University Medical Center of Princeton

Plainsboro, NJ

Final Report

Heat Recovery Replacement, Microsteam Turbines, Power Distribution Redesign, Acoustical Analysis

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University Medical Center of Princeton
Replacement Hospital
Plainsboro, NJ

courtesy of Princeton Healthcare System

Primary Project Team

Architect:	RMJM Hillier and HOK in joint venture
MEP:	Syska Hennessay Group, Inc.
Structure:	O'Donnell & Naccarato, Inc.
Civil:	French & Parrello Associates
Medical Equipment:	RTKL Associates Inc.
Co-gen Plant:	NRG Energy Inc.
GC:	Turner Construction

Architecture

- 269 single patient rooms
- State of the art laboratories, imaging rooms, and operating rooms
- Glass curtain wall on south side
- Brick curtain wall on remaining sides
- Two story concourse entrance
- Horizontal sun shades

courtesy of Princeton Healthcare System

Electrical

UMCP is supplied with electricity from the Central Utility Plant which receives grid power and generates its own. Power is distributed through the building through 480 volt risers and transformed down to required voltages on each floor.

Project Information

Building Name:	University Medical Center of Princeton Replacement Hospital
Location:	Plainsboro, NJ
Building Occupant:	University Medical Center of Princeton
Size:	639,000 square feet
Stories:	6+1
Finish Date:	March 2012
Cost:	$315 Million
Delivery Type:	Design-Bid-Build

courtesy of Princeton Healthcare System

Mechanical

- 10 AHUs with 100% outside air to service medical areas
- 7 other AHUs to service rest of building
- 1 MUA to replenish exhausted kitchen air
- The building is provided with 120 psi steam from a central utility plant on site, which is reduced to usable pressures
- The central utility plant also supplies chilled water for cooling
- All AHU use HEPA filters to provide the cleanest air possible

Structural

UMCP has a steel structure with concrete floors on metal decking The building is supported on concrete footings while the cast in place basement walls are supported by a strip footing. Particular rooms such as the Linear Accelerator have special design requirements to support the three foot thick lead entraced block and the 9,000 pound door. The building is designed to withstand wind loads of 95 mph and seismic loads of class C.

Tim Berteotti, Mechanical Option

www.engr.psu.edu/ae/thesis/portfolios/2012/TCB5052/index.html

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Executive Summary

An extensive analysis was performed on the current energy recovery system and a possible substitute. The current system is a propylene glycol runaround loop which harvests energy from the exhaust air and transfers it to the incoming ventilation air. It was proven that this system only covered 7 Tons of cooling load and a little over 5,400 MBH of heating. This reducing heating costs in half, but barely affects the cooling load. The runaround propylene glycol system saves around $53,000 a year in natural gas costs, but costs around $1.3 million to install. This payback of 23 years is unpractical for most situations, but because of the simplicity of the system and the fact that this is for a hospital I would recommend it.

The proposed alternative had a higher reduction of onsite energy but did not pay off. Saving around $55,000 a year in natural gas costs is good, but the additional capital investment of around $6.4 million creates a payback of 115 years. This is unacceptable for any building investment. The equipment would need replaced multiple times during this period and would greatly increase the payback period. Therefore, I would not recommend this alternative.

One of the design objectives of Princeton Healthcare Systems is to be environmentally conscious. Microsteam Turbines make use of wasted energy. The savings of 461 kw of peak electricity during on season peak months could save up to $7,634 and $4,219 during off peak months. This is an interesting technology that I feel will continue to grow in applications where a large constant supply of steam is required such as hospitals.

Electrical power distribution is a necessity for any building, because without power nothing would work. Therefore it is important that a building’s power system be properly design and given room for growth. Adding the 13 heat pumps increased the electrical demand by about 800 amps. If the heat pumps were being integrated as part of the original design it is very possible that the substation and emergency switchgear would have been sized larger.

Building acoustics is a very complicated subject. Being able to accurately predict how a room will perform acoustically is not straight forward and not reliable. Therefore AudioComfort panels from DuPont were selected as the means to quiet noisy rooms. By taking actual sound recordings and analyzing them through Matlab, an analytical solution was made. By calculating the T_{60} time within the patient rooms, it was possible to estimate the square footage of panels is needed. The values varied from 100 to over 300 square feet. This is almost the area of the entire wall. Therefore it is recommended to complete an analysis of the duct attenuator design to make further improvements.

Building Overview

The University Medical Center of Princeton Replacement Hospital is a new 639,000 square foot state of the art faciltiy located in Plainsboro, New Jersey. It part of a 171 acre healthcare campus located conveniently off of US route 1. The new faciltiy is being built to fullfill future ocupancy needs anticipated by the Princeton Healthcare Systems. The scope of this project is the patient tower which consists of 269 single-bed rooms within its six floors along with state-of-the-art treatment and testing equipment

Design Objectives of UMCP

The University Medical Center of Princeton has many design objectives including aesthetics, unique patient experience, improved performance, and environmental responsibility. To achieve these goals the design is well integrated and comprised of state-of-the-art equipment. The collaboration of the design teams resulted in the production of a complex building meeting the specific needs of each space.

Every interior space is laid out in a way to improve efficiency. An extensive analysis of the patient/doctor routes was performed to minimize the travel distance, providing faster and more efficient care. Segmenting the hospital into separate portals based on major type of care (i.e. maternity, cancer, etc.) decreases transportation time. To accomplish this, there are dedicated imaging and exam rooms spread throughout the building for each portal. The dedicated rooms also provide an ease in scheduling and reduce wait time for patients.

The Princeton Healthcare System spared no cost to provide the best equipment possible. Through vigorous fundraising the “Design for Healing” campaign is raising $115 million to support the $447 million project ($315 million for construction). Of the fundraised money, $15 million is allocated to program and department needs of the hospital including a fully computerized patient records system. The campaign feels no reason for money to be a deciding factor in providing the best possible care and healing for patients.

The collaboration of multiple well known firms creates a well-planned hospital. The partnership between HOK and RMJM Hillier brought together design experience of more than 260 hospital designs. Syska Hennessay worked hard to design a mechanical system that satisfies all of the environmental needs while maintaining a strong LEED initiative. RTKL Associates, an industry leader in healthcare technologies, is providing extensive planning for the medical equipment and data system. NRG is providing design and installation services for the central utility plant that will provide high pressure steam, chilled water, and electricity to the entire building. Turner Construction brings its excellent record and experience of construction with the use of 3D construction tools to insure UMCP is built on time and on budget. Together, these members of the project team, as well as many others, are striving to construct one of the most advanced healing facilities in New Jersey.

Project Goals

To begin any project one must set goals and guidelines to ensure that there is a purposeful result in the end. Each goal must be analyzed and evaluated on its importance to the big picture. Below the major goals are bulleted and will be referenced back to throughout this report.

- Provide an alternative heating/cooling system that follows the owners design objectives
- Delve into the workings of the alternative system to discover unique options/designs
- Reduce energy consumption and cost

The design objectives of Princeton Healthcare Systems were kept as a top priority. Although it could easily be said that the owner's wishes could be set aside to show alternatives that could drastically save energy, I felt that this was not a healthy practice. The owner's wishes should be respected and accepted as a challenge.

Some of these requests were to better the healing environment within the hospital. Thus the energy intensive choice to use 100% outside air took priority. Having to cool and heat almost 70% more air is a large expense; however it has its medical benefits. By not recycling any of the air it eliminates the opportunity for airborne illnesses such as pulmonary tuberculosis and biological threats such as anthrax from spreading through the building to other patients and staff. The amount of contaminants spread through the building serviced by a particular air handler can be calculated and may seem small because the dilution of mixing with return air and outside air coming in and then separated to the different spaces. This air is separated to the different spaces and therefore only a small fraction of the original contaminant will be spread to the other spaces. However, with some bacteria it only takes a single cell to create a colony in a moist location, such as an air supply unit, and have spores released into the air.

Another design objective is to provide superior comfort for the patients, doctors, surgeons, and staff. Every patient room holds only one patient and each room has its own thermostat to control a VAV box with terminal preheat. This is also an energy intensive design, but allows the occupant to set the ideal personal temperature.

The hospital also wants to be environmentally conscious and find innovative ways to reduce energy consumption when possible without impeding the overall quality of the indoor environment. This is done currently by harvesting some of the energy from the exhaust air.

It is easy to pick a system configuration from a book and follow the step by step instructions to design such a system. It is challenging and often very innovational to look into the inner functions of a design and ask "what if". This method can sometimes spark new ideas and become very prosperous.

Finally as a way to keep with the owner's requests as well as be an energy conscious engineer I decided to design an alternative system to save energy. Although the system may not pay off quickly, it could use the energy more efficiently and be less dependent on outside fuel sources.

Current Mechanical System Overview

The University Medical Center of Princeton has a large multi zone mechanical system to provide the required cooling and ventilation air for each space. There are 11 air handling units within the scope of this report (17 total for the building); eight of these units are atop the roof of the bed tower, while the other three are placed in the basement. The eight roof top units supply 100% outside air and each is connected to propylene glycol runaround heat recovery system.

Each floor is not serviced by its own air handler. The basement, first floor and lobby are supplied by the three basement units. The remainder of the building is divided into sectors. Each sector is supplied from a rooftop air handler via a vertical supply shaft. Figure 1 below illustrates the sectors of the patient tower.

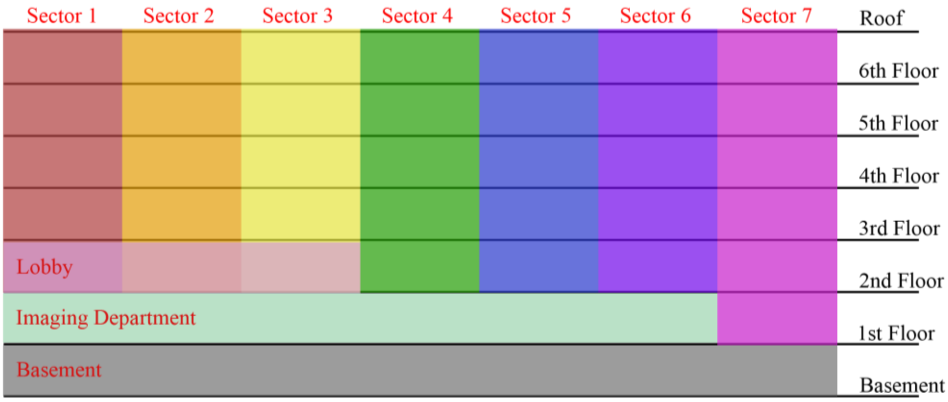


Figure 1. Sector Layout Diagram for the Patient Tower

The following table lists the sector and supply air data for each air handler.

Design Sectors and Supply Air by AHU		
Air Handler	Sector	Supply Air (CFM)
AHU -1	Lobby	60,000
AHU -2	Imaging Department	35,000
AHU -4	Basement	33,000
AHU -7	Sector 1	46,000
AHU -8	Sector 2	50,000
AHU -9	Sector 3	35,000
AHU -10	Sector 4	42,000
AHU -11	Sector 5	50,000
AHU -12	Sector 6	30,000
AHU -13	Sector 7	30,000

Table 1. Designed Sectors and Supply Air

Providing ultimate climate comfort to each space is accomplished using two simple devices. In the public spaces such as hallways and lobbies a constant air volume

(CAV) box with terminal reheat is used. This box is sized to always meet the design occupancy of the space. The patient rooms however have variable air volume (VAV) boxes with terminal reheat. This allows each patient to control the temperature to his or her personal comfort thus aiding in the healing process.

Hot and chilled water is supplied to the air handlers from steam heat exchangers and the central utility plant located next to the medical center. Steam provided from the utility plant is reduced from 150psi to 15psi at four locations to supply low pressure steam for hot water and humidification. The chilled water is supplied at 50.5 ^{o}F and distributed to the air handlers throughout the building.

Energy Rates

The University Medical Center of Princeton could receive natural gas and electricity from the Public Service Electric and Gas Company. Plainsboro is located in south central New Jersey which lies in the zone of PSE&G. Below are the total utility rates listed in terms of total monthly service charges and totaled per unit costs.

Gas:

Monthly Service Charge	$100.94 per Month
Distribution Charge	$0.2409 per therm for first 1,000
Distribution Charge	$0.1966 per therm after first 1,000

Electric:

Monthly Service Charge	$379.13 per Month
Distribution Charge	$0.0263 per kWh
Peak Off Season	$9.152 per kW
Peak On Season	$16.556 per kW

Using these values it becomes apparent that the cost per unit energy for natural gas is cheaper than electricity. Using the distribution cost of the first 1,000 therms, the cost per BTU is approximately $\$2.409 \text{ x}10^{-6}$ as compared to the distribution charge of $\$7.706 \text{ x}10^{-6}$ / BTU for electricity. This does not take into account the monthly service charge. Also there is no peak charge for gas, making it even cheaper per unit on a month by month basis. Therefore it would be beneficial for NRG to produce as much useful energy with natural gas.

CUP Assumptions

To reduce energy costs, the UMCP has commissioned the construction of a central utility plant. The CUP along with providing high pressure steam and chilled water will provide cogeneration of electricity. An exact list of equipment was not available for use of this report. Assumptions have been made as to the efficiencies of the equipment used to generate steam, electricity, and chilled water. Because of the electrical cogeneration and the large thermal steam load a reasonable assumption is that NRG chose to implement a topping-cycling system such as a gas combustion turbine. The gas is fired in the turbine, the exhaust is then used to generate steam; supplemental firing of the exhaust can be done to increase the steam production rate to meet peak loads. The exhaust could then be used in an absorption chiller to produce the buildings chilled water. Figure 2 below illustrates the setup of such a system by Solar without the absorption chiller.

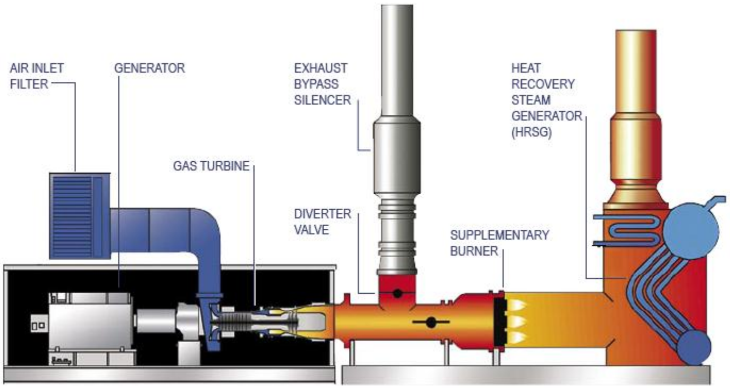


Figure 2 Combustion Gas Turbine Process Flow Diagram

An example of such a system is a Solar Mars 90 turbine. This system produces 9.5 MW and capable of producing 46.8 kpph of steam with no supplemental firing and 113.3 kpph with supplemental firing. The specific data for this system is found in Table 2 below. Rough sizing calculations can be found in Appendix A.

Solar Mars 90 Combustion Gas Turbine						
Fuel Input (MMBH)	Electrical Output (MW)	Steam Output Unfired (kpph)	Steam Output Fired (kpph)	Electrical Efficiency	Thermal Efficiency Unfired	Total Efficiency Unfired
100.4	9.5	46.8	113.3	32%	56%	88%

Table 2 Combustion Gas Turbine Assumptions

The total building cooling load (discussed in detail later) along with the exhaust flow rates makes this system a good candidate for absorption cooling. With a cooling load of 1,431 tons, and an exhaust flow rate of 316.2 klb/hr and using the following equation the exhaust temperature can be determined.

$$Tons\ of\ cooling = m * \frac{(Tg - 375)}{40950}$$

Where m is equal to the mass flow rate and Tg is the temperature of the exhaust gas, then Tg is calculated to be approximately 560^{o}F. Without the use of a exhaust condensing equipment, this temperature is typical to prevent condensation within the exhaust system. Therefore an absorption chiller is plausible and will continue to increase the total efficiency of the building as well as reducing emissions, energy consumption, and cost. An assumption of the chiller's efficiency must be made to aid in the calculation of annual energy costs. Table 3 below lists these values of a Broad single effect absorption chiller.

Broad Single-Stage Exhaust Absorption Chiller		
Exhaust Inlet Temp (^{o}F)	Chilled Water Outlet Temp (^{o}F)	IPLV COP
446 - 662	> 41	0.94

Table 3 Absorption Chiller Assumptions

Heating and Cooling Loads

Heating and cooling loads were calculated using Trane Trace700. For Tech Report Three a floor-by-floor block model was used. This was proven to be a reasonable evaluation as compared to Syska Hennessay's detailed Trace simulation. However in anticipation for the necessary evaluation of each air handling unit, the block model was updated to be more detailed. The blocks within each floor were broken down into their individual rooms and assigned to the appropriate sector AHU. Each sector was then modeled to have its own air handling unit without heat recovery as well as its own heating and cooling plant. The reason for the separate plants was to get a monthly load and peak analysis for each AHU. These values where then transcribed into excel to be further evaluated. Tables 4a and 4b show the summary of the monthly energy design peaks for each roof top AHU.

Cooling Peak Load Summary BTU by Month NO HR												
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
AHU 7	0.0	0.0	15,150.1	295,427.9	1,056,181.8	1,944,629.8	2,425,106.0	2,330,958.6	1,576,697.6	527,008.8	186,130.4	0.0
AHU 8	0.0	0.0	20,560.9	349,535.6	1,465,235.8	2,807,106.2	2,600,198.4	3,320,046.9	2,232,482.7	726,125.0	208,855.6	0.0
AHU 9	0.0	0.0	6,492.9	140,680.0	767,246.8	1,599,422.9	1,947,876.3	1,846,153.9	1,210,929.8	405,807.6	112,544.0	0.0
AHU 10	0.0	0.0	11,903.7	222,923.6	921,994.8	1,921,904.6	2,379,655.5	2,268,193.7	1,453,332.2	501,037.1	147,172.9	0.0
AHU 11	0.0	0.0	16,232.3	306,249.4	1,287,762.7	2,738,930.5	3,383,894.0	3,224,817.4	2,047,434.4	706,646.2	206,691.3	0.0
AHU 12	0.0	0.0	6,492.9	128,776.3	640,634.9	1,349,445.4	1,670,845.0	1,587,519.2	1,016,142.1	347,371.3	102,804.6	0.0
AHU 13	0.0	0.0	10,821.5	189,376.9	709,892.7	1,425,196.2	1,724,952.7	1,721,706.2	1,229,326.4	473,983.2	155,830.1	0.0
AHU 14	0.0	0.0	0.0	53,025.5	215,348.5	785,643.4	998,827.7	874,380.0	453,422.3	231,580.8	82,243.7	0.0
Total	0.0	0.0	87,654.4	1,685,995.2	7,064,298.0	14,572,279.0	17,131,355.6	17,173,776.0	11,219,767.5	3,919,560.0	1,202,272.5	0.0

Table 4a Monthly Cooling Peak Loads by AHU

Heating Peak Output Summary BTU/hr by Month NO HR												
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
AHU 7	1,491,070.0	1,457,750.0	1,124,550.0	816,340.0	458,150.0	408,170.0	399,840.0	399,840.0	408,170.0	658,070.0	857,990.0	1,274,490.0
AHU 8	1,940,890.0	1,890,910.0	1,466,080.0	1,049,580.0	599,760.0	516,460.0	508,130.0	516,460.0	549,780.0	857,990.0	1,124,550.0	1,657,670.0
AHU 9	1,124,550.0	1,074,570.0	857,990.0	633,080.0	349,860.0	316,540.0	308,210.0	308,210.0	316,540.0	483,140.0	649,740.0	957,950.0
AHU 10	1,357,790.0	1,307,810.0	1,024,590.0	741,370.0	416,500.0	358,190.0	349,860.0	349,860.0	383,180.0	599,760.0	774,690.0	1,149,540.0
AHU 11	1,965,880.0	1,907,570.0	1,482,740.0	1,007,930.0	624,750.0	549,780.0	541,450.0	549,780.0	566,440.0	866,320.0	1,149,540.0	1,690,990.0
AHU 12	999,600.0	949,620.0	741,370.0	541,450.0	308,210.0	258,230.0	258,230.0	258,230.0	266,560.0	424,830.0	566,440.0	841,330.0
AHU 13	1,024,590.0	999,600.0	774,690.0	558,110.0	324,870.0	291,550.0	274,890.0	274,890.0	283,220.0	433,160.0	574,770.0	866,320.0
AHU 14	633,080.0	583,100.0	449,820.0	324,870.0	233,240.0	141,610.0	141,610.0	141,610.0	149,940.0	224,910.0	324,870.0	524,790.0
Total	10,537,450.0	10,170,930.0	7,921,830.0	5,672,730.0	3,315,340.0	2,840,530.0	2,782,220.0	2,798,880.0	2,923,830.0	4,548,180.0	6,022,590.0	8,963,080.0

Table 4b Monthly Heating Peak Loads by AHU

Appendix B contains all of the constituent tables showing the floor by floor monthly breakdown for each AHU. As seen in Table 4a, the cooling loads are only from March through November. The cooling peak design load is 17,173.8 MBH or 1,431 Tons of refrigeration. Table 4b shows that there is a heating load twelve months out of the year. This is because of the terminal reheat in all of the VAV and CAV boxes. The supply air from the AHU is set to be 50.5 ^{o}F to ensure that the operating rooms can easily be kept at the design set point of 68^{o}F with a reasonable relative humidity. The peak design heating value is 10,537.5 MBH.

