	0	0	0	3	169	25
Auditing	40	0	0	0	2	43	13
Scanning	80	0	0	0	4	285	37
Manger Office	40	0	0	0	2	115	17
Director Office	40	0	0	0	2	128	18
Lib Office	20	0	0	0	1	101	11
Coding Room	100	195	0	89	5	369	47
Asst Dir Office	40	0	0	0	2	121	17

	Max OA at Max SA	Max SA	OA at Min SA	Min SA	Occupants	Sq Ft	ASHREA Min. (cfm)
Director Office	40	330	40	370	2	127	18
Office Mngr Uniform	20	0	0	0	1	94	11
Security	40	180	40	180	2	119	17
Tray Line Super	40	0	0	0	2	149	19
Production Mngr	20	265	0	86	1	65	9
Director Office	40	0	0	0	2	101	16
Quality Mngr Office	20	0	0	0	1	113	12
POC Coord Office	20	0	0	0	1	105	11
Director OPS Office	40	0	0	0	2	141	18
Path Office	20	0	0	0	1	108	11
Path Office	20	0	0	0	1	110	12
Path Office	20	0	0	0	1	107	11
Path Office	20	0	0	0	1	110	12
Business Mngr Office	20	0	0	0	1	108	11
Directors Office	60	0	0	0	3	194	27
Bobs Office	60	0	0	0	3	181	26
Manger Office	40	110	40	110	2	104	16
Manger Office	40	0	0	0	2	101	16
Manger Office	40	130	40	130	2	89	15
Histology Manager	40	0	0	0	2	100	16
Path Assist Office	40	0	0	0	2	164	20
Office	120	0	0	0	5	211	38
ET Nurse Office	40	0	0	0	2	105	16
Cyto Read	80	175	80	175	4	152	29
Courier Office	40	310	0	169	2	107	16
Assist Director	40	0	0	0	2	125	18
Consult	60	0	0	0	3	86	20
Asst Nurse Mng Office	60	0	0	0	3	101	21
Med Surgery APN Offic	40	350	0	312	2	158	19
MS Director Office	40	0	0	0	2	139	18
PED APT Office	20	0	0	0	1	119	12
Director Office	40	460	0	163	2	117	17
Asst Nurse Mng Office	20	450	0	261	1	90	10
ED Office	40	320	40	320	2	134	18
Practitioner Office	40	125	0	114	2	99	16
Genetic Counselor	60	0	0	0	3	92	21
Consult	80	945	0	488	4	84	25
Consult	80	0	0	0	4	76	25
Consult	80	0	0	0	4	68	24
Consult	80	925	80	409	4	93	26
Consult	80	0	0	0	4	103	26
Mngr Office	40	0	0	0	2	139	18
Call Center	40	0	0	0	2	118	17
Nurse Mngr	40	0	0	0	2	89	15
Consult	40	0	0	0	2	89	15
Security	20	0	0	0	1	87	10
Security	20	0	0	0	1	62	9
Cash Collection	40	0	0	0	2	60	14
MS Dir Office	200	400	100	512	2	138	18

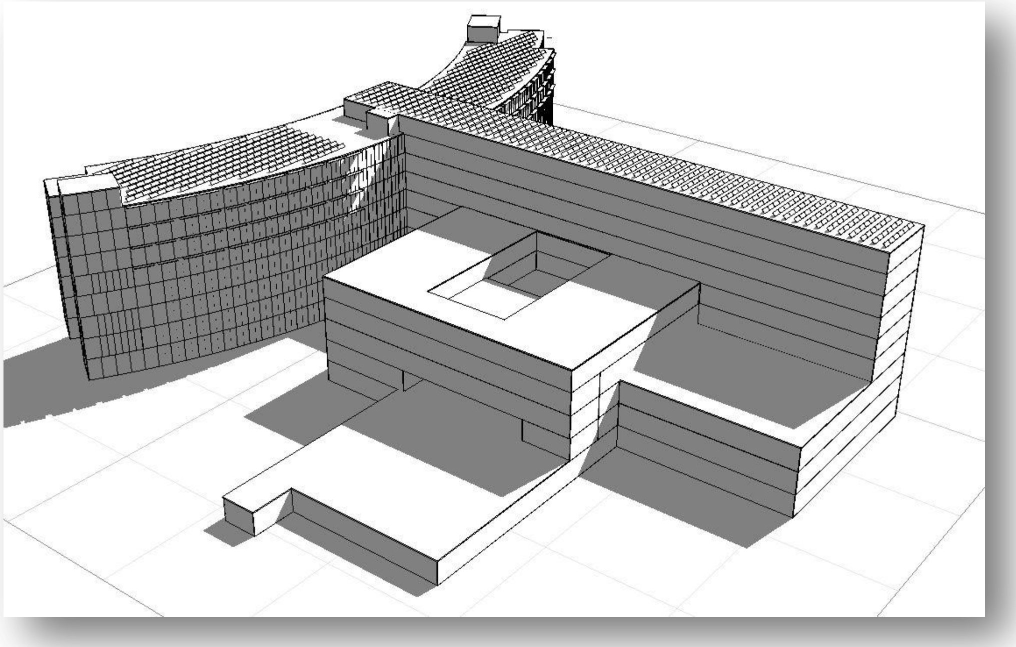
	Max OA at Max SA	Max SA	OA at Min SA	Min SA	Occupants	Sq Ft	ASHREA Min. (cfm)
Financial Counselor	40	0	0	0	2	98	16
Director Office	20	0	0	0	1	105	11
Exec Asst Office	20	0	0	0	1	76	10
Medical Dir Office	40	0	0	0	2	104	16
Asst Nurse Mng Office	60	600	60	600	3	113	22
PEDS MED Director	40	255	40	255	2	102	16
Tech Work	60	0	0	0	3	193	27
Physician Charting	60	0	0	0	3	108	21
Register Supr Office	40	0	0	0	2	101	16
Consult	60	0	0	0	3	87	20
Asst Nurse Mng Office	40	0	0	0	2	109	17
CU APN Office	100	440	50	306	5	101	31
ICU Nurse Mngr Office	40	0	0	0	2	159	20
PP Director Office	40	350	0	206	5	156	34
Intensive Office	40	0	0	0	2	133	18
APN Office	40	0	0	0	2	136	18
Asst Nurse Mng Office	40	0	0	0	2	82	15
APN Lact Office	40	440	0	175	2	118	17
Consult	60	0	0	0	3	88	20
Director Office	40	0	0	0	2	137	18
Office Mngr	40	0	0	0	2	102	16
Office Mngr	40	0	0	0	2	108	16
Office Direct	40	305	0	170	2	102	16
Clin Car Mgr Office	40	300	0	170	2	103	16
Proced Wrkrm Office	40	0	0	0	2	92	16
Consult	40	550	0	177	2	86	15
CSP Director	40	240	40	240	2	118	17
Surg Mgr Office	40	0	0	0	2	118	17
SM Office	60	0	0	0	3	95	21
Anesth Office	40	790	40	790	2	114	17
Assist RN	20	0	0	0	1	93	11
Control Clerical	40	0	0	0	2	126	18
Physician Dictation	40	0	0	0	2	80	15
Directors Office	40	60	0	83	2	123	17
Phase II Office	40	775	0	315	2	133	18
Consult	80	0	0	0	4	87	25
Consult	510	0	0	0	0	87	5
Asst Nurse Office	40	0	0	0	2	112	17
PCU APN Office	100	440	30	338	5	101	31
PCU Director Office	40	0	0	0	2	159	20

	Max OA at Max SA	Max SA	OA at Min SA	Min SA	Occupants	Sq Ft	ASHREA Min. (cfm)
PP Director Office	40	0	0	0	2	156	19
PB Asst Nurse Mngr	40	0	0	0	2	133	18
APN Lact Office	40	440	0	175	2	118	17
Consult	60	0	0	0	3	88	20
Asst Nurse Mgr	40	440	0	273	2	134	18
Director Office	40	0	0	0	2	116	17
Anesthia Office	80	150	60	150	4	170	30
Asst Nurse Mgr Office	40	200	0	72	2	107	16
Family Bereavement	80	0	0	0	4	95	26
APN Office	40	0	0	0	2	87	15
Consult	60	0	0	0	3	86	20
Asst Nurse Office	40	230	0	176	2	106	16
MS Director Office	40	0	0	0	2	159	20
PP Dir Office	40	250	0	190	2	156	19
Asst Nurse Mgr	40	0	0	0	2	133	18
Consult	60	0	0	0	3	88	20
APN Lact Office	40	440	0	175	2	118	17
Birth Reg Office	60	0	0	0	3	82	20
Educ Clinic Office	40	0	0	0	2	121	17
Director Office	40	0	0	0	2	136	18
Clerical Assist	20	0	0	0	1	127	13
Director Office	40	450	0	327	2	134	18
Assist Dir Office	40	0	0	0	2	91	15
Clinical Pharm Office	40	430	0	328	2	109	17
Biomed Mgmt	80	0	0	0	4	174	30
Equip Depot Office	20	0	0	0	1	110	12
Nurse Director	40	0	0	0	2	113	17
Consult	80	0	0	0	4	88	25
Neonatology Director	20	265	0	161	1	128	13
Consult	60	0	0	0	3	87	20
MS Direct Office	40	425	0	295	2	155	19
Asst Nurse Mngr Office	140	0	0		7	108	41
MS Direct Office	40	425	0	295	2	138	18
Asst Nurse Mgr Office	40	0	0	0	2	106	16
APN Office	40	0	0	0	2	118	17
Consult	80	0	0	0	4	89	25
Consult	80	0	0	0	4	87	25
Asst Nurse Mgr Office	40	0	0	0	2	106	16
MS Direct Office	40	1085	0	612	2	156	19
Directors Office	40	0	0	0	2	90	15
Case Management	60	430	0	205	3	201	27
APN Office	40	0	0	0	2	119	17
Consult	60	0	0	0	3	89	20
Asst Nurse Mgr Office	40	0	0	0	2	106	16
Consult	25	75	0	90	3	86	20
Asst Nurse Mgr Office	17	50	0	3	2	106	16
Rehab Dir Office	200	400	0	200	2	151	19