Base Energy Consumption

To calculate a payback period whether simple or discounted one must know three things. The first is the amount of energy consumed in a year. The second is the efficiencies of the equipment used to generate the useful product consumed. The final piece of the puzzle is to know the price for one unit of the fuel and the equipment costs. The utility rates from the Public Service Electric and Gas Company are listed above. Having the assumption of what equipment is being used; it is then possible to determine the second piece to this puzzle of the equipment efficiencies.

To know the energy consumed by the building annually for heating and cooling there are two methods that can be performed. The simplest and probably the least accurate would be to take the peak design load for the year and multiply by the appropriate number of hours. This would grossly overestimate the value because the building rarely uses the peak amount of energy for extended periods of time. The second method is to use a program such as Trane Trace700 to export the total monthly energy consumption and peak values. For this report the second method will be used.

The monthly total energy consumption by the heating and cooling plant for each floor were exported from Trace and then transcribed into Excel. The raw data entries can be found in Appendix B; below in tables 5a and 5b are the monthly totals for each AHU. Table 5a shows the energy input into the absorption chiller defined above using the equation: $E_{\text{in absorption chiller}} = E_{\text{consumed by building}} / COP_{\text{absorption chiller}}$.

Energy Consumption by Absorption Chiller NO HR (BTU/hr)

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
AHU 7	0.0	0.0	16,117.2	38,788,295.1	238,218,821.4	771,730,850.8	1,104,630,043.6	1,089,340,596.3	558,748,078.9	119,797,844.5	16,483,269.8	0.0
AHU 8	0.0	0.0	21,873.3	47,391,415.3	320,351,968.5	1,101,994,884.7	1,587,611,261.3	1,558,809,861.4	790,351,949.3	154,052,607.2	16,303,678.4	0.0
AHU 9	0.0	0.0	6,907.4	17,411,158.8	169,995,951.5	636,049,525.8	913,090,027.9	888,521,690.1	445,645,771.3	89,492,942.0	9,746,288.7	0.0
AHU 10	0.0	0.0	12,663.5	29,511,707.0	213,812,806.6	760,857,510.7	1,096,368,837.8	1,071,966,276.7	537,826,828.6	109,726,909.7	11,893,327.3	0.0
AHU 11	0.0	0.0	17,268.4	40,227,329.0	305,940,907.5	1,089,872,463.2	1,568,210,782.0	1,534,109,132.5	772,526,348.7	155,232,615.0	16,757,261.8	0.0
AHU 12	0.0	0.0	6,907.4	17,880,859.5	146,422,273.9	536,595,015.6	771,543,200.8	751,424,355.7	374,984,602.3	78,398,566.3	8,689,462.2	0.0
AHU 13	0.0	0.0	11,512.3	26,076,445.3	165,729,503.8	562,347,966.1	765,609,776.2	802,132,456.4	477,012,105.2	141,017,262.7	21,260,862.3	0.0
AHU 14	0.0	0.0	0.0	4,496,693.1	48,586,389.0	297,002,780.2	442,428,091.5	405,454,130.3	165,781,309.1	61,154,335.4	8,307,254.8	0.0
Total	0.0	0.0	93,249.4	221,783,903.2	1,609,058,622.4	5,756,450,997.1	8,249,492,021.0	8,101,758,499.4	4,122,876,993.3	908,873,083.0	109,441,405.4	0.0

Table 5a Monthly Energy Consumed by the Absorption Chiller in BTU/hr

Heating Monthly Consumption of GCT for Steam (BTU) Summary NO HR

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
AHU 7	1,587,370,750	1,366,551,375	1,029,974,750	691,166,875	527,155,125	471,686,250	474,839,750	479,406,375	479,108,875	595,490,875	723,639,000	1,293,321,750
AHU 8	2,066,390,375	1,780,611,875	1,343,004,250	904,682,625	695,227,750	629,242,250	636,174,000	638,643,250	630,997,500	776,088,250	939,862,000	1,681,960,875
AHU 9	1,206,585,625	1,014,683,250	781,904,375	537,032,125	409,717,000	367,472,000	369,911,500	371,666,750	368,706,625	446,562,375	540,319,500	978,923,750
AHU 10	1,436,746,500	1,228,883,250	929,211,500	625,969,750	476,029,750	421,304,625	421,780,625	423,451,088	421,349,250	525,087,500	641,484,375	1,165,515,750
AHU 11	2,110,494,750	1,801,243,500	1,377,811,750	941,126,375	725,543,000	651,391,125	656,180,875	659,661,625	654,574,375	800,334,500	964,896,625	1,719,847,500
AHU 12	1,049,446,125	886,966,500	672,379,750	450,712,500	334,538,750	288,009,750	286,254,500	291,579,750	297,262,000	375,876,375	463,400,875	849,972,375
AHU 13	1,081,338,125	935,741,625	706,830,250	477,561,875	367,962,875	326,788,875	327,978,875	330,567,125	330,909,250	400,732,500	484,151,500	883,485,750
AHU 14	681,825,375	548,709,000	411,814,375	270,249,000	215,702,375	176,149,750	180,047,000	181,489,875	179,407,375	208,874,750	263,213,125	535,529,750
Total	11,220,197,625	9,563,390,375	7,252,931,000	4,898,501,125	3,751,876,625	3,332,044,625	3,353,167,125	3,376,465,838	3,362,315,250	4,129,047,125	5,020,967,000	9,108,557,500

Table 5b Monthly Energy Consumed by the Combustion Gas Turbine in BTU

The values in table 5b were calculated in a very similar way to that of table 5a. The energy consumption of the gas fired boiler in therms of gas were converted to BTU output of the boiler and then adjusted for the efficiency of the combustion gas turbine without supplemental firing. The supplemental firing will increase the thermal efficiency of the system as well as the total efficiency because it will make better use of the fuel entering the system.

The absorption chiller uses energy that would have been wasted. After leaving the steam generator, the exhaust with no further treatment can easily be designed to be 560^{o}F. At this temperature the cooling load of the building can be met by use of four absorption chillers. Therefore there is no cost to produce the chilled water. Because there is a steam load year round there will always be exhaust to power the absorption chiller. Therefore my only energy cost is that to produce the steam for heating.

To calculate the cost to generate the steam to heat the building is simple. Take the energy requirement to generate the steam and using the conversion of 100,000 BTU/Therm of natural gas, the volume is determined. This value is then multiplied by the cost per therm. This must be done on a month to month basis because there are two rates for monthly gas consumption. The detailed calculations can be found in Appendix C. Table 6a summarizes these calculations.

Heating Natural Gas Cost Summary		
Steam Energy Requirement (MMBTU)	Natural Gas Consumption (Therms)	Total Cost ($)
68,369.50	683,695	$134,946

Table 6a Natural Gas Cost for Building Heating

Although the absorption chillers operate off of waste heat, assuming that chilled water is free creates a problem when comparing different systems. Therefore it will be assumed that the remaining energy in the exhaust (about 12% without supplemental firing) is not free. To evaluate the cooling costs given the data in table 5a, the efficiency of the exhaust gas generation must be accounted for. Therefore each monthly value will be divided by this 12% efficiency and then converted to therms of natural gas and finally to a dollar amount. These monthly calculations are also in Appendix C. A summary is shown below in table 6b.

Chilled Water Natural Gas “Cost” Summary			
Chilled Water Energy Requirement (MMBTUH)	Natural Gas Consumption (MMBTUH)	Natural Gas Consumption (Therms)	Total Cost ($)
29,079.8	242331.9	2,423,319	$476,779

Table 6b Natural Gas “Cost” for Building Chilled Water Cooling

The total costs of natural gas for heating and cooling with no heat recovery will be the baseline for comparison. Throughout the remainder of this report these costs will be used to analyze the payback of the alternative systems including the current heat recovery design by Syska Hennessy.

Current Heat Recovery System

In keeping with the design initiative to be environmentally responsible, the Princeton Healthcare Systems decided to implement an energy recovery system. Syska Hannessy chose to use a runaround heat recovery system with a 30% propylene glycol solution. This system takes advantage of the sensible heat being released into the environment via the exhaust air.

The runaround heat recovery system is a series of heat exchangers in parallel. Figure 3 below is a simplified single line diagram. The entire system can be broken into three parts. The first is the heat recovery units. These are simply the exhaust fan units with an air to water heat exchanger inside that transfers some of the sensible energy to the glycol fluid or visa versa in the summer months. Each heat recovery unit connects in parallel with the others feeding into a common water line. The second part is the circulation equipment. There are two pumps each sized to handle the full flow of 900 gpm as a redundancy precaution. The glycol solution then continues onto the third part, the air handling units. These units are also connected in parallel. The fluid then cycles back to the heat recovery units.

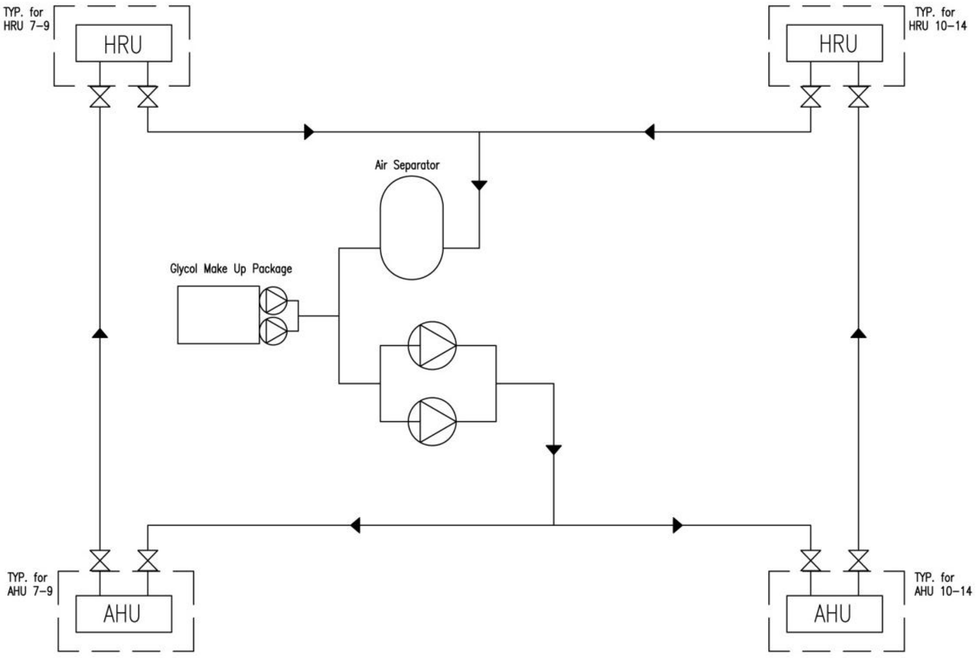


Figure 3 Simplified Single Line Diagram of the Current Heat Recovery System

Air handling units 7-14 are equipped with a heat recovery coil that is supplied with the propylene glycol solution. The heat recovery coil is the first coil that incoming air crosses and functions as a “preheating” or “precooling” coil for that air handling unit. The basic idea is that by “preheating” or “precooling” the air will save energy by reducing the load on the actual heating and cooling coils. Figure 4 shows a typical cross section for air handlers 7-14.

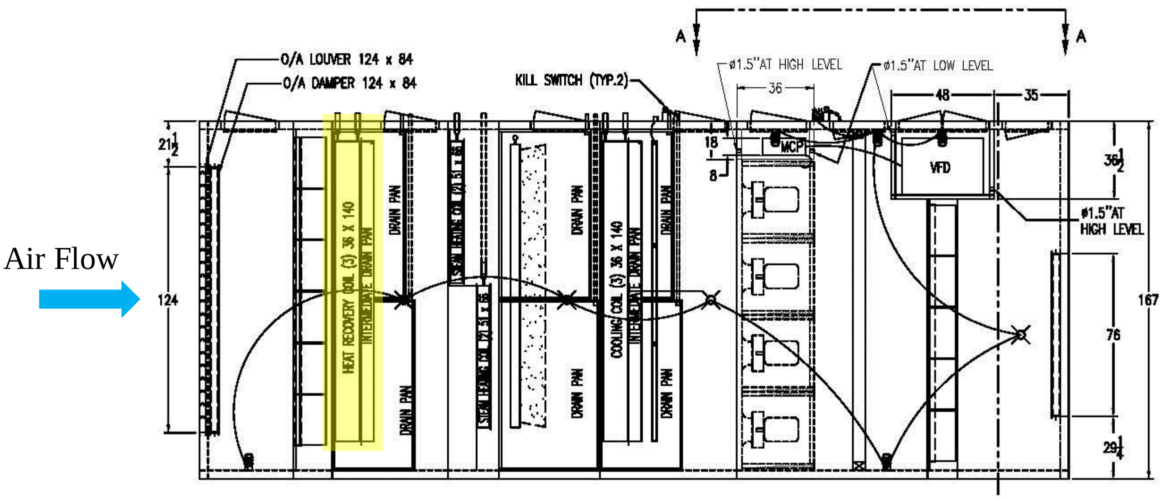


Figure 4 Typical Plan View of Air Handling Unit with Heat Recovery Coil

In order to estimate the amount of energy saved by the runaround heat recovery system some interesting tactics were used. The Trace model that was used to generate the data to estimate the base energy consumptions contained no heat recovery. To make sure that all of the conditions remained the same except for the addition of a heat recovery system an alternative model was created. The new alternative was duplicated from the first but the new system included a coil loop energy recovery setting. The specifics of the settings are listed below.

Type:	Coil Loop (outdoor air preconditioning)
Supply-side deck:	Ventilation upstream
Exhaust-side deck:	System exhaust

The monthly plant energy consumption was again exported from Trace and transcribed into excel in the same manner as before. See Appendix D for the constituent tables. Below in tables 7a and 7b are the summary results for the monthly energy consumption of the combustion gas turbine and the absorption chillers for each AHU.

Energy Consumption by Absorption Chiller WITH HR (BTU/hr)												
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
AHU 7	0	0	16,117	39,445,646	241,888,933	761,195,971	1,083,438,255	1,075,144,815	559,589,626	123,108,774	17,467,569	0
AHU 8	0	0	44,898	49,777,909	324,855,569	1,079,232,822	1,528,201,035	1,513,735,866	786,117,736	161,618,472	17,849,776	0
AHU 9	0	0	13,815	18,569,293	174,090,866	624,481,996	884,572,981	868,316,503	445,389,048	94,470,848	10,836,501	0
AHU 10	0	0	26,478	31,444,617	219,496,415	751,699,499	1,065,606,898	1,051,175,115	540,270,884	115,329,932	13,151,619	0
AHU 11	0	0	35,688	42,634,545	308,556,496	1,055,646,481	1,495,336,955	1,475,676,298	760,969,180	160,446,523	18,282,638	0
AHU 12	0	0	16,117	20,130,357	150,331,841	514,694,071	724,991,030	718,338,089	370,051,594	81,170,721	9,734,776	0
AHU 13	0	0	25,327	27,448,708	167,458,647	549,837,581	736,393,935	774,606,616	469,372,562	143,480,889	22,907,117	0
AHU 14	0	0	0	4,635,992	49,006,587	290,003,319	430,158,313	397,464,614	166,352,318	61,249,887	8,563,978	0
Total	0	0	178,440	234,087,067	1,635,685,354	5,626,791,741	7,948,699,401	7,874,457,916	4,098,112,947	940,876,045	118,793,974	0

Table 7a Energy Consumption by Absorption Chiller with Heat Recovery

Heating Monthly Consumption of GCT for Steam (BTU) Summary with HR												
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
AHU 7	940,650,375	840,809,375	680,337,875	541,271,500	507,535,000	463,653,750	467,268,375	475,196,750	476,654,500	553,260,750	582,341,375	780,178,875
AHU 8	958,515,250	818,645,625	736,520,750	670,163,375	666,593,375	614,307,750	621,789,875	628,870,375	623,827,750	668,378,375	659,200,500	798,207,375
AHU 9	565,517,750	476,401,625	438,782,750	400,211,875	395,262,963	360,436,125	363,411,125	368,557,875	367,323,250	395,689,875	391,777,750	472,340,750
AHU 10	666,638,000	568,106,000	513,291,625	467,015,500	458,521,875	414,878,625	416,128,125	422,048,375	421,869,875	458,283,875	454,743,625	553,573,125
AHU 11	1,014,356,000	854,658,000	760,871,125	687,924,125	679,281,750	620,510,625	625,449,125	634,210,500	633,243,625	685,083,000	678,865,250	835,722,125
AHU 12	489,090,000	410,564,875	364,154,875	328,469,750	316,287,125	279,025,250	277,403,875	284,633,125	291,490,500	326,074,875	328,960,625	404,451,250
AHU 13	517,248,375	440,181,000	388,639,125	350,291,375	343,523,250	310,798,250	311,928,750	316,644,125	319,470,375	343,017,500	347,033,750	427,819,875
AHU 14	327,874,750	256,965,625	211,477,875	179,600,750	182,650,125	170,571,625	174,290,375	175,703,500	173,769,750	182,679,875	179,853,625	248,903,375
Total	5,479,890,500	4,666,332,125	4,094,076,000	3,624,948,250	3,549,655,463	3,234,182,000	3,257,669,625	3,305,864,625	3,307,649,625	3,612,468,125	3,622,776,500	4,521,196,750

Table 7b Energy Consumption by Combustion Gas Turbine with Heat Recovery

Note that comparing the values in table 7a to tables 5a, some of the numbers are smaller and some are larger. This may seem counter intuitive because the heat recovery should be decreasing all of the loads. Upon further inspection it can be seen that for the Heating Monthly Consumption in all 12 months, the consumed energy is always lower with the heat recovery system.

One of the reasons for the increase in certain monthly cooling energy consumption is caused by the outside air temperature. During the spring and fall months the outside air temperature will be very close to the supply air set point, therefore requiring very little cooling energy for that month. However the heat recovery system is not temperature modulated and has the same temperature heat sink year round (the exhaust air). Therefore the heat recovery system heats the intake air thus requiring it to then be cooled back down.

Heating Natural Gas Cost Summary with HR		
Steam Energy Requirement (MMBTU)	Natural Gas Consumption (Therms)	Total Cost ($)
46,276.70	462,767	$91,512

Table 8a Natural Gas Cost of Building Heating with Heat Recovery

Table 8a is the summary of the natural gas consumption in MMBTU, Therms, and dollars. Here it is very clear that the heat recovery system is saving heating energy and reducing the amount of natural gas. Below in Table 8b is the summary of the cost for the absorption chiller. These numbers were found using the same method as used to define the baseline gas consumption previously.

Chilled Water Natural Gas “Cost” Summary with HR			
Chilled Water Energy Requirement (MMBTUH)	Natural Gas Consumption (MMBTUH)	Natural Gas Consumption (Therms)	Total Cost ($)
28,477.7	237,314	2,373,140	$466,914

Table 8b Natural Gas “Cost” of Building Chilled Water Cooling

The evaluation of the effectiveness of this system will be a little skewed at this point. Because the absorption chiller is running off essentially free energy, no alternative system will pay off unless it produces more energy without any increased capital or operation costs. This is why the natural gas “costs” where calculated, as a means of comparison. Although the dollar costs are sky high, the percent savings will be close. The calculations for the simple payback are skewed in favor of the system by reducing the number of years to pay off the additional investment. Although this may be the case, it still provides a relative means of comparison between systems.