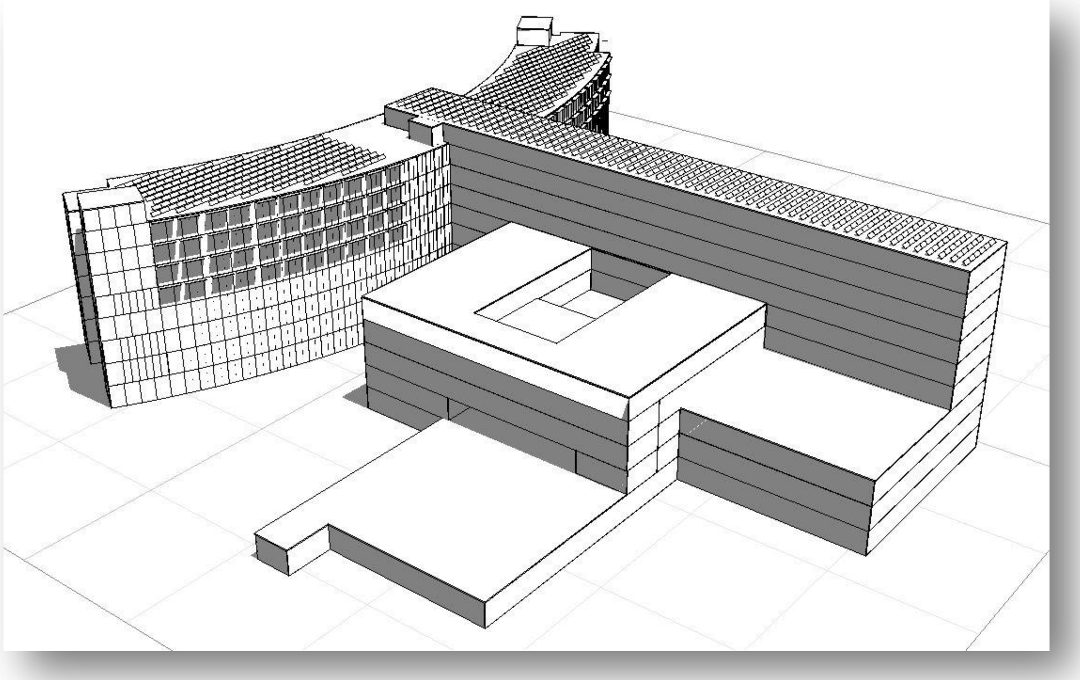
Appendix G

Summer Solstice

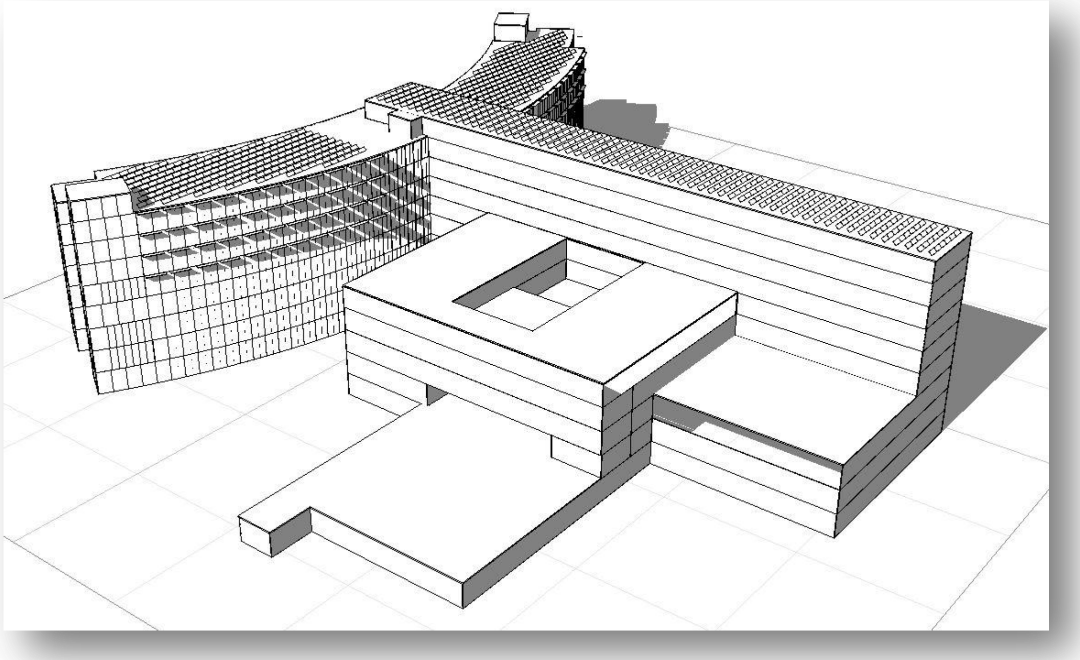
9am



Noon

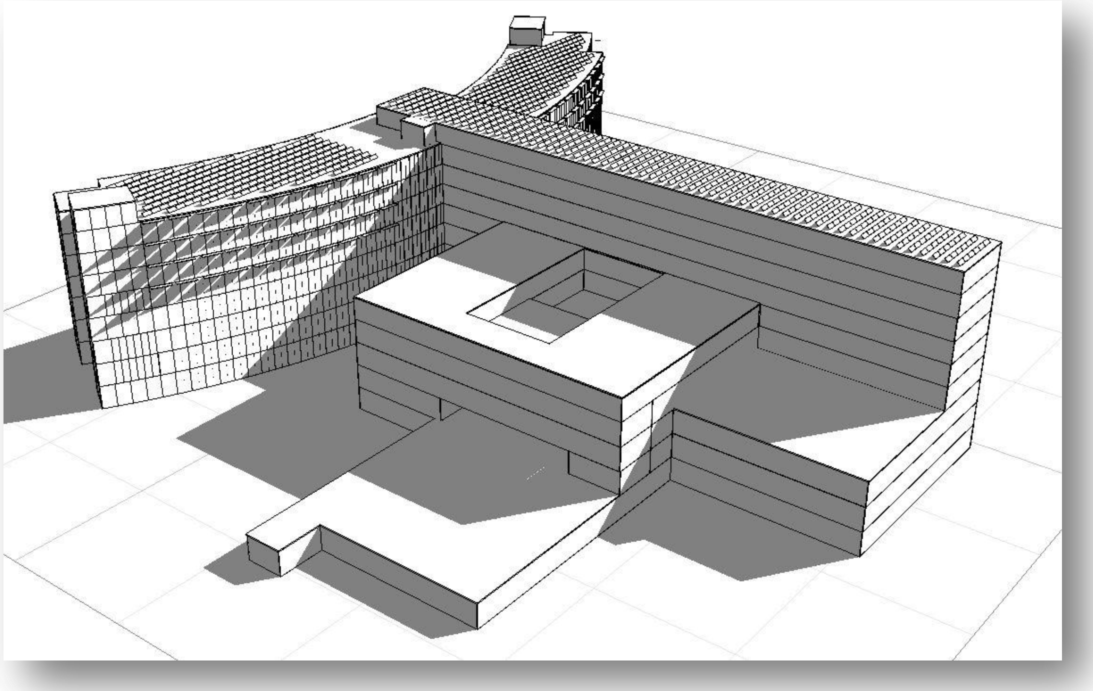


4 pm



Equinox

9 am



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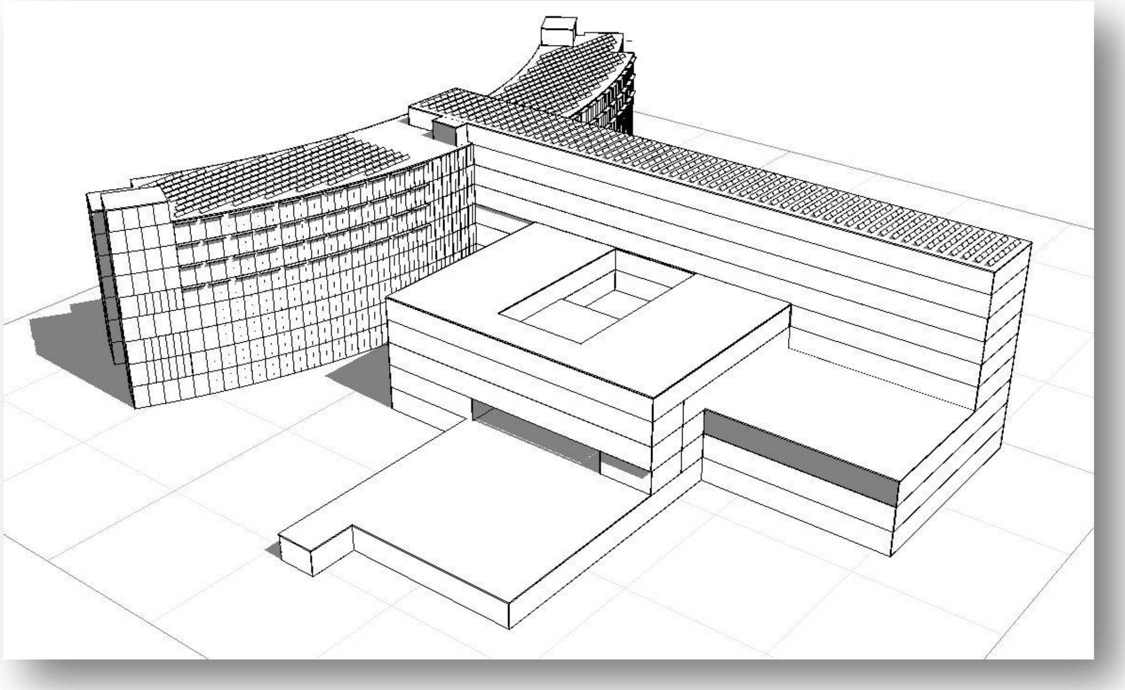
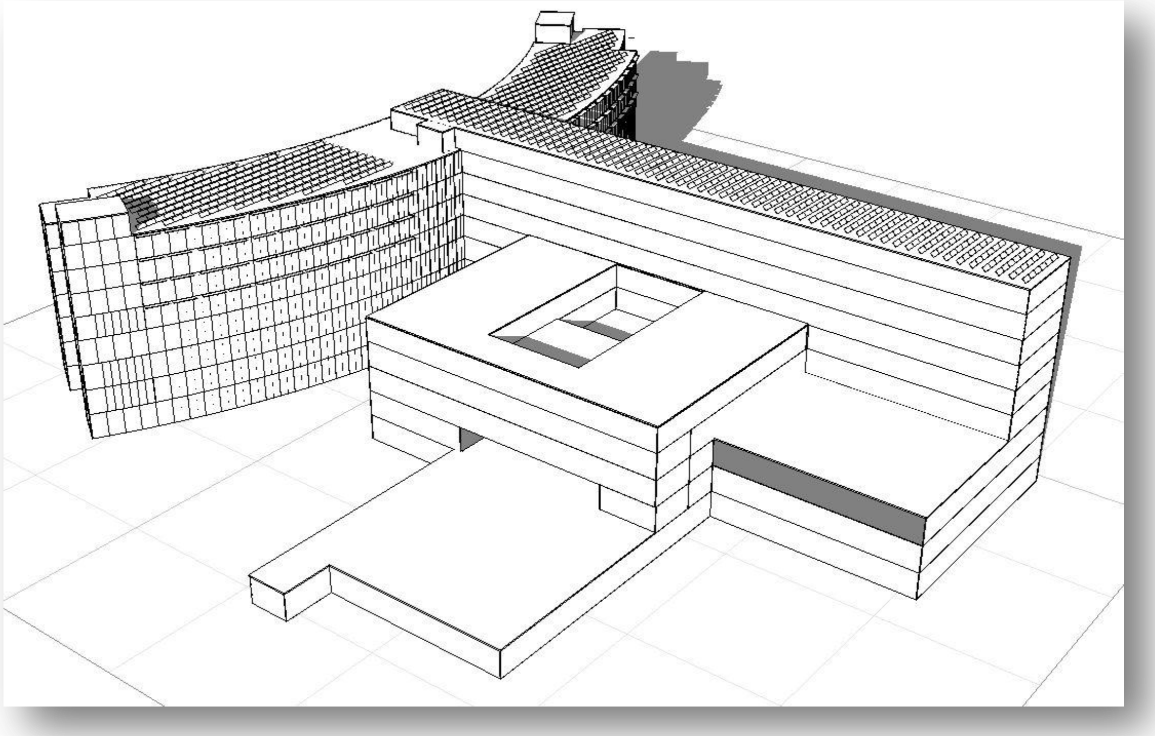