The years to pay off were calculated for the runaround glycol heat recovery system. Using the simple payback equation $SPB = \frac{\Delta I_o}{S_o}$ where $\Delta I_o$is the additional capital investment and S_o is the first year savings, it was determined that it will take approximately 29 years to pay off. In other words, after 29 years, the savings in natural gas will pay for the additional capital investment. Table 9 below summarizes the calculation, note that the savings from heating and cooling must be added; this is because the heat recovery system has one capitol cost and two fuel cost benefits.

Simple Payback of Runaround Glycol Heat Recovery System												
NG Cost Heating No HR	NG Cost Heating with HR	NG Heating Cost Savings		NG Cost Cooling No HR	NG Cost Cooling with HR	NG Cooling Cost Savings		Total Cost Savings		Additional Capital Investment		Simple Payback (years)
$134,946	$91,512	$43,434		$476,779	$466,914	$9,865		$53,299		$1,233,000		23

Table 9 Simple Payback for Runaround Glycol Heat Recovery System

Because the payback is over 20 years, it would be more accurate to calculate a discounted payback; this method takes into account for inflation as well as the predicted change in future fuel costs. However, with the artificial cost of producing the chilled water, it would be pointless. The payback is not to be taken as a definite number but rather as a means to relatively compare systems.

Proposed Alternatives

While the University Medical Center already has a system to provide energy savings, it was a primary goal to attempt to further reduce energy consumption in one way or another. Many ideas were considered; each idea was then evaluated against the design objectives and requirements of Princeton Healthcare Systems. Although it is clear that some of the proposals could provide a large decrease in energy costs, if it was against one of the design objectives it was not pursued.

Economizer

A common way to reduce energy consumption for building HVAC systems is to reduce the amount of air that needs conditioning. This is sometimes done by implementing a dedicated outdoor air system, or reusing some of the exhaust air. By simply recirculating some of the building air that is already conditioned the energy costs can drop significantly, especially during the winter and summer months. It was determined using ASHRAE standard 62.2 that the max amount of ventilation air required for the hospital is less than 30%. By implementing an economizer, this system now becomes “smarter” and will adjust the amount of recirculated air between 0% and 70% to reduce the conditioning energy during the fall and spring. This system creates a very large health risk in that any contaminants or micro-organisms in the return air will be distributed through the rest of the rooms supplied by that air handler. Therefore this idea was not perused on grounds of not meeting the Princeton Healthcare Systems requirements to provide a healthy indoor environment.

Heat and Enthalpy Wheel

Another initial idea to decrease energy consumption is to implement a heat recovery wheel; this idea was dismissed because of a few minor issues. The wheel is benefitial because it not only transfers heat efficiently, but it can also transfers enthalpy. The first issue with this system deals with air contamination. The University Medical Center of Princeton is dedicated to providing the healthiest environment possible. Because of the mechanisms of a recovery wheel there is a possibility that contaminants in the exhaust air could leak into the intake. This presents a potential health risk for building occupants, especially from the exhaust air leaving imaging and operating rooms. The other downside to the recovery wheel is that there is a need for considerable duct work across the roof to allow the air flows to cross. Again this system does not comply with the design goals for the University Medical Center of Princeton and was not perused.

Water Source Heat Pump

A third alternative considered was a water source heat pump. Because of the Carnegie Lake nearby, it possible to use it as a source for chilled water either by pulling the cool lake water into the building or circulating a refrigerant and using the lake as a heat sink. The downside to this system is the location. The winter causes the lake to become very cold creating and creates a risk of freezing the equipment. Also the near freezing water would not be as useful in the winter when the outside air would need heated rather than cooled. This idea was thought to be impractical for the location, but in warmer climates this could prove to be very beneficial.

Ground Source Heat Pump

Energy conservation has been implemented with heat recovery units, an alternative could be ground source heat pumps. By implementing a series of deep wells on the 171 acre health care campus, it may be possible to supplement the energy consumption comparably to the heat recovery units. The benefits of the ground source heat pump are similar to the heat recovery units in that it will reduce the cooling energy needed in the summer and the heating energy in the winter. This system is very similar to the current heat recovery because it uses fluid in a closed loop system to put energy into or take out of the outside air. There is no increased risk of contamination and therefore meets the design objectives of the hospital. Also this system requires almost no change to the current air handler units. Because the ground source heat pump system uses a water refrigerant, the heat recovery coils already within the AHU can be reused.

I chose to evaluate the ground source heat pump alternative to the glycol heat recovery units. I feel that the GSHP will be the healthier and more practical of the other listed alternatives. I am also curious as to how the heat pump will compare the runaround energy recovery system (call it educational inquiry).

A few simple tasks will be performed to compare the ground source heat pump system to the current heat recovery system. First the GSHP system must be designed; this includes the following steps:

- Size the Heat Pumps and place them inside the building
- Size and Design the plumbing layout for the load side of the system
- Size and Design the well field

- Size circulation pumps and expansion tanks
- Provide appropriate power distribution equipment for heat pumps

After the system is designed it will be evaluated the same way the runaround heat recovery system was. The final result will again be a number of years expressing a simple payback.

Microsteam Power System

As an additional investigation, microsteam turbines will be considered. The central utility plant provides high pressure steam which must be reduced to a lower pressure for use in much of the building equipment. Currently this is accomplished with a number of pressure reducing valve stations. I will explore replacing these pressure reducing valve stations with Microsteam Power Systems by Carrier. These systems will take the 150 psi steam and reduce it to 15 psi by doing work. Each system is capable of producing around 275kW of electricity. This electricity will then be used to offset electricity usage of the building.

Ground Source Heat Pump System

The function of a ground source heat pump system is very simple when broken down into its parts. It is essential to have a decent understanding of how the system works before trying to create a functional design. Research was done by reading many helpful manuals and design booklets such as the McQuay Geothermal Heat Pump Design Manual.

Basics of a GSHP Design

The first part to understand is the source loop. This is what provides the heat sink for the heat pump. There are many types of source loop options such as a vertical well field, a horizontal well field, water surface, and even types of open water systems. As discussed earlier, a water surface closed loop system is not practical because of the freezing winter temperatures. An open loop system with ground water could be considered, but because of the size of the hospital a large amount of water would be needed and this could cause an environmental issues. Because of the large lot of land the hospital sits on a horizontal field would work very well. A vertical well field would also work, and would allow much of the land to be undisturbed and allow for additional development in the future.

The second and third parts go hand in hand into understanding the heat pump itself. There are a couple types of heat pumps and selecting the appropriate one for an application is very important. Understanding the load side (the third part) is essential in deciding which type of heat pump to choose. One type of heat pump is a water-to-air configuration; this is where the heat pump cools or heats the air using the water from the source loop. This type of system is very good when trying to move air directly into a space. Another version of this is a water-to-water heat pump. This is where the heat pump heats or cools water to be used in another piece of equipment process. Because the goal is to use the heat pump to provide hot or cold water to the air handling units for heating and cooling the air, it is logical to select a water-to-water heat pump.

Selecting a GSHP

To begin the design process the goal for the heating and cooling loads must be known. The goal is to replace the current heat recovery system; therefore it is best to determine the amount of energy savings provided by the current heat recovery system. This has already been done to determine the cost reduction for the runaround glycol system. The difference between the energy peak loads of the base system and then with the runaround heat recovery system is the energy savings of the recovery system. This was accomplished by finding the peak monthly load from tables 5a and 5b and subtracting the peak monthly values from 7a and 7b respectively. See table 10 below for the details.

Peak Heating and Cooling Savings from HR						
Heating Peak Load no HR (MBH)	Heating Peak Load with HR (MBH)	Peak Savings of HR (MBH)		Cooling Peak Load no HR (Tons)	Cooling Peak Load with HR (Tons)	Peak Savings of HR (Tons)
10,537	5,431	5,106		1,431	1,424	7

Table 10 Peak Savings from the use of the Heat Recovery System

These peak energy savings are the design loads to cover the heating and precooling effect of the runaround heat recovery system.

To size for the 7 ton cooling capacity, a small heat pump would work great. Using Carrier heat pumps a small 8 ton unit could be used. This unit has a load coil flow rate of 15 gpm. The source loop entering water temperature is 60°F and the leaving water temperature for the load side can range from 36 to 72°F. To integrate the heat pump into the existing coils, it must be determined that the water flow rates are similar and to get the same energy savings the water temperature must be the same or very close. An analysis of the current water flow data for the heat recovery units is summarized in table 11 below. This table gives the detailed coil data for the heat recovery coil such as water flow rate, entering and leaving water temperature, air flow rate, and surface area. This data was taken from the approved submittals for the construction process.

Heat Recovery Coil Details					
AHU	Water Flow Rate (gpm)	Winter Entering Water Temperature (^{o}F)	Summer Entering Water Temperature (^{o}F)	Air Flow Rate (CFM)	Face Area (SF)
7	123	61.1	82.2	46000	105
8	120	62.5	81.7	50000	116.25
9	101	58.6	83.1	35000	79.15
10	110	60.3	82.5	42000	95.81
11	121	61.2	82.2	50000	116.25
12	95	58.5	83.1	30000	70
13	95	58.5	83.1	30000	70
14	96	54.5	84.1	20000	48.75

Table 11 Heat Recovery Coil Data

The coils are connected in parallel; therefore the flow rates must be added to determine the total flow requirement. The total is 861 gpm. To determine the entering water temperature for the winter the maximum temperature is shown as 62.5^{o}F, the entering water temperature for the summer is the minimum of 81.7^{o}F.

Considering these design criteria it is determined that the leaving water temperature from the 8 ton heat pump would be adequate at 73^{o}F. However the load side flow rate of 15 gpm would not fulfill the flow rates needed to maintain the same 7 tons of peak load reduction. Therefore it is logical to begin to design for the flow rate. These calculations can be found in Appendix E along with the data sheet highlighting the selected heat pump.

The largest load side flow rate for the Carrier heat pumps is 70 gpm. This is still far from the desired 861gpm. Therefore, the simple solution is to use a number of these heat pumps in parallel. 861gpm divided by 70gpm per heat pump is 12.3 heat pumps. Therefore 13 heat pumps in parallel will suffice. The reason for choosing the largest flow rate is that the efficiency of the large tonnage heat pump is higher, and the higher the flow rate the more efficient. Following the calculations in Appendix E shows that 13 of these heat pumps will provide a peak load of 374.6 Tons. This results in 53 times more cooling energy.

On the heating side, the peak design value is 5,106 MBTUH. The heat output of the heat pump at 70 gpm load side with a leaving water temperature of 89.2^{o}F is 323 MTUH. This would require about 16 heat pumps. The decision was made to only use the 13 heat pumps to size for the flow rate and accept the increase in cooling and the decrease in heating.

Sizing the Ground Heat Exchanger

The next step is to size the ground source heat exchanger. By using the equation below the total length of vertical wells was determined.

$$L_c = q_{d\,cool}\left(\frac{\frac{COPc+1}{COPc}\,(Rp + Rs\;x\;Fc)}{(Tewt\max - Tgmax)}\right)$$

Again the calculation details are contained within Appendix E. Using the cooling capacity for one heat pump it is determined that 25,637 feet is required. This number may seem to be large for only 30 Tons of capacity. This is because the water temperature going into the ground is so close to the ground temperature. It is a basic understanding that the closer the temperatures the smaller the delta T and therefor slows the heat transfer rate. This means that to shed the same amount of energy over a smaller delta T the length of the heat exchanger must be much longer.

Because of the long ground heat exchanger it was advantageous to determine the amount of heating capacity capable with bypassing the heat pump. In order to do this, a very similar equation to the one above was used and solved for $q_{d\,heat}$. The details for this calculation are also shown in Appendix E. It is determined that the heating capacity is 8,008 MBTUH well over the goal of 5,106 MNBTUH. The entering water temperature would even be approximately 60^{o}F. The flow rate can be the same if the ground loop is sized for the 70 gpm flow rate on the source side.

To use the heat pump for cooling and only use the ground heat exchanger for the heating some system adjustments must be made. The basic idea is to bypass heat pumps for the heating season. This can be done by connecting the load loop and source loop together and using a specific layout of valves. To demonstrate this, a single line diagram was produced and can be seen in full in Appendix F but for quick reference is shown below in figure 5.

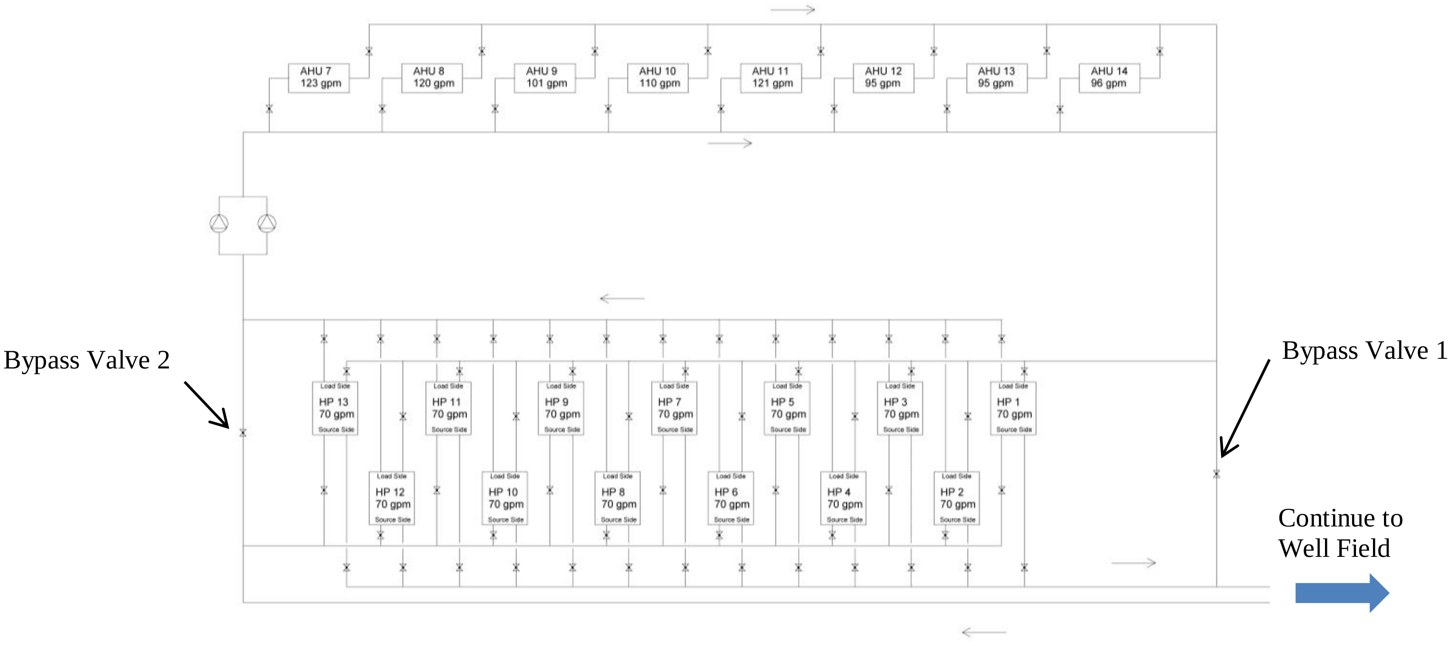


Figure 5 Single Line Diagram of Load Side and Heat Pump Configuration

Note how each AHU is in parallel and is therefore distributed with approximately equal temperature fluid. The heat pumps are also in parallel for both the source and load loops. Each piece of equipment is accompanied by a set of isolation valves. These valves provide a shut off point to all water entering and leaving for servicing or replacement procedures. There are two pumps shown in parallel as well, each pump is sized to meet the full system load as a redundancy measure.

During summer operation when the heat pumps are in used, the two bypass valves would remain closed. For the winter operation the bypass valves would be opened and each isolation valve for the heat pumps would be closed. This scheme would force the water flowing from the AHUs directly into the ground wells and then back into the AHUs. The main lines are 8 inch steel pipe, the lines feeding into each air handling unit are 4 inches, and the lines leading into each heat pump are 3 inch.

Room Layout

An important part of any building design is making sure that everything can fit within. That is also true with mechanical equipment. Because the heat pumps must be connected to a ground loop system and are not design to be outdoors it was decided to place them in a room on the lower level. Fortunately there was a vacant room on the eastern side of the building. A layout of the 13 heat pumps within this rooms with proper maintenance clearances was created in cad and can been seen both in figure 6 below and much larger in Appendix G.

Figure 6 Location of the Available Room and the Layout of the Heat Pumps within

Well Field Layout

Next the well field had to be laid out and the lines sized. Knowing that the total length of the wells needs to be 333,281feet and using a well depth of 300 feet there needs to be 1,111 wells. Using a 15 foot separation between well dictates and area of approximately a 500’ X 500’. Looking at the site map it was determined that the well field would not fit between the east side of the hospital and the existing road. The next best place is to extend the feeders from the building across the road and into a non-developed area. This diagram was too large to include within this portion of the report and can be viewed in Appendix G.

The next important step is to determine the path of the water through the well field. This became a bit tricky. It is common to have all the wells in parallel; this did not work well because of the large number of well required. Because the 900 gallons per minute would be split between 1,111 wells the total flow rate through each well would be about 0.8 gpm. This flow rate is so low that it would require a ¼ inch plastic pipe. This is undesirable because it drastically reduces the available surface area for heat transfer to the ground. Another option is to have all the wells in series. This would require an 8 inch plastic line to run through every well; this is also undesirable because of the increase cost for pipe as well as the increase radius needed. The solution is to have 101 sets of 11 wells in series. This means the 900 gpm is divided into 101 groups of wells each receiving 9gpm. This larger flow rate allows for a 1-1/2 inch plastic line to be used within the wells. This configuration though unusual not only provides the appropriate length of wells required but also helps to maximize the face area for heat transfer. Figure 7 below shows a small section of two set of 11 wells off the main feeder. A larger section of the field layout can be found in Appendix G.

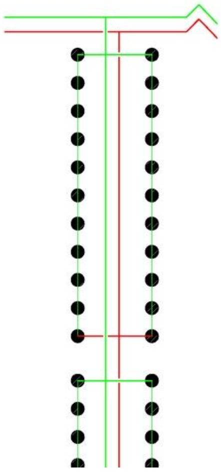


Figure 7 Two Set of Ground Wells in Series

The Green line is the supply and the red line is the return. The 11 wells are connected in series therefore the temperature drop from one well to the next will only be a fraction of the total temperature drop. It is estimated that the total delta T for this well field is 10^{o}F. This means that each well produces just under a one degree temperature difference.

Pump Sizing

Now that the major plumbing layout has been determined, the next step is to size the circulations pumps. The source loop and the load loop will each require its own circulation pump and must overcome any friction and flow resistance. To calculate this it must be understood that when equipment and piping is in parallel only the circuit with the largest head loss is considered; when the equipment and piping is in series the head loss of each piece must be added together. The detailed calculations for head loss are in Appendix H. Note that there is no account for elevation change. This is because this is a closed loop system and although there is a gravity force to be countered, it is done so by the weight of the water pushing back down on the other side of the loop.

A summary of the pump sizing criteria is shown in table 12. Note that the initial head loss does not account for the NPSHR. To determine the NPSHR an initial selection of a pump based off of the flow rate and system head loss must be made. Then using the information given on the pump curve the NPSHR will be known. Next, add the system head loss to the NPSHR and resize the pump. Also included in Appendix H are the pump curves used to size the Bell and Gossett pumps for both loops. An approximate system curve was drawn on the pump curve to find the approximate operating point of the system to ensure that the system will operate as intended.

Load Side Pump Criteria				Source Side Pump Criteria		
System Head Loss (ft)	Flow Rate (gpm)	NPSHR (ft)		System Head Loss (ft)	Flow Rate (gpm)	NPSHR (ft)
46.39	900	12		116	900	10

Table 12 Pump Sizing Criteria for Load Side and Source Side Hydronic Loops

Because the two loops are separate for the cooling season and one single loop during the winter, the pumps must work when in series. The two sets of pumps are design for the same water flow which is a good start. The next concern is that the net positive suction heat requirement is met. This is done by taking the head produced by the pump and subtracting the head loss from each component as the water flows through the system to the next pump. The remaining head must be equal to or larger than the NPSHR for the next pump. The math for this is shown in Appendix H.

For the load loop it was determined to use a Bell and Gossett 1510 Series 5BC with a 9 inch impeller. By sketching the system curve it is determined to operate at 925 gpm with around 17 HP with an efficacy between 82 and 83%.

For the source (ground heat exchanger) loop a Bell and Gossett 1510 Series 5G with a 12 inch impeller was selected. After sketching the system curve it is estimated to operate at 925 gpm with just under 40 HP and an efficiency of about 82.5%.

Expansion Tank Sizing

Because the fluid temperature within the hydronic system will be changing, it is essential to include an expansion tank. This tank helps regulate the pressure within the system by absorbing any excess water caused by thermal expansion. The size of a tank depends on two things; the volume of fluid and the change in temperature. For the load side loop a 14 gallon tank is required. For the source side loop it is recommended to use an 85 gallon tank. Because RSMeans did not have information on a single tank of this size, it was replaced with two 45 gallon tanks. The sizing calculations are shown in Appendix H.

Changing water temperatures

It was contemplated to change the water temperature of the water entering the coils for preheating and precooling. For the cooling capacity in the summer, it is better to maximize the efficiency of the heat pump. For the winter, it was investigated as to different possible temperatures. To accomplish this, the equation solver software EES was used.

The coil data above in table 11 was used with LMTD method of solving a cross flow heat exchanger to calculate the U value for each coil. The summary of these calculations can be found in Appendix I.

Using EES, a series of entering water temperatures were input and the exiting water temperature, exiting air temperature, and heat transfer rate were computed. The eNTU (efficiency Number of Transfer Units) method for cross flow heat exchangers was used for this calculation. The equations for heating and cooling are the same, but the hot and cold fluids are reversed; therefore it was easier to create two separate programing files. The coding used is also placed in Appendix I. To compare the entering water temperature and the approximate length of ground heat exchanger required, EES was coded to use the Lc equation listed previously. The resulting length is then divided by the heat transfer in BTUs to obtain a value in ft/BTU. This value was then plotted against the entering water temperature; as shown in figure 8 below.

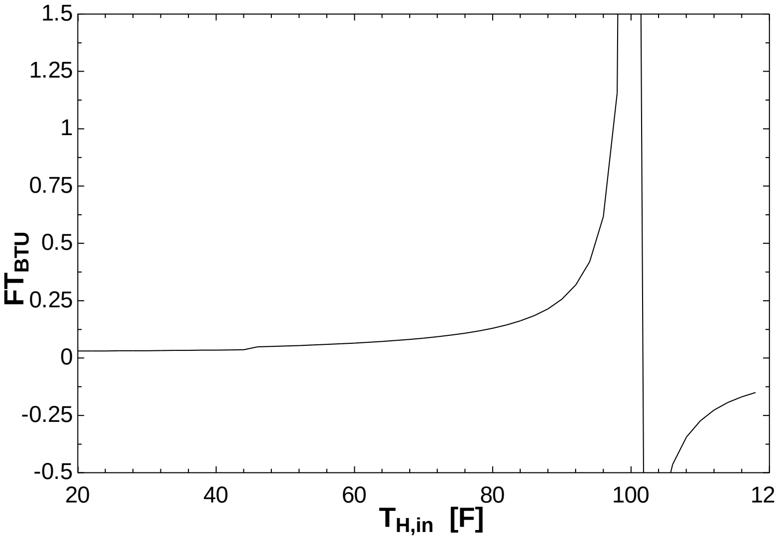


Figure 8 EES Plot of Feet of GHX Required for BTU of Energy Savings

The important thing to note is the fact that as the entering water temperature ($T_{h,in}$) approaches 95^{o}F the length of the heat exchanger asymptotes to infinity. The reason this asymptote appears at 95^{o}F becomes evident once the exiting water temperature is analyzed. When the entering water temperature rises, so does the exiting water temperature; as the exiting water temperature becomes closer to the ground temperature the delta T decreases and thus an infinitely long heat exchanger is required. After the asymptote, the feet per BTU become negative, this is because the exiting water temperature becomes hotter than the ground temperature and needs to be cooled rather than heated.

Based on this analysis, it is logical to want to provide the greatest amount of heating capacity (i.e. the highest entering water temperature) without needing an infinitely long ground heat exchanger. Using the ground water temperature of about 60^{o}F is therefore best. At this entering water temperature the heat exchanger needs only 0.065 ft/BTU. Above this temperature the length per BTU begins to grow exponentially.

The coding in EES was also used to calculate the annual energy savings of the alternative design. The 8760 temperature data was placed into a parametric table as the entering air temperature for the heat exchanger. To only calculate the heating capacity with an entering water temperature of 60^{o}F a condition was coded that for an entering air temperature of above the entering water temperature the heat transfer rate is equal to zero. This process was completed for air handing units 7-14 and the resulting heat transfer rates were compiled in Excel. Once in Excel, hour-by-hour heat transfer rates were totaled. Although the heat transfer rates are in BTU/hr, they are for a period of one hour. therefore by adding each of the hourly rates an annual energy savings is found. The compiled EES results in Excel are in Appendix I.

This process was repeated for the summer cooling. Because of the low outside air temperatures as compared to the entering water temperature, an error occurred with the NTU defining equations. This problem was averted by using Excel to replace any outside air temperatures below the entering water temperature with the entering water temperature. Then in the coding of EES, any entering air temperature equal to or below the entering water temperature was recorded as zero. Again the results for each air handling unit were compiled and summed in Excel to determine the annual energy savings. For the compiled results see Appendix I.

Using the 8760 temperature data in EES has another advantage. By setting the heat transfer to equal zero when it is assumed the heating and cooling will not be operating, it is very easy to find the hours of operation. Using Excel and coding it to count if a value is greater than zero the hours of operation are totaled. Knowing the hours of operation assists in better estimating the operating costs of the equipment.

A summary of the total annual heating energy savings, cooling energy savings, and hours of operation is shown below in table 13. Although there are 13 heat pumps with the potential to produce 30 tons of cooling capacity each; it is shown here that the peak cooling capacity is only 219 tons. One contributing factor to this is that the design cooling temperature is 93^{o}F and the max temperature of the 8760 data is 91^{o}F. Another possible reason for this is inaccuracies of the calculated U value.

Energy Savings of GSHP and GHX and hours of Operation						
Heating Capacity Peak (MBH)	Heating Capacity Annual Savings (MBH)	Heating Hours of Operation		Cooling Capacity Peak (Tons)	Cooling Capacity Annual Savings (Tons)	Hours of Operation
7,178.50	18,693,690	5,243		219	101,830	983

Table 13 Energy Savings of the New System Design and Hours of Operation of Both Systems

Energy and Cost Savings

All of the equipment for this system uses electricity. Therefore to calculate the energy consumption some equipment information must be known. Table 14 below summarizes all of the important information for the various pieces of equipment.

Energy Consumption Rates for Equipment		
Heat Pump Energy Consumption (kW)	20 HP Centrifugal Pump (kW)	40 HP Centrifugal Pump (kW)
14.26	14.92	29.84

Table 14 Energy Consumption Rates for GSHP and GHX Equipment

Using these values and multiplying them by the hours of operation reveals the total energy consumption in kilowatts hours. This number is then multiplied by the rate costs listed earlier. Table 15 shows the results for the annual energy costs for heating and cooling and the total annual cost. Details of these calculations are shown in Appendix J.

Annual Alternative System Costs		
Annual Preheating Cost of GHX	Annual Precooling Cost GSHP	Annual Energy Costs of GSHP and GHX
$9,858.78	$20,080.39	$29,939.17

Table 15 Annual Energy Costs of GSHP and GHX Equipment

These energy costs must be compared to the savings in natural gas for the base system. To calculate these savings the total energy savings will be converted to natural gas consumption savings and then to a dollar amount. Although the natural gas has a two-tier rate system; it is assumed that the natural gas reduction will not take away from the first 1000 therms consumed by the combustion gas turbine. See table 16 below for the calculation summary.

Alternative Heating Savings				Alternative Cooling Savings		
Heating Annual Savings (MBH)	Natural Gas Consumption Savings (Therms)	Natural Gas Cost Savings		Cooling Annual Savings (MBH)	Natural Gas Consumption Savings (Therms)	Natural Gas Cost Savings
18,693,690	333,816	$65,428		1,221,956	101,830	$19,959

Table 16 Annual Operating Cost Savings for Heating and Cooling

The annual total natural gas savings is $85,387. Therefore the total system savings to be used to calculate the payback will be the difference between the natural gas savings and the additional electrical cost. This difference is $55,448. For reasons mentioned earlier, this number is not to be taken as an actual savings value because the savings in natural gas for cooling is not accurate. For a reality check, assuming the absorption chiller is free to operate there is still a total annual savings because of the large reduction in heating energy.

Simple Payback of Alternative System

The final piece of the puzzle to calculate a simple payback is the capital investment required to install the new system. Not only does this system have the equipment already talked about, but it also includes changes in the power distribution system. However, the heat pumps require an additional power panel to be installed. The panel boards, feeders, circuit breakers, and branch circuit wires have all been sized for the electrical breadth. For calculation details refer to the discussion on the breadth in the following pages. The additional capital investment is calculated in detail in Appendix K.

Now that all the pieces are gathered a simple payback can be calculated. Table 17 below shows the calculation details for the simple payback. This again is not to be taken as an actual payback but a way to relatively compare systems.

Simple Payback for GSHP and GHX Alternative		
Total Cost Savings	Additional Capital Investment	Simple Payback (years)
$55,448	$6,359,695	115

Table 17 Simple Payback of Alternative System

The calculated simple payback is 115 years. Although the energy savings of the system is much higher, the cost of using electricity makes the annual dollar savings about the same. The additional capital investment is over five times more than the heat recovery system. This proves that the proposed alternative of a ground source heat pump with the bypass option is not a practical substitution for the runaround heat recovery system.

Final Thoughts

This investigation has proven to be very educational. The cost of operating electrical equipment is much higher than that for natural gas for New Jersey. Therefore it is most economical to get as much energy from natural gas as possible. Therefore generating electricity, steam, and chilled water from natural gas is the most efficient use of natural resources and money.

It was also discovered that although the runaround glycol heat recovery system may seem inefficient as compared to other energy recovery systems, it is much more economical than a ground source heat pump system. The major issue is the large capital investment in the heat pumps as well as the electrical demand to operate them.

Other thoughts

After analyzing this system a few other design ideas were thought of. The first was to decrease the capital investment by only providing a couple heat pumps in series to create a large temperature drop for only 70 gpm and mix it back into the 900 gpm system. This would provide a much lower energy savings but would decrease the capital investment costs, electrical costs, the length of ground heat exchanger, and pump sizes.

There was yet another idea for a hybrid system. Instead of using a heat pump to provide the cooling power during the summer months, use the runaround heat recovery. In the winter months use the ground heat exchanger loop. This system would likely have a greater payback than the single runaround system, but would be interesting to see the actual numbers.

Microsteam Power Turbine

The University Medical Center of Princeton has a high steam demand all year long. This is because steam is used for so many applications. The high pressure steam produced by the central utility plant is used for domestic hot water, sterilization, and humidification. The steam is also used to generate hot water for use in the air handling units and in the terminal reheat for the VAV and CAV boxes throughout the building.

High pressure steam is great to transfer a large amount of energy efficiently; however it is not good for all uses. To make the steam useful with other equipment, the pressure is reduced from 150psi to 15psi. This is currently done through four pressure reducing stations throughout the building. Each station is two stage with valves in parallel. This allows the pressure reducing valves to be sized to accommodate different flow requirements.

Work can be gained by reducing pressure. When steam (or air) pressure is reduced there is a loss of potential energy. With the pressure reducing valve stations this work is lost to the environment. As a way to conserve this lost energy the implementation of Carrier Microsteam Turbines was analyzed. The original idea was to place one microsteam turbine in place of two of the pressure reducing stations to supplement the utility electricity and therefore reduce the electrical consumption.

The Microsteam Turbine Sizing

Sizing a microsteam turbine is a short process and very straight forward. The first step is to determine the steam load of each pressure reducing station. The second step is to determine how much power will be generated and then integrate the turbine into the power distribution system.

While reading the design manual supplied by Carrier, a very important detail was discovered. Carrier recommends that the structure supporting the turbine be design to support 520 lb/ft^2. This is an uncommonly large value for a typical floor design load in a hospital. After a quick review of the structural design documents it was determined that the greatest design load for any of the elevated floors was 120 lb/ft^2. The basement however was designed to carry 275 lb/ft^2. Therefore it would not be logical to quadruple the structure to support a steam turbine. To get around this design problem it was decided to only place the turbines in the basement level mechanical room.

Table 18 below shows the design summary for selecting the microturbine for the basement level pressure reducing valve station (PRVS 1). Included in this table is the steam inlet and outlet pressure, the design flow rate, and steam temperature.

Microsteam Turbine Design Criteria			
Inlet Pressure (psi)	Outlet Pressure (psi)	Steam Flow Rate (lb/hr)	Steam Temperature (^oF)
150	15	41,400	365.87

Table 18 Pressure Reducing Valve Station 1 Design Data

To select the turbine from this point is very simple. Using the performance data sheet provided by Carrier and shown in Appendix L, select the inlet steam pressure of 150 psig, and inlet temperature of 366^{o}F (zero degrees of superheating), and the exhaust steam pressure of 15 pisg the steam requirement and the electricity generated are given. The required flow of steam for one turbine at these conditions is 11,150 lb/hr. This is just over a quarter of the actual flow rate. Although having an excess of flow would not cause any complications, it is possible to set these turbines in parallel to produce more power. It would not be logical to place 4 of these units because the flow rate given in table 18 is a peak design load which will not be required at all times. Instead it was decided to place 3 turbines in place of this PRV station giving a potential to generate 725 kilowatts of electricity.

Integrating into the Power Distribution System

There were two ideas of how to integrate the steam generated electricity into the power distribution system. The first proved to be very difficult and the second was much simpler and just as effective.

The first idea was to use paralleling switch gear to feed the generated electricity into the building and offset the power required from the utility. There are a few issues with this design. The first is the fact that paralleling switchgear is very complicated to understand and size. The other issue is that Princeton Healthcare Systems has entered an agreement to sell electricity back into the grid when the central utility plant is over generating. The power from the microsteam turbines may also need to be accounted for in the equipment to sell back to the grid and could cause complications in the contract.

The second idea is much simpler and has the same end effect. By using automatic transfer switches to take a load off the main power distribution system and place it on the microsteam turbine, the load on the power distribution system is decreased. Also, there is no paralleling switchgear needed. This is very similar to switching a load from normal to emergency power.

The microsteam turbines will be placed within the main mechanical room on the lower level in the patient towers. This is the same room that houses air handling units 1, 2 and 3. Table 19 below summarizes the electrical load demands of these three AHUs.

AHU Electrical Load Requirements						
Unit	**HP**	**kVA**	**FLA**	**Volt**	**Phase**	**kW**
AHU 1	12x10 = 120	130	156	480	3	191
AHU 2	9x7.5 = 67.5	80	96	480	3	118
AHU 3	12x7.5 = 90	103	124	480	3	152

Table 19 Electrical Load Design Requirements for AHU 1, 2, and 3

The horse power values were found on the submittal sheets for the air handling units, the others were calculated using the following equations.

$$3\ phase\ kVA = \frac{Volts * FLA * \sqrt{3}}{1000}$$

$$3\ phase\ watts = \sqrt{3} * Volts * FLA * PF$$

These air handling units do not have a single motor fan, but a wall of stacked fans that are tied together through electrical controls. The total horse power is the sum of all the horse power of all the fans. The full load amps (FLA) were determined using the NEC table 430.250. This table reports the full load amps based on the horse power of the motor.

It can be seen that each of the microsteam turbines has the potential to power one of these air handling units. Although the turbine can provide more power than required, to be certain the turbine can provide enough power for the fan startup it was decided to not add any other loads.

Tying into the existing power system

It was decided earlier to use an automatic transfer switch to take the AHU loads off the power distribution system and place them onto the turbine. Each air handling unit requires that a separate transfer switch be installed. Once the turbine is generating power at full capacity, the transfer switch will switch over to power the air handling unit. The specifics of the electrical design are discussed in more detail in the electrical breadth.

Energy Savings

Determining the annual energy savings would require more knowledge of steam demand on a monthly or even daily basis. If the steam flow rate through the turbine is not at or above the 11,150 lb/hr there will not be enough power to safely switch the load off the normal power distribution system. It can be assumed that at some points throughout the year that all three air handling units will be power solely by the turbines and therefore reducing the building peak load by 461 kilowatts.

Depth Summary

In summary, it is concluded that the runaround heat recovery system is more effective than a ground source heat pump system in reducing energy consumption and costs. Using the assumption that the central utility plant is using a combustion gas turbine to generate electricity and high pressure steam, and using the exhaust to power absorption chillers, the total energy efficiency is close to 91%. This is extremely difficult to compete against. The runaround propylene glycol system saves around $53,000 a year in natural gas costs, but costs around $1.3 million to install. This payback of 23 years is unpractical for most situations, but because of the simplicity of the system and the fact that this is for a hospital I would recommend it.

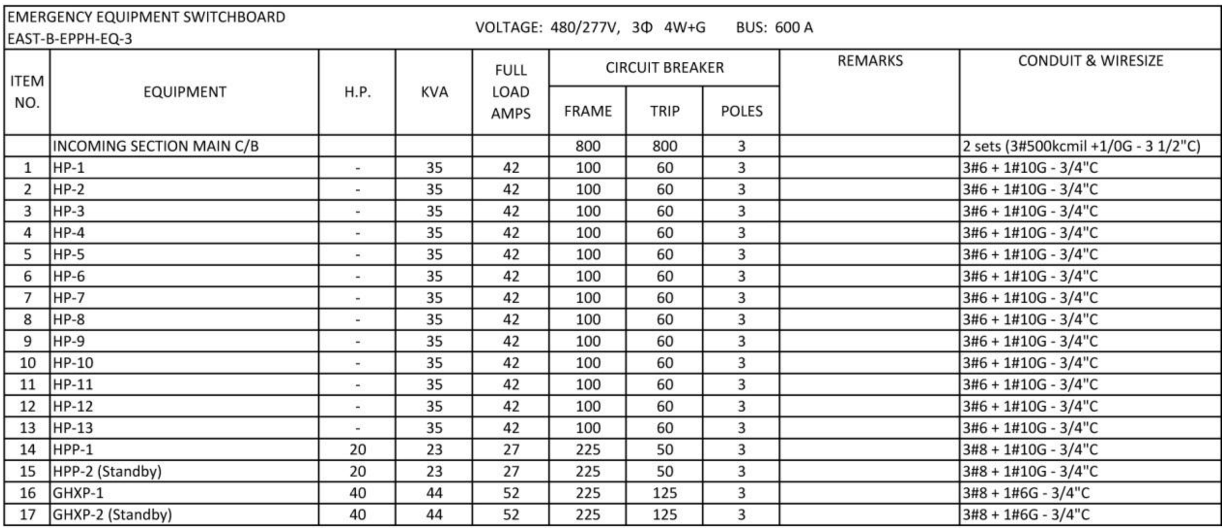
However the alternative system design is not as effective. Saving around $55,000 a year in natural gas costs is good, but the additional capital investment of around $6.4 million creates a payback of 115 years. This is unacceptable for any building investment. The equipment would need replaced multiple times during this time greatly increasing the payback period. Therefore, I would not recommend this alternative.

Even though there is not enough data to perform a simple payback, I would still recommend the installation of the Microsteam turbines. One of the design objectives of Princeton Healthcare Systems is to be environmentally conscious. These units do just that by making useful work of wasted energy. The savings of 461 kw of peak electricity during on season peak months could save up to $7,634 and $4,219 during off peak months. This is an interesting technology that I feel will continue to grow in applications where a large constant supply of steam is required such as hospitals.

Electrical Breadth

Because of the integration of the mechanical depth with the power distribution system it is essential to redesign the parts that were affected to better understand the implications of changing the mechanical system. This also proved effective in better estimating the capital investment cost for the ground source heat pump design.

The first step in designing a power distribution system is to determine the electrical loads. Table 20 is a section of the panel board schedule for the all of the heat pumps and water pumps for the ground source heat pump design described earlier; the full schedule can be seen in Appendix M.