4 pm



Appendix H

$$\delta = 23.45\sin(360\frac{284+n}{365})$$

$\delta = declination$

$$cos\theta_z = cos\phi \; cos\delta \; cos\omega + sin\phi \; sin\delta$$

$$cos\theta = sin\delta \; sin\phi \; cos\beta - sin\delta \; cos\phi \; sin\beta \; cos\gamma + cos\delta \; cos\phi \; cos\beta \; cos\omega \\ + cos\delta \; sin\phi \; sin\beta \; cos\gamma \; cos\omega + cos\delta \; sin\beta \; sin\gamma \; sin\omega$$

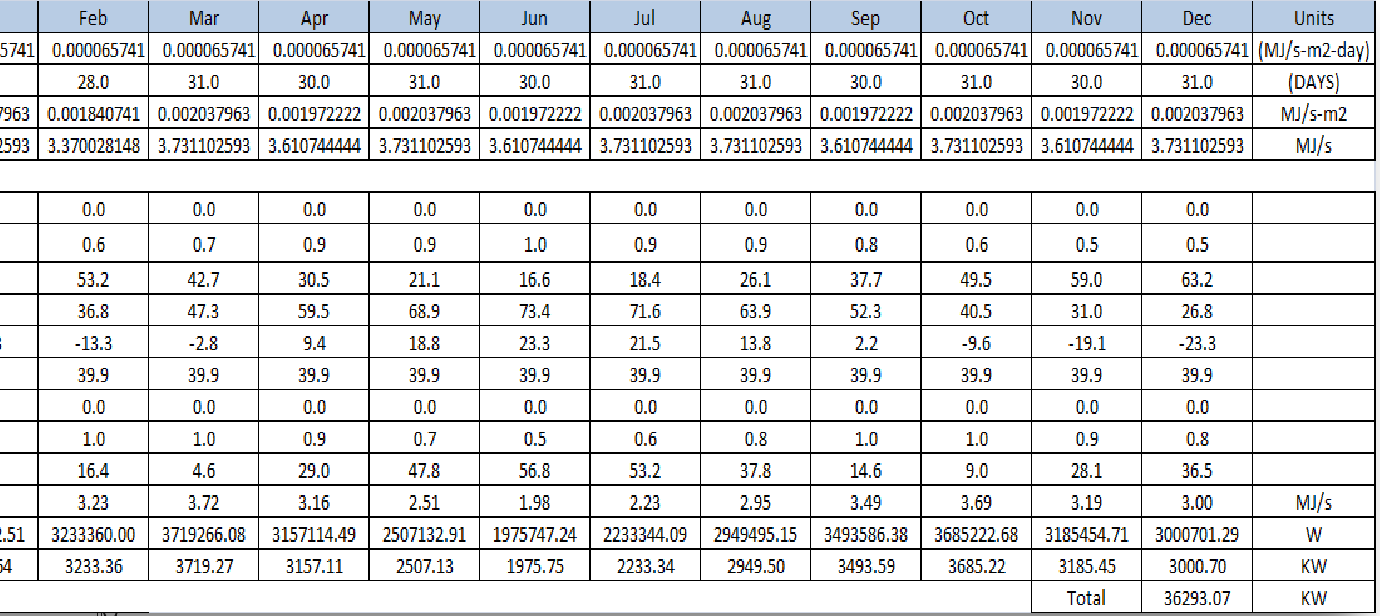
In this case, $\omega = 0$ because the values were calculated for noon of each month
$\gamma = 0$, since the panels will be facing directly south
β will change monthly since the panels will not be fixed, and adjust monthly in the North South direction

These values were calculated for every month of the year.

G, the solar energy hitting the plates was calculated using the following equation:

$$G = G_b cos\theta$$

$\theta =$ the incident angle calculated above
$G_b =$the solar radiation absorbed on a horizontal surface



	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Units
5741	0.000065741	0.000065741	0.000065741	0.000065741	0.000065741	0.000065741	0.000065741	0.000065741	0.000065741	0.000065741	0.000065741	(MJ/s-m2-day)
	28.0	31.0	30.0	31.0	30.0	31.0	31.0	30.0	31.0	30.0	31.0	(DAYS)
7963	0.001840741	0.002037963	0.001972222	0.002037963	0.001972222	0.002037963	0.002037963	0.001972222	0.002037963	0.001972222	0.002037963	MJ/s-m2
2593	3.370028148	3.731102593	3.610744444	3.731102593	3.610744444	3.731102593	3.731102593	3.610744444	3.731102593	3.610744444	3.731102593	MJ/s
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.6	0.7	0.9	0.9	1.0	0.9	0.9	0.8	0.6	0.5	0.5	
	53.2	42.7	30.5	21.1	16.6	18.4	26.1	37.7	49.5	59.0	63.2	
	36.8	47.3	59.5	68.9	73.4	71.6	63.9	52.3	40.5	31.0	26.8	
	-13.3	-2.8	9.4	18.8	23.3	21.5	13.8	2.2	-9.6	-19.1	-23.3	
	39.9	39.9	39.9	39.9	39.9	39.9	39.9	39.9	39.9	39.9	39.9	
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	1.0	1.0	0.9	0.7	0.5	0.6	0.8	1.0	1.0	0.9	0.8	
	16.4	4.6	29.0	47.8	56.8	53.2	37.8	14.6	9.0	28.1	36.5	
	3.23	3.72	3.16	2.51	1.98	2.23	2.95	3.49	3.69	3.19	3.00	MJ/s
.51	3233360.00	3719266.08	3157114.49	2507132.91	1975747.24	2233344.09	2949495.15	3493586.38	3685222.68	3185454.71	3000701.29	W
54	3233.36	3719.27	3157.11	2507.13	1975.75	2233.34	2949.50	3493.59	3685.22	3185.45	3000.70	KW
										Total	36293.07	KW

Appendix I

Column Design before Panels

Column 1

Column Below Level	Area (ft^2)	Wall Area (ft^2)	Wall Load (lbs)	Dead Load (psf)	Live Load (psf)	Reduced LL (psf)	Total Load	Column Load (Kips)	Column
Roof	146	381.25	9531.3	63	30	-	90.6	22.76	W8 x 31
8	292	381.25	19062.5	90	80	-	236.0	87.97	W8 x 31
7	438	381.25	28593.8	90	80	48.7	185.9	110.01	W8 x 31
6	584	381.25	38125.0	90	80	44.8	179.7	143.08	W8 x 31
5	730	381.25	47656.3	90	80	42.2	175.5	175.79	W8 x 31
4	876	381.25	57187.5	90	80	40.3	172.4	208.24	W8 x 31
3	1022	381.25	66718.8	90	80	38.8	170.0	240.49	W8 x 35
2	1168	381.25	76250.0	90	80	37.6	168.1	272.58	W8 x 40
1	1314	381.25	85781.3	90	80	36.6	166.5	304.54	W8 x 48

Column 2

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	379	366	9150.0	63	30	-	90.6	43.49	W8 x 31
8	758	366	18300.0	90	80	41.8	174.9	150.85	W8 x 31
7	1137	366	27450.0	90	80	37.8	168.5	219.00	W8 x 35
6	1516	366	36600.0	90	80	35.4	164.7	286.22	W10 x 45
5	1895	366	45750.0	90	80	33.8	162.1	352.84	W10 x 49
4	2274	366	54900.0	90	80	32.6	160.1	419.04	W10 x 49
3	2653	366	64050.0	90	80	31.6	158.6	484.92	W12 x 58
2	3032	366	73200.0	90	80	30.9	157.4	550.54	W12 x 65
1	3411	366	82350.0	90	80	30.3	156.4	615.96	W12 x 65