EMERGENCY EQUIPMENT SWITCHBOARD
EAST-B-EPPH-EQ-3
VOLTAGE: 480/277V, 3Φ 4W+G BUS: 600 A

ITEM NO.	EQUIPMENT	H.P.	KVA	FULL LOAD AMPS	CIRCUIT BREAKER			REMARKS	CONDUIT & WIRESIZE
					FRAME	TRIP	POLES		
	INCOMING SECTION MAIN C/B				800	800	3		2 sets (3#500kcmil +1/0G - 3 1/2"C)
1	HP-1	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
2	HP-2	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
3	HP-3	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
4	HP-4	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
5	HP-5	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
6	HP-6	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
7	HP-7	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
8	HP-8	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
9	HP-9	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
10	HP-10	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
11	HP-11	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
12	HP-12	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
13	HP-13	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
14	HPP-1	20	23	27	225	50	3		3#8 + 1#10G - 3/4"C
15	HPP-2 (Standby)	20	23	27	225	50	3		3#8 + 1#10G - 3/4"C
16	GHXP-1	40	44	52	225	125	3		3#8 + 1#6G - 3/4"C
17	GHXP-2 (Standby)	40	44	52	225	125	3		3#8 + 1#6G - 3/4"C

Table 20 Sample of the Panel Board Schedule for the Ground Source Heat Pumps

The same equations listed earlier for 3 phase kVA and 3 phase watts was used to determine the size of the breaker as well as the branch circuit wire size. Tables 310.16 and C.1 of the 2008 NEC were used to size the wire and conduit respectively. The steps to complete the sizing are as follows:

- Determine the circuit breaker trip amperage
- Size the wire to meet the trip amperage of the breaker (and exception is made for motors: the breaker must cover start up current but the wire may be size for full load amps)
- Size the conduit based on the size and number of current carrying conductors
- Size the panel board for 25% growth
- Size the breaker supplying power to the panel board from the substation or distribution panel
- Size the feeder to the breaker on the substation or distribution panel

It was determined that the panel board must be 800 Amps based on the volt amp method. While analyzing the double-ended substation supplying power to the patient tower it was discovered that there was an 800 amp breaker open. Considering that the current heat recovery system was connected to emergency power, it was decided to connect the heat pumps to emergency power as well. To do this was a bit more complicated.

The integration of the microsteam turbines was very simple. The only change was to add an automatic transfer switch after the panel boards powering the air handling units.

Both of these changes are shown in the form of two drawings in Appendix M. Drawing E7.05 shows the integration of the changes in the riser diagram. This diagram helps the contractor to visualize what level the equipment goes as well as how the panel boards branch off the bus ducts. Drawing E7.02 is the single line diagram for the substations, distribution panels, and panel boards in the patient tower. Much like drawing E7.03, this drawing shows the integration of the panel boards into the breaker frames of the switch gear.

There are two emergency power distribution panels feeding the patient tower, each of these has room to expand. There was a 400 amp frame open and a 600 amp breaker on an 800 amp frame. By changing the 400 amp frame to 600 amps and moving the 600 amp to the new breaker it frees the 800 amp breaker. Doing so will only add 200 amps to the distribution panel and it was sized to handle up to 400 additional amps. This is shown in Appendix M as drawing E7.03.

The cost estimate for the electrical changes made for the ground source heat pump can be found in Appendix K as part of the mechanical depth. The cost estimate of the microsteam power distribution was not done because of the lack of other data to perform a reasonable energy savings value.

Acoustical Breadth

The acoustics in hospitals can play a vital role in a patient's health. A major complaint by both patients and medical staff is the noisy environments in hospitals. Research has been done relating the noise in patient and operating rooms to decreased patient care and recovery. High levels of background noise make patients uncomfortable and can retard their recovery. Medical nurses and doctors may have difficulty concentrating due to the noisy environment causing medical malpractice as well as missed auditory cues such as patient alarms. An acoustical analysis of the patients' rooms as well as nurse station and family respite was done to determine if the rooms were in compliance with national acoustics standards.

Current Conditions

To alleviate the complicated mess of predicting the noise level within the various spaces, a visit to the University Medical Center of Princeton was made. Fortunately on Friday March 16th the major construction and fit out of the hospital was completed; however the building had not been turned over and therefore was mostly vacant. This provided the perfect opportunity to obtain base level readings of only the background noise within the space generate by the mechanical system.

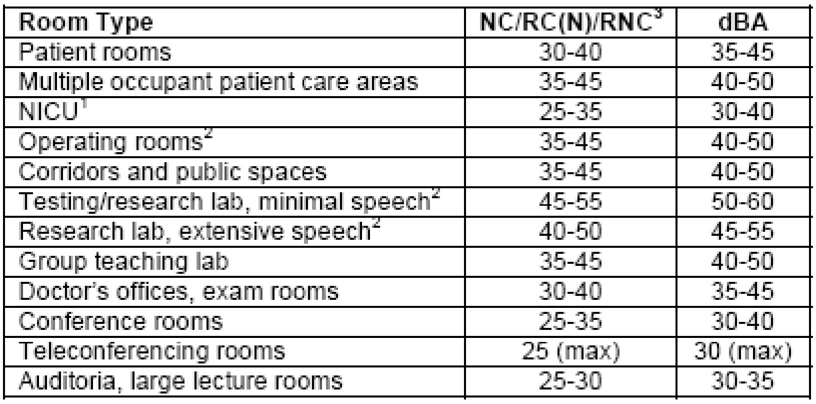
A sound level meter was used to measure the background noise in the space. Random rooms (approximately 2 on each patient floor) were selected to be analyzed. Once in these rooms the data in table 21 was recorded.

Acoustical Readings from Rooms						
Floor	**Room**	**Range**	**Response**	**dBA**	**dBC**	**File No.**
6	T.6104	LOW	SLOW	39	55	2-010
6	T.6210	LOW	SLOW	39	60	2-009
5	T.5156	LOW	SLOW	41	58	2-008
5	T.5108	LOW	SLOW	44	55	2-007
4	T.4242	LOW	SLOW	38	54	2-006
4	T.4112	LOW	SLOW	-	-	-
4	T.4158	LOW	SLOW	44	62	2-005
3	T.3208	LOW	SLOW	42	55	2-004
3	T.3135	LOW	SLOW	46	60	2-003
3	T.3111	LOW	SLOW	52	63	2-002
2	T.2112	LOW	SLOW	49	63	2-001
2	T.2208	LOW	SLOW	42	56	Crash
2	T.2022	LOW	SLOW	53	59	1-001

Table 21 Sound Level Meter Settings and Readings

The file numbers correspond to a recorded .wav file of the background noise in the room. These .wav files were then interpreted with a Matlab program written by Ryan TerMuelen. A calibration was recorded using the same recording set up to generate a relative base. The output of the Matlab coding was the Excel table shown in Appendix N. Using the .wav files Matlab calculated the dB level for each third octave band from 31.5 Hz to 8 kHz.

The dBA was then compared to the standards for hospital acoustics as listed in "Green Guide for Health Care: Acoustic Environment Technical Brief". In this brief there is more discussion about the health effects of a noisy healthcare environment as well as the design challenges. Figure 9 below was taken from the brief and expresses the design standards as defined by the American Institute of Architects and the American Hospital Association.



Room Type	NC/RC(N)/RNC[3]	dBA
Patient rooms	30-40	35-45
Multiple occupant patient care areas	35-45	40-50
NICU[1]	25-35	30-40
Operating rooms[2]	35-45	40-50
Corridors and public spaces	35-45	40-50
Testing/research lab, minimal speech[2]	45-55	50-60
Research lab, extensive speech[2]	40-50	45-55
Group teaching lab	35-45	40-50
Doctor's offices, exam rooms	30-40	35-45
Conference rooms	25-35	30-40
Teleconferencing rooms	25 (max)	30 (max)
Auditoria, large lecture rooms	25-30	30-35

Figure 9 2006 AIA/AHA Draft Interim Sound and Vibration Guidelines for Hospitals and Healthcare Facilities

By simply comparing the dBA values of the rooms to the guidelines only rooms 2022, 2112, 3111,and 3135 are not compliant. As another check the NC of each room was plotted using Excel. Graph 1 below shows the results. Notice that now only rooms 2022, 2112, and 3111 are not compliant.

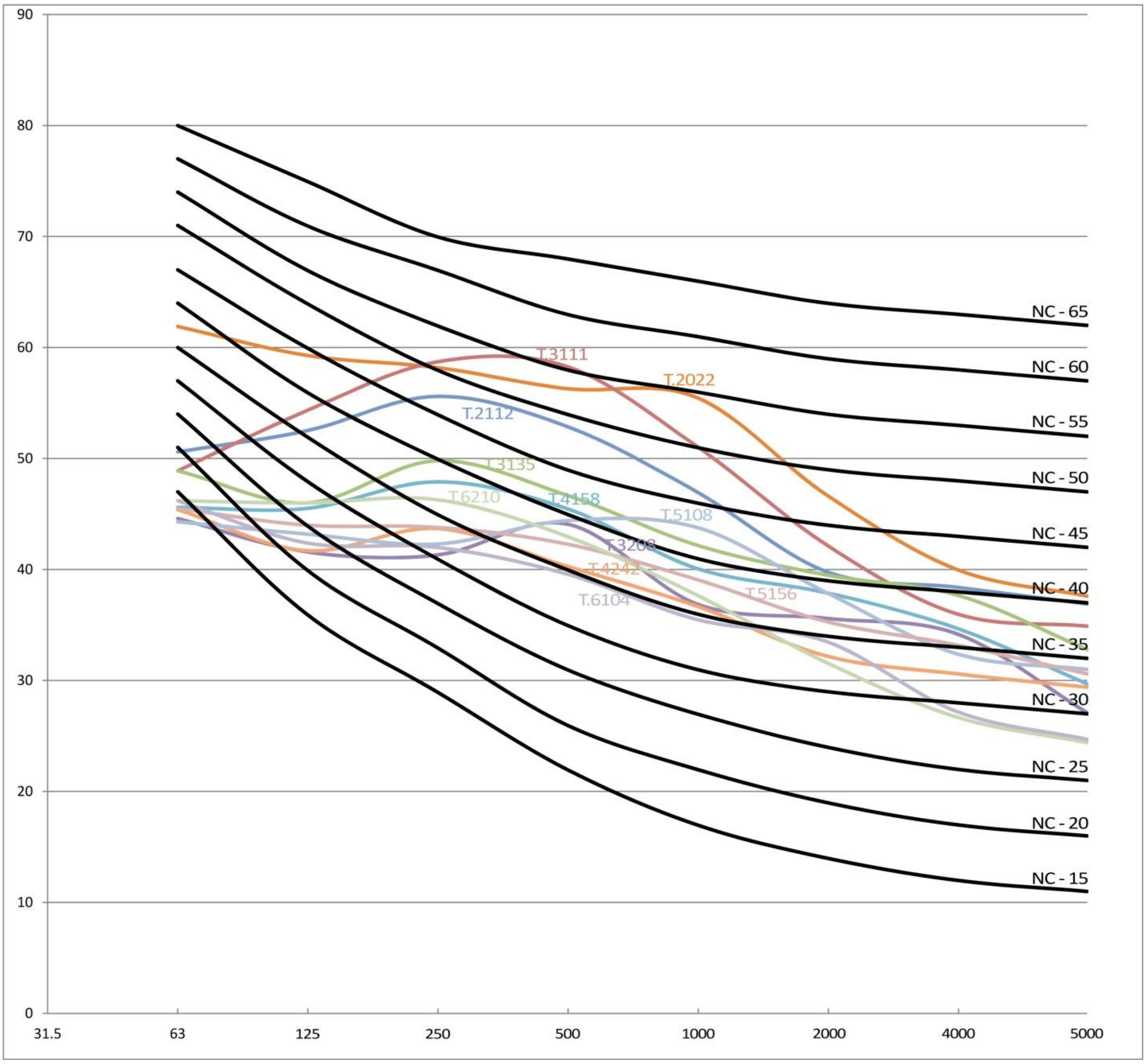


Figure 10 NC Plot for Each Room

Note that the family respite (room T.3111) is considered to be a corridor/public space and can have a higher NC and dBA than the patient rooms.

To calculate the amount of acoustically absorbent material required to drop the NC rating of the non-compliant rooms, a few other calculations must be done. The first equation is to calculate the total absorption in the room using the equation below.

$$A = 0.161\ V/T_{60}$$

Where A is the total absorption, V is the volume of the room, and T_{60} is the amount of time it takes for a sound impulse in the room to decay by 60 dB. To estimate the T_{60} an Excel spreadsheet was developed. The inputs of the program are the square footage of each material in the room, and the room volume. The materials are selected from a drop down list which extracts the absorption coefficients from a reference table. From that the T_{60} and total absorption A is estimated for each frequency band from 125-8000 Hz.

To determine the noise reduction in dBs the following equation was used.

$$NR = 10\log\left(\frac{A_2}{A_1}\right)$$

As the new room absorption A_2 decreases the log of the ratio becomes larger therefore giving a larger noise reduction value. The next step is to select a material to be used as an abortive panel within the patient rooms.

Material Selection

Selecting any material for inside a hospital can be very difficult. There are a lot of safety and manageability factors to consider. One of the major challenges with acoustically absorbent material is the fact that it is very porous. These materials provide wonderful hiding places for dirt and bacteria and are difficult to sterilize. That is why many surfaces in a hospital are very solid and acoustically reflective. Fortunately DuPont has taken this problem as a challenge and developed a product specifically for hospital applications.

DuPont has developed what they call AudioComfort Acoustical Panels. These panels come in different shapes and sizes that provide the most absorption in the 250 – 2000 Hz frequency bands. This matches very well with where the rooms are over the NC curves. See Figured 11 through 13.

The wonderful part about this product is that it is easy to clean. DuPont has made it a point to ensure that no common cleaning chemical will deteriorate the surface and that typical cleaning practices will disinfect the surface. The product brochure and data sheet are shown in Appendix N.

Noise Reduction Calculations

Using the same Excel program to calculate the T_{60}, an area of the AudioComfort panels was added and the same area was subtracted from the gypsum wall board area using the guess test and revise method. The Excel sheet then calculated the Noise Reduction and subtract it from the original noise levels exported from Matlab. These new dB levels were then checked against the NC curve values for compliance. As a second check the dBA was calculated manually using dB addition. The resulting required square footage of AudioComfort panels was then recorded for each non-compliant room.

A copy of the Excel sheet used for these calculations for room T.3111 is shown in Appendix N with data for room T.3111.

AudioComfort Panel Area Summary						
File Name	**Room Type**	**Compliant based on dBA**	**NC**	**Compliant based in NC**	**DuPont Panel Area Required to meet dBA compliance**	**Area of Dupont panel to meet dBA**
1-001 T.2022.wav	Staff Work	NO	55	NO	245	400
2-001 T.2112.wav	Hold Recovery Room	NO	48	NO	310	310
2-002 T.3111.wav	Family Respite	NO	56	NO	483	250
2-003 T.3135.wav	Critical Patient Room	NO	43	Yes	--	100
2-004 T.3208.wav	Intermediate Patient Room	Yes	39	Yes	--	--
2-005 T.4158.wav	Patient Room	Yes	41	Yes	--	--
2-006 T.4212.wav	Patient Room	Yes	36	Yes	--	--
2-007 T.5108.wav	Patient Room	Yes	43	Yes	--	--
2-008 T.5156.wav	Patient Room	Yes	38	Yes	--	--
2-009 T.6210.wav	Nursery Patient Room	Yes	38	Yes	--	--
2-010 T.6104.wav	Patient Room	Yes	35	Yes	--	--

Table 22 Summary of Results from DuPont AudioComfort Panel Area Calculations

A separate graph of the before and after room sound curves for each of the 3 NC non-compliant rooms are shown below as figures 11, 12, and 13. Note that the NC of a room is determined by the maximum NC curve touched by the room sound curve. The areas in red are the target problem frequencies.

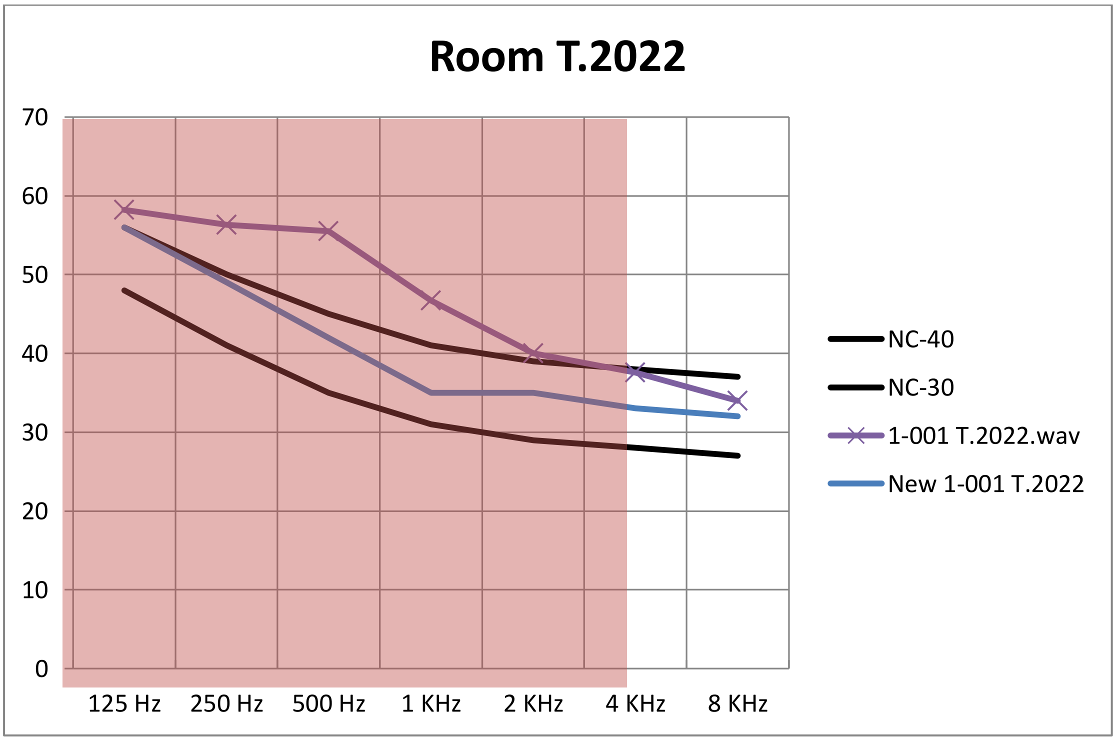


Figure 11 The Before and After Sound Curves against The 30 and 40 NC Curve Ratings for Room T.2022

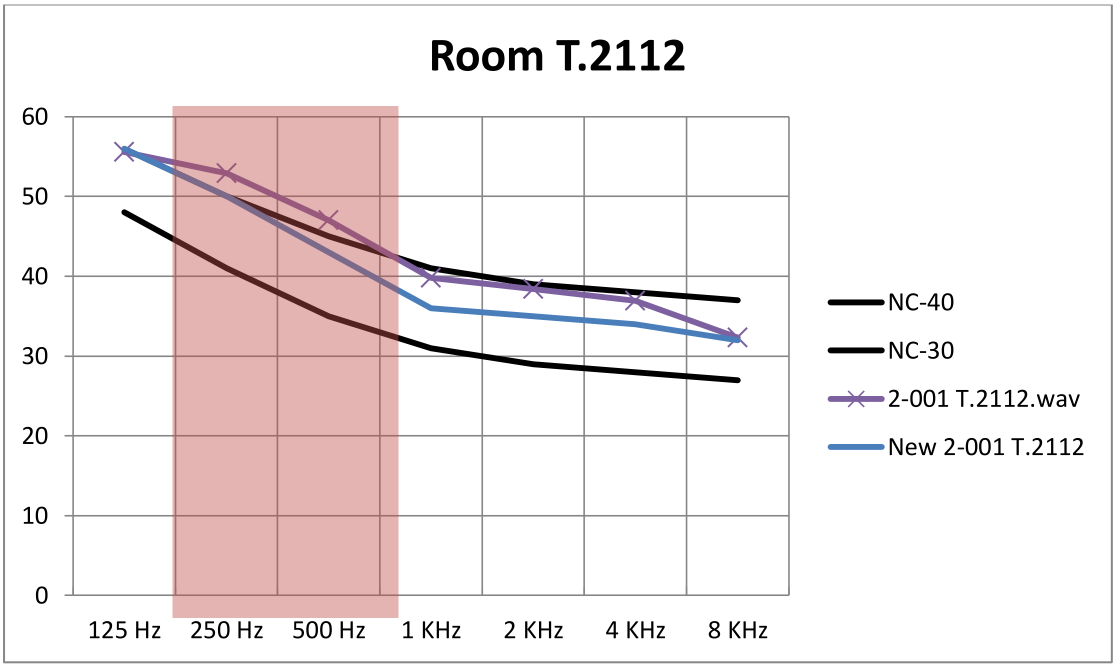


Figure 12 The Before and After Sound Curves against The 30 and 40 NC Curve Ratings for Room T.2112

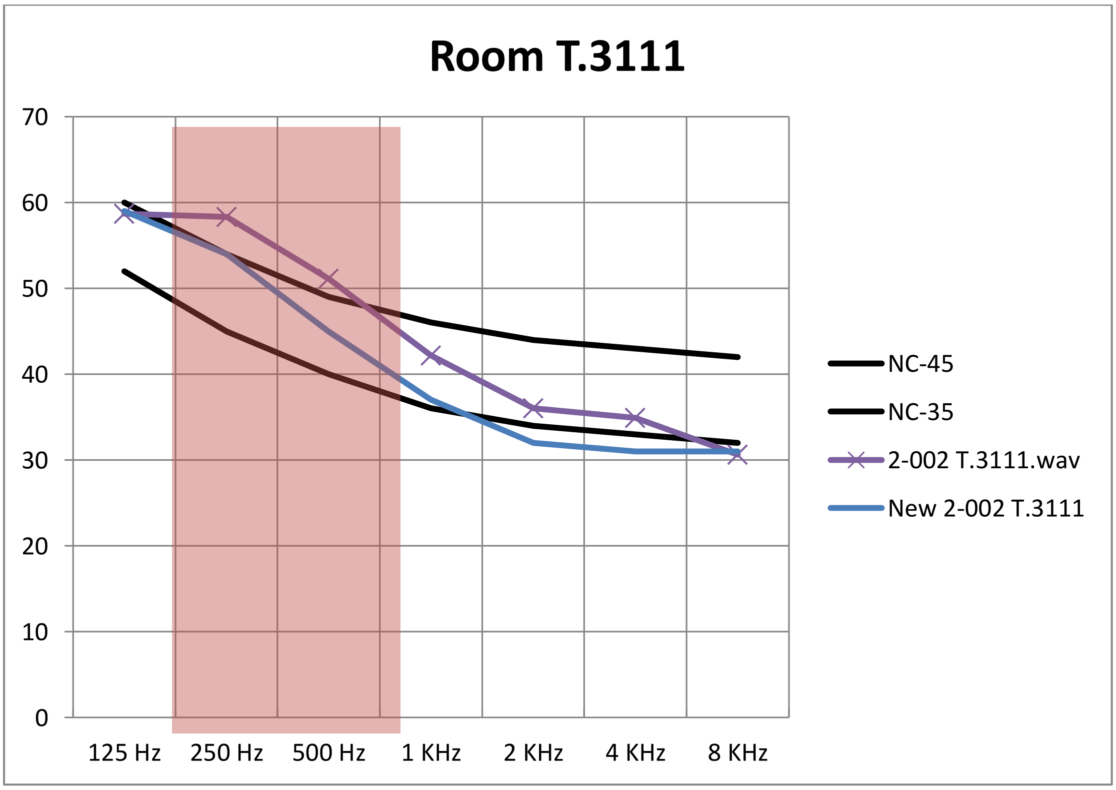


Figure 13 The Before and After Sound Curves against The 35 and 45 NC Curve Ratings for Room T.3111

The amount of AudioComfort panel needed to meet the NC requirement was sometimes different than that required for the dBA. This is because they are two different measurements; dBA is a single value calculated by adding or subtracting a certain dB value for each frequency and then using dB addition to find the single value. The NC rating requires that all dB levels of each frequency be equal to or less than specified values. Therefore it would be best to implement the larger area of the two.

Because some of the rooms would require such a large amount of the wall to be AudioComfort panels, some other options have been considered. Another way to reducing the background noise in a room created by the mechanical system is to install sound attenuators within the duct work. The mechanical plans for the University Medical Center of Princeton call for these to be installed in some locations but not all. Therefore a second look into the effectiveness of the current attenuator plan could be done to determine if more attenuators are needed or if there is a flaw in the in stallion or construction.

Another option is to change the ceiling tile material. Currently there are 2’x2’ acoustical ceiling tile. Every ceiling tile has a slightly different absorption coefficient and therefore specific tiles could be selected to bring the room into compliance.

Breadth Summary

After completing the electrical and acoustical breadth some important lessons were learned. The first lesson is how much a small change in one system can greatly affect that of another. No single system or components of a building can be designed without having to consider the affects it will have on the rest of the building. As and Architectural Engineer it is a prime responsibility to try to design a building to be as integrated as possible. The more a building’s systems are integrated, the more efficient the design, the more the building will reduce both capital and operation costs.

Electrical power distribution is a necessity for any building, because without power nothing would work. Therefore it is important that a building’s power system be properly design and given room for growth. By adding the 13 heat pumps the electrical demand increased and took some of the growth already designed into the system. If the heat pumps were being integrated as part of the original design it is very possible that the substation and emergency switchgear would have been sized larger.

Building acoustics is a very complicated subject. Being able to accurately predict how a room will perform acoustically is not straight forward and not reliable. The absorption coefficients for each material are measured in a testing lab with specific acoustical attributes and under specific conditions. These materials may perform differently once applied in a new situation with other materials. Therefore it is okay to be overly conservative during design to maximize the chance that the room will meet the various standards.

Acknowledgements

I would like to take this opportunity to thank all those who played a vital role in this project.

Turner Construction, for granting access to the drawings and information on this wonderful building.

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The rest of the AE faculty and staff and students.

References

ASHRAE (2007). Handbook – Fundamentals. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE (2007). Handbook – Applications. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Author. RSMeans mechanical cost data 2012. Norwell, MA: RSMeans, 2011.

Author. RSMeans Plumbing cost data, 2011. Kingston, MA: R.S. Means Co, 2010.

Davenny, Benjamin. Green Guide for Health Care Technical Brief: Acoustic Environment. 2007

Dept, Rsm. Heavy Construction Cost Data. City: R S Means Co, 2011.

HOK/RMJM Hillier – A Joint Venture. Architectural Construction Documents. HOK/RMJM Hillier. New York, NY and Princeton, NJ.

McQuay. Geothermal Heat Pump Design Manual. McQuay Air Conditioning. 2002.

National Fire Protection Association. NEC 2008. National Fire Protection Association. Massachusetts. 2008

Princeton Healthcare Systems. 2011. “New Hospital Project”. Website. November 2011. Princeton, NJ. < http://www.princetonhcs.org/default.aspx?p=8485>.

Statesupply.com

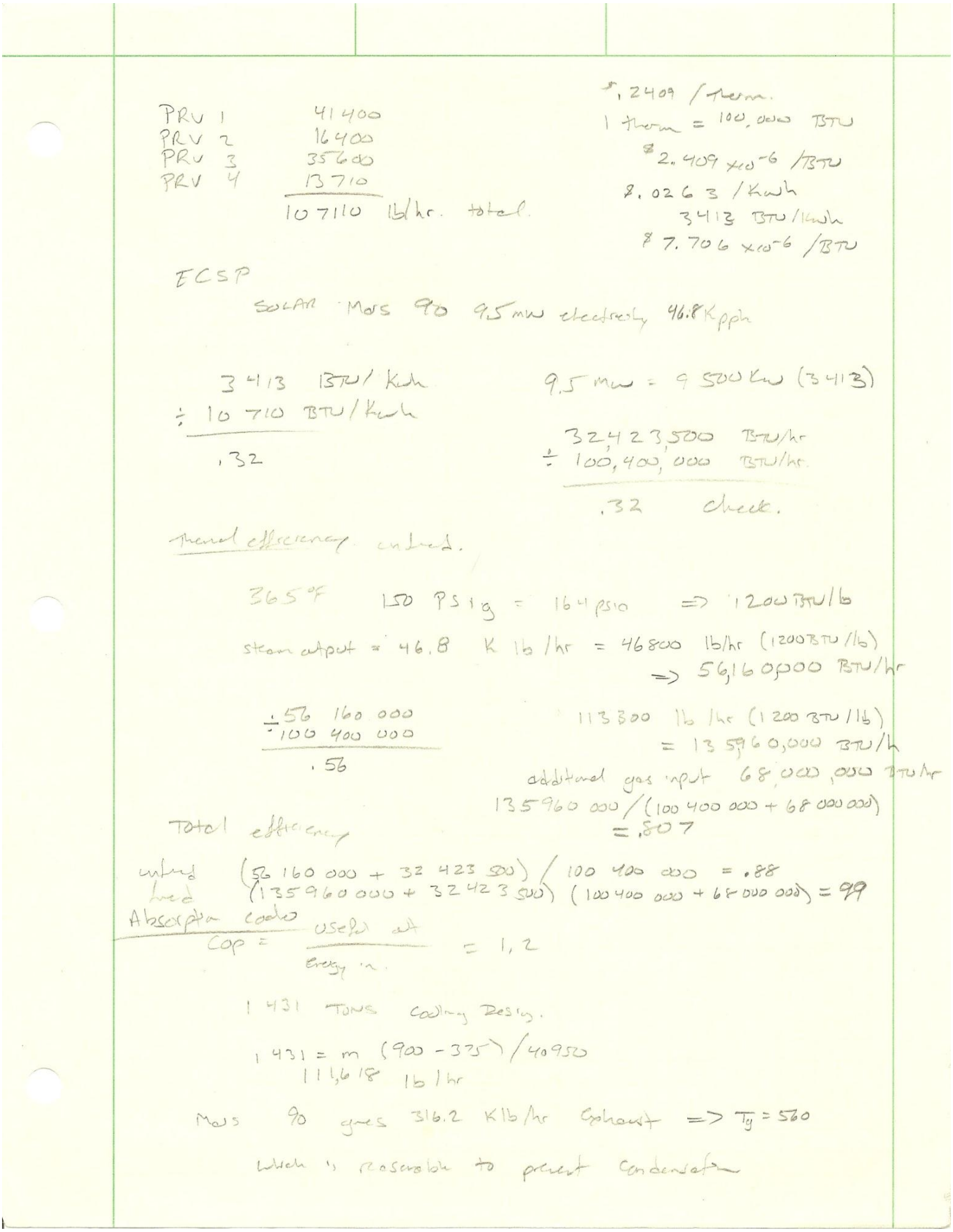
Syska Hennessy. 2009. MEP Construction Documents. Syska Hennessy. New York, NY. 2009.

Turner Construction. 2009. Turner Construction Corp. Mechanical Bid. Turner Construction Corp. New York, NY. 2009.

Qualityswitchgear.com

Appendix A

Combined Heat and Power Calculations and Assumptions



PRV 1	41400
PRV 2	16400
PRV 3	35600
PRV 4	13710
	107110 lb/hr. total.

$.2409 / therm.
1 therm = 100,000 BTU
$ 2.409×10^{-6} /BTU
$ .0263 / Kwh
3413 BTU/Kwh
$ 7.706×10^{-6} /BTU

ECSP

SOLAR Mars 90 9.5 mw electricity 46.8 Kpph

3413 BTU/Kwh
÷ 10 710 BTU/Kwh
.32

9.5 mw = 9 500 Kw (3413)
32,423,500 BTU/hr
÷ 100,400,000 BTU/hr
.32 check.

thermal efficiency unfired.

365°F 150 Psig = 164 psia => 1200 BTU/lb

steam output = 46.8 K lb/hr = 46800 lb/hr (1200 BTU/lb)
=> 56,160,000 BTU/hr

56 160 000
÷ 100 400 000
.56

113300 lb/hr (1200 BTU/lb)
= 135,960,000 BTU/h
additional gas input 68,000,000 BTU/hr
135 960 000 / (100 400 000 + 68 000 000)
= .807

Total efficiency

unfired (56 160 000 + 32 423 500) / 100 400 000 = .88
fired (135 960 000 + 32 423 500) (100 400 000 + 68 000 000) = 99

Absorption cooler

COP = useful out / Energy in = 1,2

1 431 TONS Cooling Design.

1 431 = m (900 − 375) / 40950
111,618 lb/hr

Mars 90 gives 316.2 Klb/hr exhaust => T_g = 560

which is reasonable to prevent condensation

Appendix B

Constituent Tables for Heating Energy Consumption and Peak Values

AHU 7 Monthly Heating Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	therms	2,536.5	2,041.3	1,533.6	1,002.2	672.0	619.8	628.1	634.4	632.9	764.4	976.4	1,996.1	14,037.7
	therms/hr	4.2	3.9	3.0	2.2	1.0	0.9	0.9	0.9	0.9	1.5	2.2	3.5	4.2
Level 3	therms	2,298.0	1,880.0	1,512.7	1,089.6	934.3	779.3	787.5	793.4	788.1	894.3	1,056.7	1,873.0	14,686.9
	therms/hr	3.8	3.5	2.8	2.2	1.7	1.2	1.2	1.2	1.2	1.6	2.1	3.2	3.8
Level 4	therms	1,850.0	1,509.7	1,203.0	854.8	637.0	574.8	578.8	587.2	589.4	695.3	831.7	1,501.3	11,413.0
	therms/hr	3.0	2.8	2.3	1.7	0.9	0.9	0.9	0.9	0.9	1.3	1.7	2.6	3.0
Level 5	therms	1,701.9	1,386.8	1,096.8	771.5	572.2	524.1	530.6	534.6	529.5	619.9	744.6	1,372.2	10,384.7
	therms/hr	2.8	2.6	2.1	1.6	0.8	0.8	0.8	0.8	0.8	1.2	1.5	2.4	2.8
Level 6	therms	2,285.0	2,369.1	1,578.1	928.4	728.4	673.0	667.2	673.3	681.0	1,029.4	1,255.4	1,952.0	14,820.3
	therms/hr	4.1	4.7	3.3	2.1	1.1	1.1	1.0	1.0	1.1	2.3	2.8	3.6	4.7
Monthly Totals therms		10,671.4	9,186.9	6,924.2	4,646.5	3,543.9	3,171.0	3,192.2	3,222.9	3,220.9	4,003.3	4,864.8	8,694.6	65,342.6
Monthly Peak therm/hr		17.9	17.5	13.5	9.8	5.5	4.9	4.8	4.8	4.9	7.9	10.3	15.3	17.9

Peak BTU/hr output (83.3% eff.)	1,491,070.0	1,457,750.0	1,124,550.0	816,340.0	458,150.0	408,170.0	399,840.0	399,840.0	408,170.0	658,070.0	857,990.0	1,274,490.0	1,491,070.0
Monthly Total Consumed by CGT for steam (BTU)	1,587,370,750	1,366,551,375	1,029,974,750	691,166,875	527,155,125	471,686,250	474,839,750	479,406,375	479,108,875	595,490,875	723,639,000	1,293,321,750	9,719,711,750

AHU 8 Monthly Heating Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	therms	3,661.4	2,967.2	2,293.0	1,563.4	1,134.4	1,077.9	1,103.0	1,101.8	1,073.3	1,239.9	1,515.7	2,918.1	21,649.1
	therms/hr	6.0	5.6	4.4	3.2	1.6	1.5	1.5	1.5	1.6	2.3	3.2	5.0	6.0
Level 3	therms	2,632.7	2,147.7	1,707.2	1,209.5	1,025.2	849.8	859.9	864.8	855.9	976.1	1,166.9	2,128.5	16,424.2
	therms/hr	4.3	4.0	3.2	2.4	1.9	1.3	1.2	1.3	1.3	1.8	2.4	3.7	4.3
Level 4	therms	2,423.6	1,965.3	1,524.6	1,047.2	743.1	663.8	664.5	670.5	670.4	809.3	1,002.0	1,934.3	14,118.6
	therms/hr	4.0	3.7	3.0	2.2	1.1	1.0	1.0	1.0	1.1	1.6	2.2	3.4	4.0
Level 5	therms	2,091.5	1,701.6	1,338.8	935.2	680.7	611.9	615.6	623.9	625.4	745.0	904.2	1,683.5	12,557.3
	therms/hr	3.5	3.2	2.5	1.9	1.0	0.9	0.9	0.9	1.0	1.4	1.9	2.9	3.5
Level 6	therms	3,082.5	3,188.7	2,165.0	1,326.6	1,090.4	1,026.8	1,033.8	1,032.4	1,017.0	1,447.1	1,729.6	2,642.9	20,782.8
	therms/hr	5.5	6.2	4.5	2.9	1.6	1.5	1.5	1.5	1.6	3.2	3.8	4.9	6.2
Monthly Totals therms		13,891.7	11,970.5	9,028.6	6,081.9	4,673.8	4,230.2	4,276.8	4,293.4	4,242.0	5,217.4	6,318.4	11,307.3	85,532.0
Monthly Peak therm/hr		23.3	22.7	17.6	12.6	7.2	6.2	6.1	6.2	6.6	10.3	13.5	19.9	23.3

Peak BTU/hr output (83.3% eff.)	1,940,890.0	1,890,910.0	1,466,080.0	1,049,580.0	599,760.0	516,460.0	508,130.0	516,460.0	549,780.0	857,990.0	1,124,550.0	1,657,670.0	1,940,890.0
Monthly Total Consumed by CGT for steam (BTU)	2,066,390,375	1,780,611,875	1,343,004,250	904,682,625	695,227,750	629,242,250	636,174,000	638,643,250	630,997,500	776,088,250	939,862,000	1,681,960,875	12,722,885,000

AHU 9 Monthly Heating Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	therms	1,754.5	1,407.3	1,040.8	665.5	436.6	412.4	420.8	419.6	408.9	491.3	640.1	1,366.8	9,464.6
	therms/hr	2.9	2.7	2.1	1.5	0.6	0.6	0.6	0.6	0.6	1.0	1.5	2.4	2.9
Level 3	therms	1,512.3	1,234.9	985.9	704.3	599.2	488.4	489.5	492.6	490.8	562.5	674.2	1,225.3	9,459.9
	therms/hr	2.5	2.3	1.9	1.4	1.1	0.8	0.7	0.7	0.8	1.1	1.4	2.1	2.5
Level 4	therms	2,563.1	2,111.2	1,744.4	1,297.8	1,038.3	965.4	981.8	986.3	970.6	1,101.8	1,263.0	2,119.3	17,143.0
	therms/hr	4.1	3.9	3.2	2.5	1.5	1.4	1.4	1.4	1.4	1.9	2.5	3.6	4.1
Level 5	therms	1,361.7	1,105.8	864.0	598.5	426.6	375.8	374.7	380.9	385.6	468.5	576.4	1,092.2	8,010.7
	therms/hr	2.3	2.1	1.7	1.3	0.6	0.6	0.6	0.6	0.6	0.9	1.2	1.9	2.3
Level 6	therms	919.9	962.2	621.4	344.2	253.7	228.4	220.0	219.2	222.8	378.0	478.7	777.4	5,625.9
	therms/hr	1.7	1.9	1.4	0.9	0.4	0.4	0.4	0.4	0.4	0.9	1.2	1.5	1.9
Monthly Totals therms		8,111.5	6,821.4	5,256.5	3,610.3	2,754.4	2,470.4	2,486.8	2,498.6	2,478.7	3,002.1	3,632.4	6,581.0	49,704.1
Monthly Peak therm/hr		13.5	12.9	10.3	7.6	4.2	3.8	3.7	3.7	3.8	5.8	7.8	11.5	13.5

Peak BTU/hr output (83.3% eff.)	1,124,550.0	1,074,570.0	857,990.0	633,080.0	349,860.0	316,540.0	308,210.0	308,210.0	316,540.0	483,140.0	649,740.0	957,950.0	1,124,550.0
Monthly Total Consumed by CGT for steam (BTU)	1,206,585,625	1,014,683,250	781,904,375	537,032,125	409,717,000	367,472,000	369,911,500	371,666,750	368,706,625	446,562,375	540,319,500	978,923,750	7,393,484,875