Column 3

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	232	450	11250.0	63	30	-	90.6	32.27	W8 x 31
8	464	450	22500.0	90	80	47.9	184.6	108.14	W8 x 31
7	843	450	33750.0	90	80	40.7	173.1	179.64	W8x 31
6	1222	450	45000.0	90	80	37.2	167.5	249.64	W10 x 39
5	1601	450	56250.0	90	80	35.0	164.0	318.80	W8 x 48
4	1980	450	67500.0	90	80	33.5	161.6	387.42	W10 x 49
3	2359	450	78750.0	90	80	32.4	159.8	455.64	W10 x 54
2	2738	450	90000.0	90	80	31.5	158.3	523.55	W12 x 65
1	3117	450	101250.0	90	80	30.7	157.2	591.23	W12 x 65

Column 4 (x9)

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	758	0	0.0	63	30	-	90.6	68.67	W8 x 31
8	1516	0	0.0	90	80	35.4	164.7	249.62	W10 x 39
7	1895	0	0.0	90	80	33.8	162.1	307.09	W8 x 48
6	2274	0	0.0	90	80	32.6	160.1	364.14	W10 x 49
5	2653	0	0.0	90	80	31.6	158.6	420.87	W10 x 49
4	3032	0	0.0	90	80	30.9	157.4	477.34	W12 x 58
3	3411	0	0.0	90	80	30.3	156.4	533.61	W12 x 65
2	3790	0	0.0	90	80	29.7	155.6	589.70	W12 x 65
1	4169	0	0.0	90	80	29.3	154.9	645.65	W12 x 72

Column 5 (x8)

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	379	481	12025.0	63	30	-	90.6	46.36	W8 x 31
8	758	481	24050.0	90	80	41.8	174.9	156.60	W8 x 31
7	1137	481	36075.0	90	80	37.8	168.5	227.63	W8 x 35
6	1516	481	48100.0	90	80	35.4	164.7	297.72	W10 x 45
5	1895	481	60125.0	90	80	33.8	162.1	367.22	W10 x 49
4	2274	481	72150.0	90	80	32.6	160.1	436.29	W12 x 53
3	2653	481	84175.0	90	80	31.6	158.6	505.04	W10 x 60
2	3032	481	96200.0	90	80	30.9	157.4	573.54	W12 x 65
1	3411	481	108225.0	90	80	30.3	156.4	641.83	W12 x 72

Column 6 (x6)

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	379	481	12025.0	63	30	-	90.6	46.36	W8 x 31
8	758	481	24050.0	90	80	41.8	174.9	156.60	W8 x 31
7	1137	481	36075.0	90	80	37.8	168.5	227.63	W8 x 35
6	1516	481	48100.0	90	80	35.4	164.7	297.72	W10 x 45
5	1895	481	60125.0	90	80	33.8	162.1	367.22	W10 x 49
4	2478	434	64465.0	90	80	32.1	159.3	459.17	W10 x 54
3	3061	434	68805.0	90	80	30.8	157.4	550.46	W12 x 65
2	3644	434	73145.0	90	80	29.9	155.9	641.26	W12 x 72
1	4227	434	77485.0	90	80	29.2	154.8	731.68	W12 x 79

Column 7 (x4)

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	379	481	12025.0	63	30	-	90.6	46.36	W8 x 31
8	758	481	24050.0	90	80	41.8	174.9	156.60	W8 x 31
7	1137	481	36075.0	90	80	37.8	168.5	227.63	W8 x 35
6	1516	481	48100.0	90	80	35.4	164.7	297.72	W10 x 45
5	1895	481	60125.0	90	80	33.8	162.1	367.22	W10 x 49
4	2274	481	72150.0	90	80	32.6	160.1	436.29	W12 x 53
3	2653	481	84175.0	90	80	31.6	158.6	505.04	W10 x 60
2	3451	0	0.0	90	80	30.2	156.3	539.54	W12 x 65
1	4249	0	0.0	90	80	29.2	154.7	657.44	W12 x 72

Column 8 (x2)

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	172	484	12100.0	63	30	-	90.6	27.68	W8 x 31
8	344	484	24200.0	90	80	-	236.0	105.38	W8 x 31
7	516	484	36300.0	90	80	46.4	182.3	130.35	W8 x 31
6	688	484	48400.0	90	80	42.9	176.6	169.90	W8 x 31
5	860	484	60500.0	90	80	40.5	172.7	209.05	W8 x 31
4	1240	484	50820.0	90	80	37.0	167.3	258.23	W10 x 39
3	1620	484	50820.0	90	80	34.9	163.9	316.26	W8 x 48
2	2000	484	50820.0	90	80	33.4	161.5	373.75	W10 x 49
1	2380	484	50820.0	90	80	32.3	159.7	430.85	W12 x 53

Column 9 (x2)

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	585	0	0.0	63	30	-	90.6	53.00	W8 x 31
8	1170	0	0.0	90	80	37.5	168.1	196.64	W8 x 31
7	1755	0	0.0	90	80	34.3	162.9	285.92	W10 x 45
6	2340	0	0.0	90	80	32.4	159.8	374.04	W10 x 49
5	2925	0	0.0	90	80	31.1	157.8	461.42	W10 x 54
4	3510	0	0.0	90	80	30.1	156.2	548.28	W12 x 65
3	4095	0	0.0	90	80	29.4	155.0	634.73	W12 x 65
2	4680	0	0.0	90	80	28.8	154.0	720.87	W12 x 79
1	5265	0	0.0	90	80	28.3	153.2	806.76	W12 x 87

Column 10 (x2)

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	464	0	0.0	63	30	-	90.6	42.04	W8 x 31
8	928	0	0.0	90	80	39.7	171.5	159.16	W8 x 31
7	1392	0	0.0	90	80	36.1	165.7	230.70	W8 x 35
6	1856	0	0.0	90	80	33.9	162.3	301.20	W10 x 45
5	2320	0	0.0	90	80	32.5	159.9	371.04	W10 x 49
4	2784	0	0.0	90	80	31.4	158.2	440.41	W12 x 53
3	3248	0	0.0	90	80	30.5	156.8	509.43	W10 x 60
2	3712	0	0.0	90	80	29.8	155.8	578.17	W12 x 65
1	4176	0	0.0	90	80	29.3	154.9	646.68	W12 x 72

Column 11 (x2)

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	136	381	9525.0	63	30	-	90.6	21.85	W8 x 31
8	272	381	19050.0	90	80	-	236.0	83.24	W8 x 31
7	408	381	28575.0	90	80	49.7	187.5	105.09	W8 x 31
6	544	381	38100.0	90	80	45.7	181.2	136.65	W8 x 31
5	680	381	47625.0	90	80	43.0	176.8	167.86	W8 x 31
4	816	381	57150.0	90	80	41.0	173.6	198.81	W8 x 31
3	952	381	66675.0	90	80	39.4	171.1	229.58	W8 x 35
2	1088	381	76200.0	90	80	38.2	169.1	260.19	W10 x 39
1	1224	381	85725.0	90	80	37.1	167.4	290.67	W10 x 45

Column 12

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	222	141	3525.0	63	30	-	90.6	23.64	W8 x 31
8	336	332	16600.0	90	80	-	236.0	95.90	W8 x 31
7	450	332	24900.0	90	80	48.3	185.3	108.26	W8 x 31
6	692	156	27630.0	90	80	42.8	176.5	149.76	W8 x 31
5	934	156	30360.0	90	80	39.6	171.4	190.46	W8 x 31
4	1176	156	33090.0	90	80	37.5	168.0	230.65	W8 x 35
3	1418	156	35820.0	90	80	35.9	165.5	270.49	W8 x 40
2	1660	156	38550.0	90	80	34.7	163.6	310.06	W8 x 48
1	1902	156	41280.0	90	80	33.8	162.0	349.43	W10 x 49

Column 13

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	326	195	4875.0	63	30	-	90.6	34.41	W8 x 31
8	749	0	4875.0	90	80	41.9	175.1	136.01	W8 x 31
7	1172	0	4875.0	90	80	37.5	168.0	201.82	W8 x 31
6	1595	0	4875.0	90	80	35.0	164.0	266.51	W8 x 40
5	2018	0	4875.0	90	80	33.4	161.4	330.52	W8 x 48
4	2441	0	4875.0	90	80	32.1	159.4	394.05	W10 x 49
3	2864	0	4875.0	90	80	31.2	157.9	457.21	W10 x 54
2	3287	0	4875.0	90	80	30.5	156.7	520.09	W10 x 60
1	3710	0	4875.0	90	80	29.9	155.8	582.75	W12 x 65

Column 14

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	583	370	9250.0	63	30	-	90.6	62.07	W8 x 31
8	998	282	16300.0	90	80	39.0	170.4	186.35	W8 x 31
7	1459	0	16300.0	90	80	35.7	165.1	257.23	W10 x 39
6	1920	0	16300.0	90	80	33.7	161.9	327.17	W8 x 48
5	2381	0	16300.0	90	80	32.3	159.7	396.48	W10 x 49
4	2842	0	16300.0	90	80	31.3	158.0	465.36	W10 x 54
3	3303	0	16300.0	90	80	30.4	156.7	533.89	W10 x 65
2	3764	0	16300.0	90	80	29.8	155.6	602.16	W12 x 65
1	4225	0	16300.0	90	80	29.2	154.8	670.20	W12 x 72

Column 19

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	348	572	14300.0	63	30	-	90.6	45.83	W8 x 31
8	722	0	14300.0	90	80	42.3	175.7	141.18	W8 x 31
7	1092	0	14300.0	90	80	38.2	169.1	198.90	W8 x 31
6	1462	0	14300.0	90	80	35.7	165.1	255.69	W10 x39
5	1832	0	14300.0	90	80	34.0	162.4	311.87	W8 x 48
4	2202	0	14300.0	90	80	32.8	160.5	367.63	W10 x 49
3	2572	0	14300.0	90	80	31.8	158.9	423.07	W10 x 49
2	2942	0	14300.0	90	80	31.1	157.7	478.25	W12 x 58
1	3312	0	14300.0	90	80	30.4	156.7	533.23	W12 x 65