AHU 10 Monthly Heating Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	therms	1,751.2	1,409.5	1,060.5	696.0	462.3	411.9	410.6	414.9	418.9	520.3	670.2	1,377.7	9,604.0
	therms/hr	2.9	2.7	2.1	1.5	0.7	0.7	0.6	0.6	0.7	1.1	1.5	2.4	2.9
Level 3	therms	2,248.0	1,839.6	1,479.8	1,066.5	917.3	767.0	775.3	776.6	764.8	865.7	1,022.9	1,827.4	14,350.9
	therms/hr	3.7	3.4	2.8	2.1	1.6	1.1	1.1	1.1	1.2	1.6	2.1	3.1	3.7
Level 4	therms	1,990.7	1,624.1	1,290.8	916.3	683.5	618.8	622.5	625.5	619.9	730.1	876.5	1,608.0	12,206.7
	therms/hr	3.3	3.0	2.4	1.9	1.0	0.9	0.9	0.9	1.0	1.4	1.8	2.8	3.3
Level 5	therms	1,928.4	1,569.2	1,234.0	862.8	631.8	573.3	577.6	581.3	576.6	681.9	827.3	1,549.4	11,593.6
	therms/hr	3.2	3.0	2.4	1.8	0.9	0.9	0.9	0.9	0.9	1.3	1.7	2.7	3.2
Level 6	therms	1,740.5	1,819.0	1,181.7	666.6	505.3	461.3	449.5	448.4	452.4	732.0	915.6	1,472.9	10,845.2
	therms/hr	3.2	3.6	2.6	1.6	0.8	0.7	0.7	0.7	0.8	1.8	2.2	2.8	3.6
Monthly Totals therms		9,658.8	8,261.4	6,246.8	4,208.2	3,200.2	2,832.3	2,835.5	2,846.7	2,832.6	3,530.0	4,312.5	7,835.4	58,600.4
Monthly Peak therm/hr		16.3	15.7	12.3	8.9	5.0	4.3	4.2	4.2	4.6	7.2	9.3	13.8	16.3

Peak BTU/hr output (83.3% eff.)	1,357,790.0	1,307,810.0	1,024,590.0	741,370.0	416,500.0	358,190.0	349,860.0	349,860.0	383,180.0	599,760.0	774,690.0	1,149,540.0	1,357,790.0
Monthly Total Consumed by CGT for steam (BTU)	1,436,746,500	1,228,883,250	929,211,500	625,969,750	476,029,750	421,304,625	421,780,625	423,451,088	421,349,250	525,087,500	641,484,375	1,165,515,750	8,716,813,963

AHU 11 Monthly Heating Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	therms	2,218.4	1,782.8	1,331.7	865.1	568.4	511.6	511.7	515.3	516.5	640.2	831.7	1,738.5	12,031.9
	therms/hr	3.7	3.4	2.7	1.9	0.8	0.8	0.8	0.8	0.8	1.3	1.9	3.1	3.7
Level 3	therms	2,879.0	2,351.4	1,879.1	1,343.5	1,147.7	950.7	958.8	962.0	951.3	1,083.7	1,291.3	2,334.4	18,132.9
	therms/hr	4.7	4.4	3.5	2.7	2.1	1.4	1.4	1.4	1.5	2.0	2.7	4.0	4.7
Level 4	therms	4,041.6	3,320.3	2,713.5	1,990.6	1,570.0	1,465.5	1,493.5	1,499.2	1,471.7	1,672.1	1,933.5	3,318.7	26,490.2
	therms/hr	6.5	6.1	4.9	3.8	2.2	2.1	2.1	2.1	2.2	2.9	3.8	5.6	6.5
Level 5	therms	2,707.7	2,208.4	1,753.7	1,238.7	920.4	837.8	847.7	858.0	854.9	1,003.0	1,200.4	2,189.3	16,620.0
	therms/hr	4.4	4.1	3.3	1.5	1.3	1.3	1.2	1.3	1.3	1.8	2.5	3.8	4.4
Level 6	therms	2,341.5	2,446.3	1,584.6	889.0	671.1	613.5	599.6	600.2	606.1	981.4	1,229.8	1,981.1	14,544.2
	therms/hr	4.3	4.9	3.4	2.2	1.1	1.0	1.0	1.0	1.0	2.4	2.9	3.8	4.9
Monthly Totals therms		14,188.2	12,109.2	9,262.6	6,326.9	4,877.6	4,379.1	4,411.3	4,434.7	4,400.5	5,380.4	6,486.7	11,562.0	87,819.2
Monthly Peak therm/hr		23.6	22.9	17.8	12.1	7.5	6.6	6.5	6.6	6.8	10.4	13.8	20.3	23.6

Peak BTU/hr output (83.3% eff.)	1,965,880.0	1,907,570.0	1,482,740.0	1,007,930.0	624,750.0	549,780.0	541,450.0	549,780.0	566,440.0	866,320.0	1,149,540.0	1,690,990.0	1,965,880.0
Monthly Total Consumed by CGT for steam (BTU)	2,110,494,750	1,801,243,500	1,377,811,750	941,126,375	725,543,000	651,391,125	656,180,875	659,661,625	654,574,375	800,334,500	964,896,625	1,719,847,500	13,063,106,000

AHU 12 Monthly Heating Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	therms	1,309.4	1,049.0	775.9	494.6	307.7	263.7	260.3	267.6	278.8	362.1	480.8	1,023.1	6,873.0
	therms/hr	2.2	2.0	1.6	1.1	0.5	0.4	0.4	0.4	0.5	0.8	1.1	1.8	2.2
Level 3	therms	1,765.9	1,441.6	1,153.5	823.0	697.3	568.4	571.3	581.1	586.5	674.4	804.4	1,437.5	11,104.9
	therms/hr	2.9	2.7	2.2	1.7	1.3	0.9	0.9	0.9	0.9	1.3	1.6	2.5	2.9
Level 4	therms	1,490.0	1,213.3	958.7	673.6	491.3	436.4	437.2	444.1	447.6	536.7	650.2	1,201.9	8,981.0
	therms/hr	2.5	2.3	1.8	1.4	0.7	0.7	0.7	0.7	0.7	1.0	1.4	2.1	2.5
Level 5	therms	1,487.3	1,211.9	961.9	678.6	498.0	443.0	444.8	453.7	459.2	549.1	660.9	1,204.3	9,052.7
	therms/hr	2.5	2.3	1.8	1.4	0.7	0.7	0.7	0.7	0.7	1.0	1.4	2.1	2.5
Level 6	therms	1,002.5	1,047.0	670.2	360.2	254.7	224.7	210.8	213.7	226.3	404.6	519.0	847.3	5,981.0
	therms/hr	1.9	2.1	1.5	0.9	0.5	0.4	0.4	0.4	0.4	1.0	1.3	1.6	2.1
Monthly Totals therms		7,055.1	5,962.8	4,520.2	3,030.0	2,249.0	1,936.2	1,924.4	1,960.2	1,998.4	2,526.9	3,115.3	5,714.1	41,992.6
Monthly Peak therm/hr		12.0	11.4	8.9	6.5	3.7	3.1	3.1	3.1	3.2	5.1	6.8	10.1	12.0

Peak BTU/hr output (83.3% eff.)	999,600.0	949,620.0	741,370.0	541,450.0	308,210.0	258,230.0	258,230.0	258,230.0	266,560.0	424,830.0	566,440.0	841,330.0	999,600.0
Monthly Total Consumed by CGT for steam (BTU)	1,049,446,125	886,966,500	672,379,750	450,712,500	334,538,750	288,009,750	286,254,500	291,579,750	297,262,000	375,876,375	463,400,875	849,972,375	6,246,399,250

AHU 13 Monthly Heating Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	therms	1,344.4	1,083.5	820.5	542.8	364.4	324.1	323.6	328.8	333.8	413.1	526.8	1,062.3	7,468.1
	therms/hr	2.2	2.1	1.6	1.2	0.5	0.5	0.5	0.5	0.5	0.8	1.2	1.9	2.2
Level 3	therms	1,597.6	1,306.1	1,047.8	751.8	642.6	532.4	537.2	540.9	536.9	611.1	725.1	1,298.4	10,127.9
	therms/hr	2.6	2.4	2.0	1.5	1.2	0.8	0.8	0.8	0.8	1.1	1.5	2.2	2.6
Level 4	therms	1,311.6	1,072.1	860.1	616.8	464.0	416.8	419.0	424.5	425.6	502.3	597.3	1,067.3	8,177.4
	therms/hr	2.2	2.0	1.6	1.2	0.7	0.7	0.6	0.6	0.7	0.9	1.2	1.8	2.2
Level 5	therms	1,367.0	1,114.9	886.4	627.9	466.4	421.2	424.3	429.8	430.1	507.9	608.8	1,107.0	8,391.7
	therms/hr	2.3	2.1	1.7	1.3	0.7	0.7	0.6	0.6	0.7	0.9	1.3	1.9	2.3
Level 6	therms	1,648.9	1,714.1	1,137.0	671.2	536.3	502.4	503.9	503.8	498.5	737.4	897.7	1,404.4	10,755.6
	therms/hr	3.0	3.4	2.4	1.5	0.8	0.8	0.7	0.8	0.8	1.7	2.1	2.6	3.4
Monthly Totals therms		7,269.5	6,290.7	4,751.8	3,210.5	2,473.7	2,196.9	2,204.9	2,222.3	2,224.6	2,694.0	3,254.8	5,939.4	44,733.1
Monthly Peak therm/hr		12.3	12.0	9.3	6.7	3.9	3.5	3.3	3.3	3.4	5.2	6.9	10.4	12.3

Peak BTU/hr output (83.3% eff.)	1,024,590.0	999,600.0	774,690.0	558,110.0	324,870.0	291,550.0	274,890.0	274,890.0	283,220.0	433,160.0	574,770.0	866,320.0	1,024,590.0
Monthly Total Consumed by CGT for steam (BTU)	1,081,338,125	935,741,625	706,830,250	477,561,875	367,962,875	326,788,875	327,978,875	330,567,125	330,909,250	400,732,500	484,151,500	883,485,750	6,654,048,625

AHU 14 Monthly Heating Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	therms	4,583.7	3,688.8	2,768.5	1,816.8	1,450.1	1,184.2	1,210.4	1,220.1	1,206.1	1,404.2	1,769.5	3,600.2	25,902.6
	therms/hr	7.6	7.0	5.4	3.9	2.8	1.7	1.7	1.7	1.8	2.7	3.9	6.3	7.6
Level 2	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 3	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 4	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 5	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 6	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monthly Totals therms		4,583.7	3,688.8	2,768.5	1,816.8	1,450.1	1,184.2	1,210.4	1,220.1	1,206.1	1,404.2	1,769.5	3,600.2	25,902.6
Monthly Peak therm/hr		7.6	7.0	5.4	3.9	2.8	1.7	1.7	1.7	1.8	2.7	3.9	6.3	7.6

Peak BTU/hr output (83.3% eff.)	633,080.0	583,100.0	449,820.0	324,870.0	233,240.0	141,610.0	141,610.0	141,610.0	149,940.0	224,910.0	324,870.0	524,790.0	633,080.0
Monthly Total Consumed by CGT for steam (BTU)	681,825,375	548,709,000	411,814,375	270,249,000	215,702,375	176,149,750	180,047,000	181,489,875	179,407,375	208,874,750	263,213,125	535,529,750	3,853,011,750

Constituent Tables for Cooling Energy Consumption and Peak Values

AHU 7 Monthly Cooling Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	kWh	0.0	0.0	0.0	161.0	5,028.4	19,659.0	27,853.9	26,818.4	13,538.0	2,728.8	305.9	0.0	96,093.4
	Kw	0.0	0.0	0.0	2.1	40.5	54.1	65.1	61.0	53.2	12.0	3.4	0.0	65.1
Level 3	kWh	0.0	0.0	0.0	156.9	1,783.7	11,003.4	16,313.9	15,034.4	6,198.8	2,267.7	292.8	0.0	53,051.6
	Kw	0.0	0.0	0.0	2.0	8.7	30.6	38.0	33.8	18.2	9.4	3.1	0.0	38.0
Level 4	kWh	0.0	0.0	0.0	342.4	2,810.9	7,010.7	9,229.0	9,396.5	5,551.6	1,685.3	494.5	0.0	36,520.9
	Kw	0.0	0.0	0.0	4.0	7.1	15.6	18.4	18.2	11.3	5.6	4.0	0.0	18.4
Level 5	kWh	0.0	0.0	0.0	91.0	2,988.2	11,935.8	16,966.3	16,472.7	8,359.7	1,587.6	172.6	0.0	58,573.9
	Kw	0.0	0.0	0.0	1.2	10.4	30.4	36.4	34.2	19.3	7.3	1.9	0.0	36.4
Level 6	kWh	0.0	0.0	1.4	2,618.0	8,081.4	17,426.6	25,589.3	26,902.3	14,886.9	2,136.7	166.0	0.0	97,808.6
	Kw	0.0	0.0	1.4	18.0	30.9	49.0	66.2	68.2	43.7	14.4	4.8	0.0	68.2
Monthly Totals kWh		0.0	0.0	1.4	3,369.3	20,692.6	67,035.5	95,952.4	94,624.3	48,535.0	10,406.1	1,431.8	0.0	342,048.4
Monthly Peak kW		0.0	0.0	1.4	27.3	97.6	179.7	224.1	215.4	145.7	48.7	17.2	0.0	224.1

Monthly BTU (1.1089kW/Ton)	0.0	0.0	15,150.1	295,427.9	1,056,181.8	1,944,629.8	2,425,106.0	2,330,958.6	1,576,697.6	527,008.8	186,130.4	0.0	2,425,106.0
Monthly Energy consumed by A.C. (BTUH)	0.0	0.0	16,117.2	38,788,295.1	238,218,821.4	771,730,850.8	1,104,630,043.6	1,089,340,596.3	558,748,078.9	119,797,844.5	16,483,269.8	0.0	3,937,753,917.5

AHU 8 Monthly Cooling Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	kWh	0.0	0.0	0.0	204.5	6,910.8	27,241.6	38,654.1	37,274.1	18,921.9	3,569.5	388.5	0.0	133,165.0
	Kw	0.0	0.0	0.0	2.7	55.7	75.6	8.9	83.4	74.3	17.0	4.3	0.0	83.4
Level 3	kWh	0.0	0.0	0.0	182.6	2,090.1	13,048.9	19,366.1	17,827.7	7,332.9	2,687.5	340.7	0.0	62,876.5
	Kw	0.0	0.0	0.0	2.3	10.4	36.3	45.0	40.2	21.7	11.1	3.6	0.0	45.0
Level 4	kWh	0.0	0.0	0.0	133.7	4,400.6	17,580.2	24,990.1	24,264.5	12,316.0	2,333.4	254.0	0.0	86,272.5
	Kw	0.0	0.0	0.0	1.8	15.3	44.8	53.6	50.4	28.4	10.8	2.8	0.0	53.6
Level 5	kWh	0.0	0.0	0.0	111.6	3,669.9	14,660.0	20,838.9	20,233.5	10,269.2	1,947.5	212.0	0.0	71,942.6
	Kw	0.0	0.0	0.0	1.5	12.8	37.4	44.7	42.0	23.7	9.0	2.3	0.0	44.7
Level 6	kWh	0.0	0.0	1.9	3,484.2	10,755.6	23,192.8	34,056.8	35,804.4	19,813.0	2,843.7	221.0	0.0	130,173.4
	Kw	0.0	0.0	1.9	24.0	41.2	65.3	88.1	90.8	58.2	19.2	6.3	0.0	90.8
Monthly Totals kWh		0.0	0.0	1.9	4,116.6	27,827.0	95,723.5	137,906.0	135,404.2	68,653.0	13,381.6	1,416.2	0.0	484,430.0
Monthly Peak kW		0.0	0.0	1.9	32.3	135.4	259.4	240.3	306.8	206.3	67.1	19.3	0.0	306.8

Monthly BTU (1.1089kW/Ton)	0.0	0.0	20,560.9	349,535.6	1,465,235.8	2,807,106.2	2,600,198.4	3,320,046.9	2,232,482.7	726,125.0	208,855.6	0.0	3,320,046.9
Monthly Energy sonsumed by A.C. (BTUH)	0.0	0.0	21,873.3	47,391,415.3	320,351,968.5	1,101,994,884.7	1,587,611,261.3	1,558,809,861.4	790,351,949.3	154,052,607.2	16,303,678.4	0.0	5,576,889,499.5

AHU 9 Monthly Cooling Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	kWh	0.0	0.0	0.0	106.0	3,600.4	14,198.6	20,147.6	19,428.3	9,866.5	1,850.8	201.5	0.0	69,399.7
	Kw	0.0	0.0	0.0	1.4	29.0	39.4	46.2	43.5	38.7	8.9	2.2	0.0	46.2
Level 3	kWh	0.0	0.0	0.0	104.9	1,200.3	7,494.6	11,123.0	10,239.4	4,211.5	1,538.3	195.7	0.0	36,107.7
	Kw	0.0	0.0	0.0	1.3	6.0	20.9	25.9	23.1	12.5	6.4	2.1	0.0	25.9
Level 4	kWh	0.0	0.0	0.0	125.9	4,134.5	16,513.4	23,473.1	22,789.8	11,564.9	2,197.8	239.3	0.0	81,038.7
	Kw	0.0	0.0	0.0	1.7	14.4	42.1	50.4	47.4	26.6	10.1	2.6	0.0	50.4
Level 5	kWh	0.0	0.0	0.0	73.8	2,430.0	9,708.4	13,800.5	13,400.0	6,801.8	1,287.6	140.2	0.0	47,642.3
	Kw	0.0	0.0	0.0	1.0	8.5	24.8	29.6	27.9	15.7	6.0	1.5	0.0	29.6
Level 6	kWh	0.0	0.0	0.6	1,101.8	3,401.3	7,334.7	10,770.3	11,322.9	6,265.8	899.2	69.9	0.0	41,166.5
	Kw	0.0	0.0	0.6	7.6	13.0	20.6	27.9	28.7	18.4	6.1	2.0	0.0	28.7
Monthly Totals kWh		0.0	0.0	0.6	1,512.4	14,766.5	55,249.7	79,314.5	77,180.4	38,710.5	7,773.7	846.6	0.0	275,354.9
Monthly Peak kW		0.0	0.0	0.6	13.0	70.9	147.8	180.0	170.6	111.9	37.5	10.4	0.0	180.0

Monthly BTU (1.1089kW/Ton)	0.0	0.0	6,492.9	140,680.0	767,246.8	1,599,422.9	1,947,876.3	1,846,153.9	1,210,929.8	405,807.6	112,544.0	0.0	1,947,876.3
Monthly Energy sonsumed by A.C. (BTUH)	0.0	0.0	6,907.4	17,411,158.8	169,995,951.5	636,049,525.8	913,090,027.9	888,521,690.1	445,645,771.3	89,492,942.0	9,746,288.7	0.0	3,169,960,263.5

AHU 10 Monthly Cooling Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	kWh	0.0	0.0	0.0	109.9	3,423.3	13,379.0	18,951.9	18,247.6	9,210.4	1,859.4	208.9	0.0	65,390.4
	Kw	0.0	0.0	0.0	1.5	27.6	36.8	44.2	41.5	36.3	8.2	2.3	0.0	44.2
Level 3	kWh	0.0	0.0	0.0	156.8	1,794.8	11,206.1	16,631.3	15,310.0	6,296.9	2,300.1	292.6	0.0	53,988.6
	Kw	0.0	0.0	0.0	2.0	8.9	31.2	38.7	34.5	18.6	9.6	3.1	0.0	38.7
Level 4	kWh	0.0	0.0	0.0	106.1	3,491.2	13,946.4	19,824.6	19,248.7	9,769.6	1,852.3	201.6	0.0	68,440.5
	Kw	0.0	0.0	0.0	1.4	12.1	35.6	42.5	40.0	22.5	8.6	2.2	0.0	42.5
Level 5	kWh	0.0	0.0	0.0	104.1	3,422.0	13,669.5	19,430.8	18,866.0	9,574.9	1,816.6	197.7	0.0	67,081.6
	Kw	0.0	0.0	0.0	1.4	11.9	34.9	41.7	39.2	22.1	8.4	2.2	0.0	41.7
Level 6	kWh	0.0	0.0	1.1	2,086.6	6,441.3	13,890.0	20,396.2	21,442.8	11,865.9	1,702.9	132.3	0.0	77,959.1
	Kw	0.0	0.0	1.1	14.3	24.7	39.1	52.8	54.4	34.8	11.5	3.8	0.0	54.4
Monthly Totals kWh		0.0	0.0	1.1	2,563.5	18,572.6	66,091.0	95,234.8	93,115.1	46,717.7	9,531.3	1,033.1	0.0	332,860.2
Monthly Peak kW		0.0	0.0	1.1	20.6	85.2	177.6	219.9	209.6	134.3	46.3	13.6	0.0	219.9