Column 20									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	348	572	14300.0	63	30	-	90.6	45.83	W8 x 31
8	628	0	14300.0	90	80	43.9	178.3	126.28	W8 x 31
7	908	0	14300.0	90	80	39.9	171.9	170.35	W8 x 31
6	1188	0	14300.0	90	80	37.4	167.9	213.71	W8 x 35
5	1468	0	14300.0	90	80	35.7	165.1	256.60	W10 x 39
4	1748	0	14300.0	90	80	34.4	163.0	299.16	W10 x 45
3	2028	0	14300.0	90	80	33.3	161.3	341.45	W10 x 49
2	2308	0	14300.0	90	80	32.5	160.0	383.54	W10 x 49
1	2588	0	14300.0	90	80	31.8	158.9	425.46	W10 x 49
Column 22									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	583	370	9250.0	63	30	-	90.6	62.07	W8 x 31
8	905	0	9250.0	90	80	39.9	171.9	164.83	W8 x 31
7	1227	0	9250.0	90	80	37.1	167.4	214.66	W8 x 31
6	1549	0	9250.0	90	80	35.2	164.4	263.89	W8 x 40
5	1871	0	9250.0	90	80	33.9	162.2	312.71	W8 x 48
4	2193	0	9250.0	90	80	32.8	160.5	361.23	W10 x 49
3	2515	0	9250.0	90	80	32.0	159.1	409.49	W10 x 49
2	2837	0	9250.0	90	80	31.3	158.0	457.56	W10 x 54
1	3159	0	9250.0	90	80	30.7	157.1	505.47	W10 x 60
Column 23									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	326	195	4875.0	63	30	-	90.6	34.41	W8 x 31
8	750	0	4875.0	90	80	41.9	175.1	136.17	W8 x 31
7	1174	0	4875.0	90	80	37.5	168.0	202.13	W8 x 31
6	1598	0	4875.0	90	80	35.0	164.0	266.97	W8 x 40
5	2022	0	4875.0	90	80	33.3	161.3	331.12	W8 x 48
4	2446	0	4875.0	90	80	32.1	159.4	394.79	W10 x 49
3	2870	0	4875.0	90	80	31.2	157.9	458.10	W10 x 54
2	3294	0	4875.0	90	80	30.5	156.7	521.13	W10 x 60
1	3718	0	4875.0	90	80	29.8	155.7	583.93	W12 x 65
Column 29									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	691	0	0.0	63	30	-	90.6	62.60	W8 x 31
7	1382	0	0.0	90	80	36.1	165.8	229.17	W8 x 35
6	2073	0	0.0	90	80	33.2	161.1	333.93	W8 x 48
5	2764	0	0.0	90	80	31.4	158.3	437.43	W12 x 53
4	3455	0	0.0	90	80	30.2	156.3	540.13	W12 x 65
3	4146	0	0.0	90	80	29.3	154.9	642.25	W12 x 72
2	4837	0	0.0	90	80	28.6	153.8	743.95	W12 x 79
1	5528	0	0.0	90	80	28.1	152.9	845.30	W12 x 87
Column 30									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	720	0	0.0	63	30	-	90.6	65.23	W8 x 31
7	1440	0	0.0	90	80	35.8	165.3	238.03	W8 x 35
6	2160	0	0.0	90	80	32.9	160.7	347.02	W10 x 49
5	2880	0	0.0	90	80	31.2	157.9	454.72	W10 x 54
4	3600	0	0.0	90	80	30.0	156.0	561.60	W12 x 65
3	4320	0	0.0	90	80	29.1	154.6	667.90	W12 x 72
2	5040	0	0.0	90	80	28.5	153.5	773.75	W12 x 79
1	5760	0	0.0	90	80	27.9	152.6	879.26	W14 x 90
Column 31									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	675	0	0.0	63	30	-	90.6	61.16	W8 x 31
7	1350	0	0.0	90	80	36.3	166.1	224.27	W8 x 35
6	2025	0	0.0	90	80	33.3	161.3	326.70	W8 x 48
5	2700	0	0.0	90	80	31.5	158.5	427.88	W10 x 49
4	3375	0	0.0	90	80	30.3	156.5	528.27	W10 x 60
3	4050	0	0.0	90	80	29.4	155.1	628.09	W12 x 65
2	4725	0	0.0	90	80	28.7	154.0	727.49	W12 x 79
1	5400	0	0.0	90	80	28.2	153.1	826.55	W12 x 87

Column 32

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	874	0	0.0	63	30	-	90.6	79.18	W8 x 31
7	1748	0	0.0	90	80	34.4	163.0	284.86	W10 x 45
6	2622	0	0.0	90	80	31.7	158.7	416.24	W10 x 49
5	3496	0	0.0	90	80	30.1	156.2	546.20	W12 x 65
4	4370	0	0.0	90	80	29.1	154.5	675.26	W12 x 72
3	5244	0	0.0	90	80	28.3	153.3	803.68	W12 x 87
2	6118	0	0.0	90	80	27.7	152.3	931.61	W14 x 90
1	6992	0	0.0	90	80	27.2	151.5	1059.15	W14 x 99

Column 33

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	687	0	0.0	63	30	-	90.6	62.24	W8 x 31
7	1374	0	0.0	90	80	36.2	165.9	227.94	W8 x 35
6	2061	0	0.0	90	80	33.2	161.1	332.12	W8 x 48
5	2748	0	0.0	90	80	31.4	158.3	435.04	W12 x 53
4	3435	0	0.0	90	80	30.2	156.4	537.16	W12 x 65
3	4122	0	0.0	90	80	29.3	155.0	638.71	W12 x 72
2	4809	0	0.0	90	80	28.7	153.8	739.83	W12 x 79
1	5496	0	0.0	90	80	28.1	152.9	840.61	W12 x 87

Column 34

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	753	0	0.0	63	30	-	90.6	68.22	W8 x 31
7	1506	0	0.0	90	80	35.5	164.7	248.09	W8 x 40
6	2259	0	0.0	90	80	32.6	160.2	361.89	W10 x 49
5	3012	0	0.0	90	80	30.9	157.5	474.37	W12 x 58
4	3765	0	0.0	90	80	29.8	155.6	586.01	W12 x 65
3	4518	0	0.0	90	80	28.9	154.3	697.05	W12 x 72
2	5271	0	0.0	90	80	28.3	153.2	807.64	W12 x 87
1	6024	0	0.0	90	80	27.7	152.4	917.87	W14 x 90

Column 35

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	680	0	0.0	63	30	-	90.6	61.61	W8 x 31
7	1360	0	0.0	90	80	36.3	166.0	225.80	W8 x 35
6	2040	0	0.0	90	80	33.3	161.3	328.96	W8 x 48
5	2720	0	0.0	90	80	31.5	158.4	430.87	W12 x 53
4	3400	0	0.0	90	80	30.3	156.5	531.98	W12 x 65
3	4080	0	0.0	90	80	29.4	155.0	632.52	W12 x 65
2	4760	0	0.0	90	80	28.7	153.9	732.63	W12 x 79
1	5440	0	0.0	90	80	28.1	153.0	832.41	W14 x 90

Column 36

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	725	0	0.0	63	30	-	90.6	65.69	W8 x 31
7	1450	0	0.0	90	80	35.8	165.2	239.56	W8 x 35
6	2175	0	0.0	90	80	32.9	160.6	349.27	W10 x 49
5	2900	0	0.0	90	80	31.1	157.8	457.70	W10 x 54
4	3625	0	0.0	90	80	30.0	155.9	565.30	W12 x 65
3	4350	0	0.0	90	80	29.1	154.6	672.32	W12 x 72
2	5075	0	0.0	90	80	28.4	153.5	778.89	W12 x 79
1	5800	0	0.0	90	80	27.9	152.6	885.11	W14 x 90

Column 39

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	508	145	3625.0	63	30	-	90.6	49.65	W8 x 31
7	1016	145	7250.0	90	80	38.8	170.1	180.09	W8 x 31
6	1524	145	10875.0	90	80	35.4	164.6	261.71	W8 x 40
5	2032	145	14500.0	90	80	33.3	161.3	342.25	W10 x 49
4	2540	145	18125.0	90	80	31.9	159.0	422.11	W10 x 49
3	3048	145	21750.0	90	80	30.9	157.4	501.47	W10 x 60
2	3556	145	25375.0	90	80	30.1	156.1	580.46	W12 x 65
1	4064	145	29000.0	90	80	29.4	155.1	659.16	W12 x 72

Column 45									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	530	488	4880.0	63	30	-	90.6	52.90	W8 x 31
7	1060	488	4880.0	90	80	38.4	169.5	184.54	W8 x 31
6	1590	488	4880.0	90	80	35.0	164.1	265.76	W8 x 40
5	2120	488	4880.0	90	80	33.0	160.8	345.88	W10 x 49
4	2650	488	4880.0	90	80	31.7	158.6	425.30	W10 x 49
3	3180	488	4880.0	90	80	30.6	157.0	504.22	W12 x 65
2	3710	488	4880.0	90	80	29.9	155.8	582.75	W12 x 65
1	4240	488	4880.0	90	80	29.2	154.7	660.99	W12 x 72

Column 46									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	507	488	4880.0	63	30	-	90.6	50.81	W8 x 31
7	1014	488	4880.0	90	80	38.8	170.1	177.41	W8 x 31
6	1521	488	4880.0	90	80	35.4	164.6	255.26	W8 x 40
5	2028	488	4880.0	90	80	33.3	161.3	332.03	W8 x 48
4	2535	488	4880.0	90	80	31.9	159.1	408.11	W10 x 49
3	3042	488	4880.0	90	80	30.9	157.4	483.71	W12 x 58
2	3549	488	4880.0	90	80	30.1	156.1	558.93	W12 x 65
1	4056	488	4880.0	90	80	29.4	155.1	633.86	W12 x 65

Column 47									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	355	351	3510.0	63	30	-	90.6	35.67	W8 x 31
7	710	351	3510.0	90	80	42.5	176.0	128.49	W8 x 31
6	1065	351	3510.0	90	80	38.4	169.4	183.94	W8 x 31
5	1420	351	3510.0	90	80	35.9	165.5	238.49	W8 x 40
4	1775	351	3510.0	90	80	34.2	162.8	292.46	W10 x 45
3	2130	351	3510.0	90	80	33.0	160.8	346.02	W10 x 49
2	2485	351	3510.0	90	80	32.0	159.3	399.27	W10 x 49
1	2840	351	3510.0	90	80	31.3	158.0	452.27	W12 x 53

Column 48									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	291	282	2820.0	63	30	-	90.6	29.18	W8 x 31
7	582	282	2820.0	90	80	44.9	179.8	107.46	W8 x 31
6	873	282	2820.0	90	80	40.3	172.5	153.40	W8 x 31
5	1164	282	2820.0	90	80	37.6	168.1	198.53	W8 x 31
4	1455	282	2820.0	90	80	35.7	165.2	243.14	W8 x 40
3	1746	282	2820.0	90	80	34.4	163.0	287.37	W10 x 45
2	2037	282	2820.0	90	80	33.3	161.3	331.33	W8 x 48
1	2328	282	2820.0	90	80	32.4	159.9	375.06	W10 x 49

Column 49									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	566	564	5640.0	63	30	-	90.6	56.92	W8 x 31
7	1132	564	5640.0	90	80	37.8	168.5	196.42	W8 x 31
6	1698	564	5640.0	90	80	34.6	163.3	282.92	W10 x 45
5	2264	564	5640.0	90	80	32.6	160.2	368.28	W10 x 49
4	2830	564	5640.0	90	80	31.3	158.0	452.91	W10 x 54
3	3396	564	5640.0	90	80	30.3	156.5	537.02	W12 x 65
2	3962	564	5640.0	90	80	29.5	155.3	620.75	W12 x 65
1	4528	564	5640.0	90	80	28.9	154.3	704.16	W12 x 72

Column 57									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	466	465	4650.0	63	30	-	90.6	46.87	W8 x 31
7	932	465	4650.0	90	80	39.7	171.4	164.44	W8 x 31
6	1398	465	4650.0	90	80	36.0	165.7	236.26	W8 x 35
5	1864	465	4650.0	90	80	33.9	162.2	307.06	W8 x 48
4	2330	465	4650.0	90	80	32.4	159.9	377.19	W10 x 49
3	2796	465	4650.0	90	80	31.3	158.2	446.85	W10 x 54
2	3262	465	4650.0	90	80	30.5	156.8	516.16	W10 x 60
1	3728	465	4650.0	90	80	29.8	155.7	585.19	W12 x 65

Column 58									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	463	457	4570.0	63	30	-	90.6	46.52	W8 x 31
7	926	457	4570.0	90	80	39.7	171.5	163.42	W8 x 31
6	1389	457	4570.0	90	80	36.1	165.8	234.81	W8 x 35
5	1852	457	4570.0	90	80	33.9	162.3	305.16	W10 x 45
4	2315	457	4570.0	90	80	32.5	160.0	374.86	W10 x 49
3	2778	457	4570.0	90	80	31.4	158.2	444.09	W10 x 54
2	3241	457	4570.0	90	80	30.5	156.9	512.96	W10 x 60
1	3704	457	4570.0	90	80	29.9	155.8	581.56	W12 x 65

Column 59									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	452	457	4570.0	63	30	-	90.6	45.52	W8 x 31
7	904	457	4570.0	90	80	40.0	171.9	159.99	W8 x 31
6	1356	457	4570.0	90	80	36.3	166.1	229.76	W8 x 35
5	1808	457	4570.0	90	80	34.1	162.6	298.51	W10 x 45
4	2260	457	4570.0	90	80	32.6	160.2	366.61	W10 x 49
3	2712	457	4570.0	90	80	31.5	158.4	434.24	W10 x 54
2	3164	457	4570.0	90	80	30.7	157.1	501.53	W10 x 60
1	3616	457	4570.0	90	80	30.0	156.0	568.54	W12 x 65

Column 60									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	474	465	4650.0	63	30	-	90.6	47.59	W8 x 31
7	948	465	4650.0	90	80	39.5	171.2	166.93	W8 x 31
6	1422	465	4650.0	90	80	35.9	165.5	239.93	W8 x 35
5	1896	465	4650.0	90	80	33.8	162.0	311.89	W8 x 48
4	2370	465	4650.0	90	80	32.3	159.7	383.19	W10 x 49
3	2844	465	4650.0	90	80	31.3	158.0	454.01	W10 x 54
2	3318	465	4650.0	90	80	30.4	156.7	524.47	W10 x 60
1	3792	465	4650.0	90	80	29.7	155.6	594.65	W12 x 65

Column Design with Panels

Column 1									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	146	381.25	9531.3	63	30	-	90.6	23.20	W8 x 31
8	292	381.25	19062.5	90	80	-	236.0	88.41	W8 x 31
7	438	381.25	28593.8	90	80	48.7	185.9	110.44	W8 x 31
6	584	381.25	38125.0	90	80	44.8	179.7	143.52	W8 x 31
5	730	381.25	47656.3	90	80	42.2	175.5	176.23	W8 x 31
4	876	381.25	57187.5	90	80	40.3	172.4	208.68	W8 x 31
3	1022	381.25	66718.8	90	80	38.8	170.0	240.93	W8 x 35
2	1168	381.25	76250.0	90	80	37.6	168.1	273.02	W8 x 40
1	1314	381.25	85781.3	90	80	36.6	166.5	304.98	W8 x 48

Column 2									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	379	366	9150.0	63	30	-	90.6	44.62	W8 x 31
8	758	366	18300.0	90	80	41.8	174.9	151.99	W8 x 31
7	1137	366	27450.0	90	80	37.8	168.5	220.14	W8 x 35
6	1516	366	36600.0	90	80	35.4	164.7	287.36	W10 x 45
5	1895	366	45750.0	90	80	33.8	162.1	353.98	W10 x 49
4	2274	366	54900.0	90	80	32.6	160.1	420.18	W10 x 49
3	2653	366	64050.0	90	80	31.6	158.6	486.05	W12 x 58
2	3032	366	73200.0	90	80	30.9	157.4	551.68	W12 x 65
1	3411	366	82350.0	90	80	30.3	156.4	617.09	W12 x 65

Column 3

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	232	450	11250.0	63	30	-	90.6	32.97	W8 x 31
8	464	450	22500.0	90	80	47.9	184.6	108.84	W8 x 31
7	843	450	33750.0	90	80	40.7	173.1	180.34	W8x 31
6	1222	450	45000.0	90	80	37.2	167.5	250.33	W10 x 39
5	1601	450	56250.0	90	80	35.0	164.0	319.50	W8 x 48
4	1980	450	67500.0	90	80	33.5	161.6	388.11	W10 x 49
3	2359	450	78750.0	90	80	32.4	159.8	456.33	W10 x 54
2	2738	450	90000.0	90	80	31.5	158.3	524.25	W12 x 65
1	3117	450	101250.0	90	80	30.7	157.2	591.92	W12 x 65

Column 4 (x9)

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	758	0	0.0	63	30	-	90.6	70.95	W8 x 31
8	1516	0	0.0	90	80	35.4	164.7	251.89	W10 x 39
7	1895	0	0.0	90	80	33.8	162.1	309.36	W8 x 48
6	2274	0	0.0	90	80	32.6	160.1	366.41	W10 x 49
5	2653	0	0.0	90	80	31.6	158.6	423.14	W10 x 49
4	3032	0	0.0	90	80	30.9	157.4	479.62	W12 x 58
3	3411	0	0.0	90	80	30.3	156.4	535.88	W12 x 65
2	3790	0	0.0	90	80	29.7	155.6	591.97	W12 x 65
1	4169	0	0.0	90	80	29.3	154.9	647.92	W12 x 72

Column 5 (x8)

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	379	481	12025.0	63	30	-	90.6	47.50	W8 x 31
8	758	481	24050.0	90	80	41.8	174.9	157.74	W8 x 31
7	1137	481	36075.0	90	80	37.8	168.5	228.76	W8 x 35
6	1516	481	48100.0	90	80	35.4	164.7	298.86	W10 x 45
5	1895	481	60125.0	90	80	33.8	162.1	368.35	W10 x 49
4	2274	481	72150.0	90	80	32.6	160.1	437.43	W12 x 53
3	2653	481	84175.0	90	80	31.6	158.6	506.18	W10 x 60
2	3032	481	96200.0	90	80	30.9	157.4	574.68	W12 x 65
1	3411	481	108225.0	90	80	30.3	156.4	642.97	W12 x 72

Column 6 (x6)

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	379	481	12025.0	63	30	-	90.6	47.50	W8 x 31
8	758	481	24050.0	90	80	41.8	174.9	157.74	W8 x 31
7	1137	481	36075.0	90	80	37.8	168.5	228.76	W8 x 35
6	1516	481	48100.0	90	80	35.4	164.7	298.86	W10 x 45
5	1895	481	60125.0	90	80	33.8	162.1	368.35	W10 x 49
4	2478	434	64465.0	90	80	32.1	159.3	460.31	W10 x 54
3	3061	434	68805.0	90	80	30.8	157.4	551.60	W12 x 65
2	3644	434	73145.0	90	80	29.9	155.9	642.39	W12 x 72
1	4227	434	77485.0	90	80	29.2	154.8	732.82	W12 x 79

Column 7 (x4)

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	379	481	12025.0	63	30	-	90.6	47.50	W8 x 31
8	758	481	24050.0	90	80	41.8	174.9	157.74	W8 x 31
7	1137	481	36075.0	90	80	37.8	168.5	228.76	W8 x 35
6	1516	481	48100.0	90	80	35.4	164.7	298.86	W10 x 45
5	1895	481	60125.0	90	80	33.8	162.1	368.35	W10 x 49
4	2274	481	72150.0	90	80	32.6	160.1	437.43	W12 x 53
3	2653	481	84175.0	90	80	31.6	158.6	506.18	W10 x 60
2	3451	0	0.0	90	80	30.2	156.3	540.67	W12 x 65
1	4249	0	0.0	90	80	29.2	154.7	658.57	W12 x 72

Column 8 (x2)

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	172	484	12100.0	63	30	-	90.6	28.20	W8 x 31
8	344	484	24200.0	90	80	-	236.0	105.90	W8 x 31
7	516	484	36300.0	90	80	46.4	182.3	130.86	W8 x 31
6	688	484	48400.0	90	80	42.9	176.6	170.42	W8 x 31
5	860	484	60500.0	90	80	40.5	172.7	209.57	W8 x 31
4	1240	484	50820.0	90	80	37.0	167.3	258.74	W10 x 39
3	1620	484	50820.0	90	80	34.9	163.9	316.78	W8 x 48
2	2000	484	50820.0	90	80	33.4	161.5	374.27	W10 x 49
1	2380	484	50820.0	90	80	32.3	159.7	431.37	W12 x 53

Column 9 (x2)

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	585	0	0.0	63	30	-	90.6	54.76	W8 x 31
8	1170	0	0.0	90	80	37.5	168.1	198.39	W8 x 31
7	1755	0	0.0	90	80	34.3	162.9	287.67	W10 x 45
6	2340	0	0.0	90	80	32.4	159.8	375.79	W10 x 49
5	2925	0	0.0	90	80	31.1	157.8	463.17	W10 x 54
4	3510	0	0.0	90	80	30.1	156.2	550.03	W12 x 65
3	4095	0	0.0	90	80	29.4	155.0	636.49	W12 x 65
2	4680	0	0.0	90	80	28.8	154.0	722.63	W12 x 79
1	5265	0	0.0	90	80	28.3	153.2	808.51	W12 x 87

Column 10 (x2)

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	464	0	0.0	63	30	-	90.6	43.43	W8 x 31
8	928	0	0.0	90	80	39.7	171.5	160.56	W8 x 31
7	1392	0	0.0	90	80	36.1	165.7	232.09	W8 x 35
6	1856	0	0.0	90	80	33.9	162.3	302.59	W10 x 45
5	2320	0	0.0	90	80	32.5	159.9	372.43	W10 x 49
4	2784	0	0.0	90	80	31.4	158.2	441.81	W12 x 53
3	3248	0	0.0	90	80	30.5	156.8	510.82	W10 x 60
2	3712	0	0.0	90	80	29.8	155.8	579.56	W12 x 65
1	4176	0	0.0	90	80	29.3	154.9	648.07	W12 x 72

Column 11 (x2)

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	136	381	9525.0	63	30	-	90.6	22.25	W8 x 31
8	272	381	19050.0	90	80	-	236.0	83.65	W8 x 31
7	408	381	28575.0	90	80	49.7	187.5	105.49	W8 x 31
6	544	381	38100.0	90	80	45.7	181.2	137.06	W8 x 31
5	680	381	47625.0	90	80	43.0	176.8	168.27	W8 x 31
4	816	381	57150.0	90	80	41.0	173.6	199.22	W8 x 31
3	952	381	66675.0	90	80	39.4	171.1	229.98	W8 x 35
2	1088	381	76200.0	90	80	38.2	169.1	260.59	W10 x 39
1	1224	381	85725.0	90	80	37.1	167.4	291.08	W10 x 45

Column 12

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	222	141	3525.0	63	30	-	90.6	23.64	W8 x 31
8	336	332	16600.0	90	80	-	236.0	95.90	W8 x 31
7	450	332	24900.0	90	80	48.3	185.3	108.26	W8 x 31
6	692	156	27630.0	90	80	42.8	176.5	149.76	W8 x 31
5	934	156	30360.0	90	80	39.6	171.4	190.46	W8 x 31
4	1176	156	33090.0	90	80	37.5	168.0	230.65	W8 x 35
3	1418	156	35820.0	90	80	35.9	165.5	270.49	W8 x 40
2	1660	156	38550.0	90	80	34.7	163.6	310.06	W8 x 48
1	1902	156	41280.0	90	80	33.8	162.0	349.43	W10 x 49

Column 13

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	326	195	4875.0	63	30	-	90.6	35.39	W8 x 31
8	749	0	4875.0	90	80	41.9	175.1	136.99	W8 x 31
7	1172	0	4875.0	90	80	37.5	168.0	202.80	W8 x 31
6	1595	0	4875.0	90	80	35.0	164.0	267.49	W8 x 40
5	2018	0	4875.0	90	80	33.4	161.4	331.50	W8 x 48
4	2441	0	4875.0	90	80	32.1	159.4	395.02	W10 x 49
3	2864	0	4875.0	90	80	31.2	157.9	458.19	W10 x 54
2	3287	0	4875.0	90	80	30.5	156.7	521.07	W10 x 60
1	3710	0	4875.0	90	80	29.9	155.8	583.73	W12 x 65

Column 14

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	583	370	9250.0	63	30	-	90.6	63.82	W8 x 31
8	998	282	16300.0	90	80	39.0	170.4	188.10	W8 x 31
7	1459	0	16300.0	90	80	35.7	165.1	258.98	W10 x 39
6	1920	0	16300.0	90	80	33.7	161.9	328.91	W8 x 48
5	2381	0	16300.0	90	80	32.3	159.7	398.23	W10 x 49
4	2842	0	16300.0	90	80	31.3	158.0	467.11	W10 x 54
3	3303	0	16300.0	90	80	30.4	156.7	535.64	W10 x 65
2	3764	0	16300.0	90	80	29.8	155.6	603.91	W12 x 65
1	4225	0	16300.0	90	80	29.2	154.8	671.95	W12 x 72

Column 19

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	348	572	14300.0	63	30	-	90.6	46.87	W8 x 31
8	722	0	14300.0	90	80	42.3	175.7	142.22	W8 x 31
7	1092	0	14300.0	90	80	38.2	169.1	199.95	W8 x 31
6	1462	0	14300.0	90	80	35.7	165.1	256.73	W10 x39
5	1832	0	14300.0	90	80	34.0	162.4	312.91	W8 x 48
4	2202	0	14300.0	90	80	32.8	160.5	368.67	W10 x 49
3	2572	0	14300.0	90	80	31.8	158.9	424.11	W10 x 49
2	2942	0	14300.0	90	80	31.1	157.7	479.29	W12 x 58
1	3312	0	14300.0	90	80	30.4	156.7	534.27	W12 x 65

Column 20

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	348	572	14300.0	63	30	-	90.6	46.87	W8 x 31
8	628	0	14300.0	90	80	43.9	178.3	127.32	W8 x 31
7	908	0	14300.0	90	80	39.9	171.9	171.39	W8 x 31
6	1188	0	14300.0	90	80	37.4	167.9	214.75	W8 x 35
5	1468	0	14300.0	90	80	35.7	165.1	257.65	W10 x 39
4	1748	0	14300.0	90	80	34.4	163.0	300.20	W10 x 45
3	2028	0	14300.0	90	80	33.3	161.3	342.50	W10 x 49
2	2308	0	14300.0	90	80	32.5	160.0	384.58	W10 x 49
1	2588	0	14300.0	90	80	31.8	158.9	426.50	W10 x 49

Column 22

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	583	370	9250.0	63	30	-	90.6	63.82	W8 x 31
8	905	0	9250.0	90	80	39.9	171.9	166.58	W8 x 31
7	1227	0	9250.0	90	80	37.1	167.4	216.41	W8 x 31
6	1549	0	9250.0	90	80	35.2	164.4	265.64	W8 x 40
5	1871	0	9250.0	90	80	33.9	162.2	314.46	W8 x 48
4	2193	0	9250.0	90	80	32.8	160.5	362.98	W10 x 49
3	2515	0	9250.0	90	80	32.0	159.1	411.24	W10 x 49
2	2837	0	9250.0	90	80	31.3	158.0	459.31	W10 x 54
1	3159	0	9250.0	90	80	30.7	157.1	507.22	W10 x 60

Column 23

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
Roof	326	195	4875.0	63	30	-	90.6	35.39	W8 x 31
8	750	0	4875.0	90	80	41.9	175.1	137.14	W8 x 31
7	1174	0	4875.0	90	80	37.5	168.0	203.11	W8 x 31
6	1598	0	4875.0	90	80	35.0	164.0	267.95	W8 x 40
5	2022	0	4875.0	90	80	33.3	161.3	332.10	W8 x 48
4	2446	0	4875.0	90	80	32.1	159.4	395.77	W10 x 49
3	2870	0	4875.0	90	80	31.2	157.9	459.08	W10 x 54
2	3294	0	4875.0	90	80	30.5	156.7	522.11	W10 x 60
1	3718	0	4875.0	90	80	29.8	155.7	584.91	W12 x 65

Column 29									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	691	0	0.0	63	30	-	90.6	63.50	W8 x 31
7	1382	0	0.0	90	80	36.1	165.8	230.07	W8 x 35
6	2073	0	0.0	90	80	33.2	161.1	334.83	W8 x 48
5	2764	0	0.0	90	80	31.4	158.3	438.33	W12 x 53
4	3455	0	0.0	90	80	30.2	156.3	541.03	W12 x 65
3	4146	0	0.0	90	80	29.3	154.9	643.15	W12 x 72
2	4837	0	0.0	90	80	28.6	153.8	744.85	W12 x 79
1	5528	0	0.0	90	80	28.1	152.9	846.20	W12 x 87

Column 30									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	720	0	0.0	63	30	-	90.6	66.13	W8 x 31
7	1440	0	0.0	90	80	35.8	165.3	238.93	W8 x 35
6	2160	0	0.0	90	80	32.9	160.7	347.92	W10 x 49
5	2880	0	0.0	90	80	31.2	157.9	455.62	W10 x 54
4	3600	0	0.0	90	80	30.0	156.0	562.50	W12 x 65
3	4320	0	0.0	90	80	29.1	154.6	668.80	W12 x 72
2	5040	0	0.0	90	80	28.5	153.5	774.65	W12 x 79
1	5760	0	0.0	90	80	27.9	152.6	880.16	W14 x 90

Column 31									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	675	0	0.0	63	30	-	90.6	62.01	W8 x 31
7	1350	0	0.0	90	80	36.3	166.1	225.12	W8 x 35
6	2025	0	0.0	90	80	33.3	161.3	327.55	W8 x 48
5	2700	0	0.0	90	80	31.5	158.5	428.73	W10 x 49
4	3375	0	0.0	90	80	30.3	156.5	529.12	W12 x 65
3	4050	0	0.0	90	80	29.4	155.1	628.94	W12 x 65
2	4725	0	0.0	90	80	28.7	154.0	728.34	W12 x 79
1	5400	0	0.0	90	80	28.2	153.1	827.40	W12 x 87

Column 32									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	874	0	0.0	63	30	-	90.6	80.18	W8 x 31
7	1748	0	0.0	90	80	34.4	163.0	285.86	W10 x 45
6	2622	0	0.0	90	80	31.7	158.7	417.24	W10 x 49
5	3496	0	0.0	90	80	30.1	156.2	547.20	W12 x 65
4	4370	0	0.0	90	80	29.1	154.5	676.26	W12 x 72
3	5244	0	0.0	90	80	28.3	153.3	804.68	W12 x 87
2	6118	0	0.0	90	80	27.7	152.3	932.61	W14 x 90
1	6992	0	0.0	90	80	27.2	151.5	1060.15	W14 x 99

Column 33									
Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	687	0	0.0	63	30	-	90.6	63.09	W8 x 31
7	1374	0	0.0	90	80	36.2	165.9	228.79	W8 x 35
6	2061	0	0.0	90	80	33.2	161.1	332.97	W8 x 48
5	2748	0	0.0	90	80	31.4	158.3	435.89	W12 x 53
4	3435	0	0.0	90	80	30.2	156.4	538.01	W12 x 65
3	4122	0	0.0	90	80	29.3	155.0	639.56	W12 x 72
2	4809	0	0.0	90	80	28.7	153.8	740.68	W12 x 79
1	5496	0	0.0	90	80	28.1	152.9	841.46	W12 x 87

Column 34

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	753	0	0.0	63	30	-	90.6	69.27	W8 x 31
7	1506	0	0.0	90	80	35.5	164.7	249.14	W8 x 40
6	2259	0	0.0	90	80	32.6	160.2	362.94	W10 x 49
5	3012	0	0.0	90	80	30.9	157.5	475.42	W12 x 58
4	3765	0	0.0	90	80	29.8	155.6	587.06	W12 x 65
3	4518	0	0.0	90	80	28.9	154.3	698.10	W12 x 72
2	5271	0	0.0	90	80	28.3	153.2	808.69	W12 x 87
1	6024	0	0.0	90	80	27.7	152.4	918.92	W14 x 90

Column 35

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	680	0	0.0	63	30	-	90.6	62.46	W8 x 31
7	1360	0	0.0	90	80	36.3	166.0	226.65	W8 x 35
6	2040	0	0.0	90	80	33.3	161.3	329.81	W8 x 48
5	2720	0	0.0	90	80	31.5	158.4	431.72	W12 x 53
4	3400	0	0.0	90	80	30.3	156.5	532.83	W12 x 65
3	4080	0	0.0	90	80	29.4	155.0	633.37	W12 x 65
2	4760	0	0.0	90	80	28.7	153.9	733.48	W12 x 79
1	5440	0	0.0	90	80	28.1	153.0	833.26	W14 x 90

Column 36

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	725	0	0.0	63	30	-	90.6	66.39	W8 x 31
7	1450	0	0.0	90	80	35.8	165.2	240.26	W8 x 35
6	2175	0	0.0	90	80	32.9	160.6	349.97	W10 x 49
5	2900	0	0.0	90	80	31.1	157.8	458.40	W10 x 54
4	3625	0	0.0	90	80	30.0	155.9	566.00	W12 x 65
3	4350	0	0.0	90	80	29.1	154.6	673.02	W12 x 72
2	5075	0	0.0	90	80	28.4	153.5	779.59	W12 x 79
1	5800	0	0.0	90	80	27.9	152.6	885.81	W14 x 90

Column 39

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	508	145	3625.0	63	30	-	90.6	50.00	W8 x 31
7	1016	145	7250.0	90	80	38.8	170.1	180.44	W8 x 31
6	1524	145	10875.0	90	80	35.4	164.6	262.06	W8 x 40
5	2032	145	14500.0	90	80	33.3	161.3	342.60	W10 x 49
4	2540	145	18125.0	90	80	31.9	159.0	422.46	W10 x 49
3	3048	145	21750.0	90	80	30.9	157.4	501.82	W10 x 60
2	3556	145	25375.0	90	80	30.1	156.1	580.81	W12 x 65
1	4064	145	29000.0	90	80	29.4	155.1	659.51	W12 x 72

Column 45

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	530	488	4880.0	63	30	-	90.6	53.25	W8 x 31
7	1060	488	4880.0	90	80	38.4	169.5	184.89	W8 x 31
6	1590	488	4880.0	90	80	35.0	164.1	266.11	W8 x 40
5	2120	488	4880.0	90	80	33.0	160.8	346.23	W10 x 49
4	2650	488	4880.0	90	80	31.7	158.6	425.65	W10 x 49
3	3180	488	4880.0	90	80	30.6	157.0	504.57	W12 x 65
2	3710	488	4880.0	90	80	29.9	155.8	583.10	W12 x 65
1	4240	488	4880.0	90	80	29.2	154.7	661.34	W12 x 72

Column 46

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	507	488	4880.0	63	30	-	90.6	51.11	W8 x 31
7	1014	488	4880.0	90	80	38.8	170.1	177.71	W8 x 31
6	1521	488	4880.0	90	80	35.4	164.6	255.56	W8 x 40
5	2028	488	4880.0	90	80	33.3	161.3	332.33	W8 x 48
4	2535	488	4880.0	90	80	31.9	159.1	408.41	W10 x 49
3	3042	488	4880.0	90	80	30.9	157.4	484.01	W12 x 58
2	3549	488	4880.0	90	80	30.1	156.1	559.23	W12 x 65
1	4056	488	4880.0	90	80	29.4	155.1	634.16	W12 x 65

Column 47

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	355	351	3510.0	63	30	-	90.6	36.07	W8 x 31
7	710	351	3510.0	90	80	42.5	176.0	128.89	W8 x 31
6	1065	351	3510.0	90	80	38.4	169.4	184.34	W8 x 31
5	1420	351	3510.0	90	80	35.9	165.5	238.89	W8 x 40
4	1775	351	3510.0	90	80	34.2	162.8	292.86	W10 x 45
3	2130	351	3510.0	90	80	33.0	160.8	346.42	W10 x 49
2	2485	351	3510.0	90	80	32.0	159.3	399.67	W10 x 49
1	2840	351	3510.0	90	80	31.3	158.0	452.67	W12 x 53

Column 48

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	291	282	2820.0	63	30	-	90.6	29.48	W8 x 31
7	582	282	2820.0	90	80	44.9	179.8	107.76	W8 x 31
6	873	282	2820.0	90	80	40.3	172.5	153.70	W8 x 31
5	1164	282	2820.0	90	80	37.6	168.1	198.83	W8 x 31
4	1455	282	2820.0	90	80	35.7	165.2	243.44	W8 x 40
3	1746	282	2820.0	90	80	34.4	163.0	287.67	W10 x 45
2	2037	282	2820.0	90	80	33.3	161.3	331.63	W8 x 48
1	2328	282	2820.0	90	80	32.4	159.9	375.36	W10 x 49

Column 49

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	566	564	5640.0	63	30	-	90.6	57.32	W8 x 31
7	1132	564	5640.0	90	80	37.8	168.5	196.82	W8 x 31
6	1698	564	5640.0	90	80	34.6	163.3	283.32	W10 x 45
5	2264	564	5640.0	90	80	32.6	160.2	368.68	W10 x 49
4	2830	564	5640.0	90	80	31.3	158.0	453.31	W10 x 54
3	3396	564	5640.0	90	80	30.3	156.5	537.42	W12 x 65
2	3962	564	5640.0	90	80	29.5	155.3	621.15	W12 x 65
1	4528	564	5640.0	90	80	28.9	154.3	704.56	W12 x 72

Column 57

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	466	465	4650.0	63	30	-	90.6	47.17	W8 x 31
7	932	465	4650.0	90	80	39.7	171.4	164.74	W8 x 31
6	1398	465	4650.0	90	80	36.0	165.7	236.56	W8 x 35
5	1864	465	4650.0	90	80	33.9	162.2	307.36	W8 x 48
4	2330	465	4650.0	90	80	32.4	159.9	377.49	W10 x 49
3	2796	465	4650.0	90	80	31.3	158.2	447.15	W10 x 54
2	3262	465	4650.0	90	80	30.5	156.8	516.46	W10 x 60
1	3728	465	4650.0	90	80	29.8	155.7	585.49	W12 x 65

Column 58

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	463	457	4570.0	63	30	-	90.6	46.82	W8 x 31
7	926	457	4570.0	90	80	39.7	171.5	163.72	W8 x 31
6	1389	457	4570.0	90	80	36.1	165.8	235.11	W8 x 35
5	1852	457	4570.0	90	80	33.9	162.3	305.46	W10 x 45
4	2315	457	4570.0	90	80	32.5	160.0	375.16	W10 x 49
3	2778	457	4570.0	90	80	31.4	158.2	444.39	W10 x 54
2	3241	457	4570.0	90	80	30.5	156.9	513.26	W10 x 60
1	3704	457	4570.0	90	80	29.9	155.8	581.86	W12 x 65

Column 59

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	452	457	4570.0	63	30	-	90.6	45.82	W8 x 31
7	904	457	4570.0	90	80	40.0	171.9	160.29	W8 x 31
6	1356	457	4570.0	90	80	36.3	166.1	230.06	W8 x 35
5	1808	457	4570.0	90	80	34.1	162.6	298.81	W10 x 45
4	2260	457	4570.0	90	80	32.6	160.2	366.91	W10 x 49
3	2712	457	4570.0	90	80	31.5	158.4	434.54	W10 x 54
2	3164	457	4570.0	90	80	30.7	157.1	501.83	W10 x 60
1	3616	457	4570.0	90	80	30.0	156.0	568.84	W12 x 65

Column 60

Column Below Level	Area	Wall Area	Wall Load	Dead Load	Live Load	Reduced LL	Total Load	Column Load	Column
8	474	465	4650.0	63	30	-	90.6	47.89	W8 x 31
7	948	465	4650.0	90	80	39.5	171.2	167.23	W8 x 31
6	1422	465	4650.0	90	80	35.9	165.5	240.23	W8 x 35
5	1896	465	4650.0	90	80	33.8	162.0	312.19	W8 x 48
4	2370	465	4650.0	90	80	32.3	159.7	383.49	W10 x 49
3	2844	465	4650.0	90	80	31.3	158.0	454.31	W10 x 54
2	3318	465	4650.0	90	80	30.4	156.7	524.77	W10 x 60
1	3792	465	4650.0	90	80	29.7	155.6	594.95	W12 x 65