Monthly BTU (1.1089kW/Ton)	0.0	0.0	11,903.7	222,923.6	921,994.8	1,921,904.6	2,379,655.5	2,268,193.7	1,453,332.2	501,037.1	147,172.9	0.0	2,379,655.5
Monthly Energy sonsumed by A.C. (BTUH)	0.0	0.0	12,663.5	29,511,707.0	213,812,806.6	760,857,510.7	1,096,368,837.8	1,071,966,276.7	537,826,828.6	109,726,909.7	11,893,327.3	0.0	3,831,976,868.0

AHU 11 Monthly Cooling Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	kWh	0.0	0.0	0.0	141.7	4,422.1	17,287.2	24,492.0	23,581.5	11,903.6	2,400.3	269.3	0.0	84,497.7
	Kw	0.0	0.0	0.0	1.9	35.7	47.6	57.2	53.6	46.8	10.5	3.0	0.0	57.2
Level 3	kWh	0.0	0.0	0.0	190.1	2,175.2	13,582.9	20,158.8	18,557.2	7,632.0	2,787.7	354.6	0.0	65,438.5
	Kw	0.0	0.0	0.0	2.4	10.8	37.8	46.9	41.8	22.6	11.6	3.8	0.0	46.9
Level 4	kWh	0.0	0.0	0.0	201.0	6,593.9	26,334.6	37,433.1	36,342.7	18,441.3	3,507.4	382.0	0.0	129,236.0
	Kw	0.0	0.0	0.0	2.7	22.9	67.2	80.3	75.5	42.5	16.1	4.2	0.0	80.3
Level 5	kWh	0.0	0.0	0.0	142.6	4,682.1	18,700.9	26,582.5	25,809.0	13,097.4	2,488.2	270.9	0.0	91,773.6
	Kw	0.0	0.0	0.0	1.9	16.3	47.7	57.0	53.6	30.2	11.5	3.0	0.0	57.0
Level 6	kWh	0.0	0.0	1.5	2,818.9	8,701.9	18,764.9	27,554.4	28,968.2	16,030.3	2,300.5	178.8	0.0	105,319.4
	Kw	0.0	0.0	1.5	19.4	33.3	52.8	71.3	73.5	47.1	15.6	5.1	0.0	73.5
Monthly Totals kWh		0.0	0.0	1.5	3,494.3	26,575.2	94,670.5	136,220.8	133,258.6	67,104.6	13,484.1	1,455.6	0.0	476,265.2
Monthly Peak kW		0.0	0.0	1.5	28.3	119.0	253.1	312.7	298.0	189.2	65.3	19.1	0.0	312.7

Monthly BTU (1.1089kW/Ton)	0.0	0.0	16,232.3	306,249.4	1,287,762.7	2,738,930.5	3,383,894.0	3,224,817.4	2,047,434.4	706,646.2	206,691.3	0.0	3,383,894.0
Monthly Energy sonsumed by A.C. (BTUH)	0.0	0.0	17,268.4	40,227,329.0	305,940,907.5	1,089,872,463.2	1,568,210,782.0	1,534,109,132.5	772,526,348.7	155,232,615.0	16,757,261.8	0.0	5,482,894,108.2

AHU 12 Monthly Cooling Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	kWh	0.0	0.0	0.0	83.5	2,600.7	10,164.4	14,398.4	13,863.3	6,997.5	1,412.6	158.7	0.0	49,679.1
	Kw	0.0	0.0	0.0	1.1	21.0	28.0	33.6	31.6	27.6	6.2	1.7	0.0	33.6
Level 3	kWh	0.0	0.0	0.0	114.7	1,307.1	8,093.2	12,008.8	11,056.2	4,552.6	1,664.7	214.0	0.0	39,011.3
	Kw	0.0	0.0	0.0	1.4	6.4	22.5	28.0	24.9	13.4	6.9	2.3	0.0	28.0
Level 4	kWh	0.0	0.0	0.0	78.2	2,570.8	10,269.3	14,597.5	14,173.4	7,193.4	1,364.5	148.5	0.0	50,395.6
	Kw	0.0	0.0	0.0	1.0	8.9	26.2	31.3	29.5	16.6	6.3	1.6	0.0	31.3
Level 5	kWh	0.0	0.0	0.0	83.2	2,551.7	10,119.9	14,327.2	13,891.8	7,028.3	1,397.2	158.1	0.0	49,557.4
	Kw	0.0	0.0	0.0	0.2	8.8	25.6	31.3	29.4	16.3	6.1	1.7	0.0	31.3
Level 6	kWh	0.0	0.0	0.6	1,193.6	3,688.5	7,963.9	11,687.3	12,286.9	6,800.8	971.0	75.5	0.0	44,668.1
	Kw	0.0	0.0	0.6	8.2	14.1	22.4	30.2	31.3	20.0	6.6	2.2	0.0	31.3
Monthly Totals kWh		0.0	0.0	0.6	1,553.2	12,718.8	46,610.7	67,019.2	65,271.6	32,572.6	6,810.0	754.8	0.0	233,311.5
Monthly Peak kW		0.0	0.0	0.6	11.9	59.2	124.7	154.4	146.7	93.9	32.1	9.5	0.0	154.4

Monthly BTU (1.1089kW/Ton)	0.0	0.0	6,492.9	128,776.3	640,634.9	1,349,445.4	1,670,845.0	1,587,519.2	1,016,142.1	347,371.3	102,804.6	0.0	1,670,845.0
Monthly Energy sonsumed by A.C. (BTUH)	0.0	0.0	6,907.4	17,880,859.5	146,422,273.9	536,595,015.6	771,543,200.8	751,424,355.7	374,984,602.3	78,398,566.3	8,689,462.2	0.0	2,685,945,243.8

AHU 13 Monthly Cooling Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	kWh	0.0	0.0	0.0	82.9	2,582.1	10,091.4	14,294.9	13,763.7	6,947.2	1,402.5	157.5	0.0	49,322.2
	Kw	0.0	0.0	0.0	1.1	20.8	27.8	33.3	31.3	27.4	6.2	1.7	0.0	33.3
Level 3	kWh	0.0	0.0	0.0	102.6	1,168.4	7,227.3	10,723.9	9,873.5	4,066.4	1,487.1	191.5	0.0	34,840.7
	Kw	0.0	0.0	0.0	1.3	5.7	20.1	25.0	22.2	12.0	6.1	2.0	0.0	25.0
Level 4	kWh	0.0	0.0	0.0	70.6	2,324.0	9,284.4	13,197.7	12,841.5	6,504.3	1,232.3	134.1	0.0	45,588.9
	Kw	0.0	0.0	0.0	0.9	8.1	23.7	28.3	26.6	15.0	5.7	1.5	0.0	28.3
Level 5	kWh	0.0	0.0	0.0	71.1	2,339.0	9,344.1	13,282.4	12,896.7	6,545.8	1,240.8	135.1	0.0	45,855.0
	Kw	0.0	0.0	0.0	0.9	8.1	23.8	28.5	26.8	15.1	5.7	1.5	0.0	28.5
Level 6	kWh	0.0	0.0	1.0	1,937.9	5,982.4	12,900.5	18,943.2	19,915.2	11,020.5	1,581.6	122.9	0.0	72,405.2
	Kw	0.0	0.0	1.0	13.3	22.9	36.3	49.0	50.5	32.4	10.7	3.5	0.0	50.5
Monthly Totals kWh		0.0	0.0	1.0	2,265.1	14,395.9	48,847.7	66,503.8	69,676.3	41,435.1	12,249.3	1,846.8	0.0	257,221.0
Monthly Peak kW		0.0	0.0	1.0	17.5	65.6	131.7	159.4	159.1	113.6	43.8	14.4	0.0	159.4

Monthly BTU (1.1089kW/Ton)	0.0	0.0	10,821.5	189,376.9	709,892.7	1,425,196.2	1,724,952.7	1,721,706.2	1,229,326.4	473,983.2	155,830.1	0.0	1,724,952.7
Monthly Energy sonsumed by A.C. (BTUH)	0.0	0.0	11,512.3	26,076,445.3	165,729,503.8	562,347,966.1	765,609,776.2	802,132,456.4	477,012,105.2	141,017,262.7	21,260,862.3	0.0	2,961,197,890.2

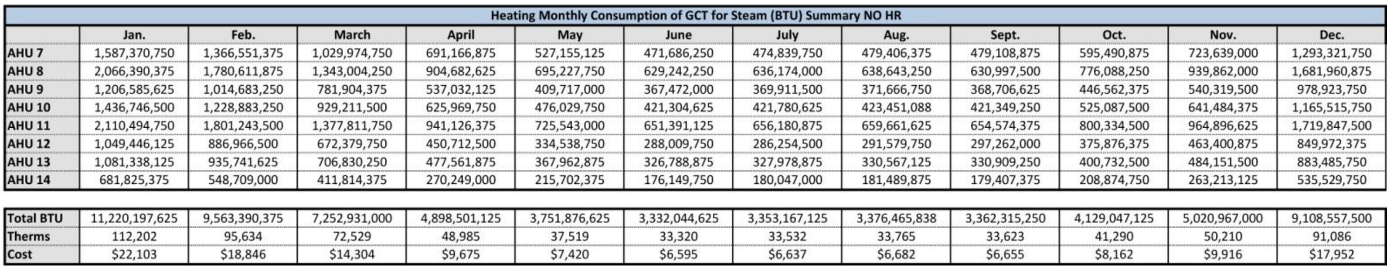
AHU 14 Monthly Cooling Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	kWh	0.0	0.0	0.0	390.6	4,220.4	25,798.8	38,431.0	35,219.3	14,400.4	5,312.1	721.6	0.0	124,494.2
	Kw	0.0	0.0	0.0	4.9	19.9	72.6	92.3	80.8	41.9	21.4	7.6	0.0	92.3
Level 2	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 3	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 4	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 5	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 6	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monthly Totals kWh		0.0	0.0	0.0	390.6	4,220.4	25,798.8	38,431.0	35,219.3	14,400.4	5,312.1	721.6	0.0	124,494.2
Monthly Peak kW		0.0	0.0	0.0	4.9	19.9	72.6	92.3	80.8	41.9	21.4	7.6	0.0	92.3

Monthly BTU (1.1089kW/Ton)	0.0	0.0	0.0	53,025.5	215,348.5	785,643.4	998,827.7	874,380.0	453,422.3	231,580.8	82,243.7	0.0	998,827.7
Monthly Energy sonsumed by A.C. (BTUH)	0.0	0.0	0.0	4,496,693.1	48,586,389.0	297,002,780.2	442,428,091.5	405,454,130.3	165,781,309.1	61,154,335.4	8,307,254.8	0.0	1,433,210,983.5

Appendix C

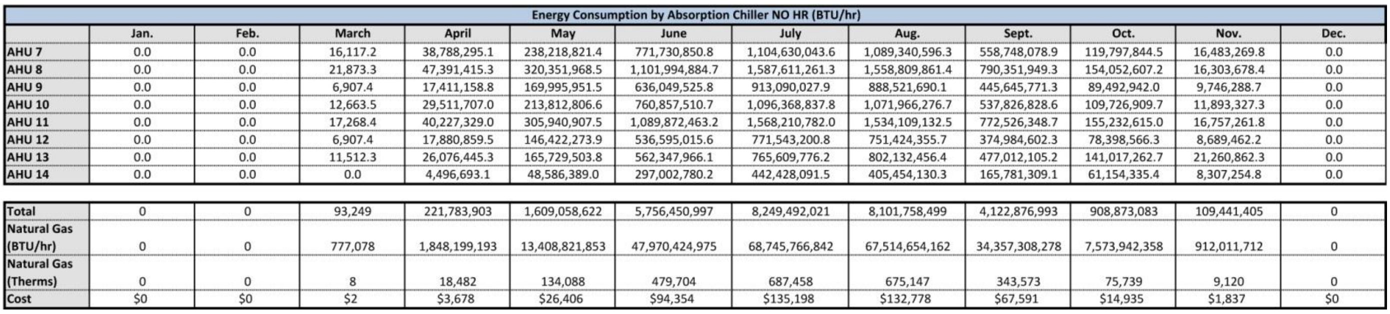
Natural Gas Monthly Consumption and Cost Values for Heating and Cooling



Heating Monthly Consumption of GCT for Steam (BTU) Summary NO HR

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
AHU 7	1,587,370,750	1,366,551,375	1,029,974,750	691,166,875	527,155,125	471,686,250	474,839,750	479,406,375	479,108,875	595,490,875	723,639,000	1,293,321,750
AHU 8	2,066,390,375	1,780,611,875	1,343,004,250	904,682,625	695,227,750	629,242,250	636,174,000	638,643,250	630,997,500	776,088,250	939,862,000	1,681,960,875
AHU 9	1,206,585,625	1,014,683,250	781,904,375	537,032,125	409,717,000	367,472,000	369,911,500	371,666,750	368,706,625	446,562,375	540,319,500	978,923,750
AHU 10	1,436,746,500	1,228,883,250	929,211,500	625,969,750	476,029,750	421,304,625	421,780,625	423,451,088	421,349,250	525,087,500	641,484,375	1,165,515,750
AHU 11	2,110,494,750	1,801,243,500	1,377,811,750	941,126,375	725,543,000	651,391,125	656,180,875	659,661,625	654,574,375	800,334,500	964,896,625	1,719,847,500
AHU 12	1,049,446,125	886,966,500	672,379,750	450,712,500	334,538,750	288,009,750	286,254,500	291,579,750	297,262,000	375,876,375	463,400,875	849,972,375
AHU 13	1,081,338,125	935,741,625	706,830,250	477,561,875	367,962,875	326,788,875	327,978,875	330,567,125	330,909,250	400,732,500	484,151,500	883,485,750
AHU 14	681,825,375	548,709,000	411,814,375	270,249,000	215,702,375	176,149,750	180,047,000	181,489,875	179,407,375	208,874,750	263,213,125	535,529,750

Total BTU	11,220,197,625	9,563,390,375	7,252,931,000	4,898,501,125	3,751,876,625	3,332,044,625	3,353,167,125	3,376,465,838	3,362,315,250	4,129,047,125	5,020,967,000	9,108,557,500
Therms	112,202	95,634	72,529	48,985	37,519	33,320	33,532	33,765	33,623	41,290	50,210	91,086
Cost	$22,103	$18,846	$14,304	$9,675	$7,420	$6,595	$6,637	$6,682	$6,655	$8,162	$9,916	$17,952



Energy Consumption by Absorption Chiller NO HR (BTU/hr)

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
AHU 7	0.0	0.0	16,117.2	38,788,295.1	238,218,821.4	771,730,850.8	1,104,630,043.6	1,089,340,596.3	558,748,078.9	119,797,844.5	16,483,269.8	0.0
AHU 8	0.0	0.0	21,873.3	47,391,415.3	320,351,968.5	1,101,994,884.7	1,587,611,261.3	1,558,809,861.4	790,351,949.3	154,052,607.2	16,303,678.4	0.0
AHU 9	0.0	0.0	6,907.4	17,411,158.8	169,995,951.5	636,049,525.8	913,090,027.9	888,521,690.1	445,645,771.3	89,492,942.0	9,746,288.7	0.0
AHU 10	0.0	0.0	12,663.5	29,511,707.0	213,812,806.6	760,857,510.7	1,096,368,837.8	1,071,966,276.7	537,826,828.6	109,726,909.7	11,893,327.3	0.0
AHU 11	0.0	0.0	17,268.4	40,227,329.0	305,940,907.5	1,089,872,463.2	1,568,210,782.0	1,534,109,132.5	772,526,348.7	155,232,615.0	16,757,261.8	0.0
AHU 12	0.0	0.0	6,907.4	17,880,859.5	146,422,273.9	536,595,015.6	771,543,200.8	751,424,355.7	374,984,602.3	78,398,566.3	8,689,462.2	0.0
AHU 13	0.0	0.0	11,512.3	26,076,445.3	165,729,503.8	562,347,966.1	765,609,776.2	802,132,456.4	477,012,105.2	141,017,262.7	21,260,862.3	0.0
AHU 14	0.0	0.0	0.0	4,496,693.1	48,586,389.0	297,002,780.2	442,428,091.5	405,454,130.3	165,781,309.1	61,154,335.4	8,307,254.8	0.0

Total	0	0	93,249	221,783,903	1,609,058,622	5,756,450,997	8,249,492,021	8,101,758,499	4,122,876,993	908,873,083	109,441,405	0
Natural Gas (BTU/hr)	0	0	777,078	1,848,199,193	13,408,821,853	47,970,424,975	68,745,766,842	67,514,654,162	34,357,308,278	7,573,942,358	912,011,712	0
Natural Gas (Therms)	0	0	8	18,482	134,088	479,704	687,458	675,147	343,573	75,739	9,120	0
Cost	$0	$0	$2	$3,678	$26,406	$94,354	$135,198	$132,778	$67,591	$14,935	$1,837	$0

Appendix D

Constituent Tables for Heating Energy Consumption and Peak Values

AHU 7 Monthly Heating Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	therms	1,248.3	976.8	787.6	655.4	651.6	600.0	607.6	614.0	613.2	662.4	657.4	942.2	9,016.5
	therms/hr	2.2	2.0	1.4	1.0	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.7	2.2
Level 3	therms	1,183.5	970.7	906.1	837.1	841.7	766.9	777.0	792.3	791.3	826.9	816.8	983.0	10,493.3
	therms/hr	2.1	1.9	1.4	1.2	1.2	1.2	1.1	1.2	1.2	1.2	0.9	1.7	2.1
Level 4	therms	779.8	658.9	671.7	637.8	626.0	564.2	567.8	576.3	578.8	632.9	632.2	695.6	7,622.0
	therms/hr	1.3	1.2	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.1	1.3
Level 5	therms	829.0	674.1	619.9	572.3	564.2	514.8	522.2	531.5	528.6	564.3	555.0	675.4	7,151.3
	therms/hr	1.5	1.3	1.0	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	1.2	1.5
Level 6	therms	2,283.1	2,372.0	1,588.4	936.2	728.5	671.1	666.7	680.5	692.5	1,032.9	1,253.5	1,948.7	14,854.1
	therms/hr	4.1	4.7	3.3	2.1	1.1	1.1	1.0	1.0	1.1	2.4	2.8	3.6	4.7
Monthly Totals therms		6,323.7	5,652.5	4,573.7	3,638.8	3,412.0	3,117.0	3,141.3	3,194.6	3,204.4	3,719.4	3,914.9	5,244.9	49,137.2
Monthly Peak therm/hr		11.2	11.1	8.1	6.1	4.9	4.9	4.7	4.8	4.9	6.3	6.5	9.3	11.2

Peak BTU/hr output (83.3% eff.)	932,960.0	924,630.0	674,730.0	508,130.0	408,170.0	408,170.0	391,510.0	399,840.0	408,170.0	524,790.0	541,450.0	774,690.0	932,960.0
Monthly Total Consumed by CGT for steam (BTU)	940,650,375	840,809,375	680,337,875	541,271,500	507,535,000	463,653,750	467,268,375	475,196,750	476,654,500	553,260,750	582,341,375	780,178,875	7,309,158,500

AHU 8 Monthly Heating Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	therms	1,859.7	1,479.2	1,253.2	1,081.4	1,105.3	1,049.7	1,073.9	1,072.7	1,045.2	1,097.5	1,072.2	1,446.9	14,636.9
	therms/hr	3.2	2.9	2.2	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.6	2.6	3.2
Level 3	therms	1,300.5	1,060.0	978.9	902.4	907.8	827.7	839.7	856.1	853.1	890.3	876.8	1,064.7	11,358.0
	therms/hr	2.3	2.1	1.6	1.3	1.3	1.3	1.2	1.2	1.3	1.3	1.3	1.9	2.3
Level 4	therms	922.3	772.5	782.6	746.1	731.2	652.2	652.6	658.6	658.8	725.0	725.4	806.1	8,833.4
	therms/hr	1.6	1.5	1.2	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.1	1.3	1.6
Level 5	therms	1,019.4	827.4	755.9	693.2	672.3	601.3	606.5	622.8	627.4	678.5	672.0	827.7	8,604.4
	therms/hr	1.8	1.6	1.2	1.0	1.0	0.9	0.9	0.9	1.0	1.0	1.0	1.5	1.8
Level 6	therms	1,341.9	1,364.4	1,180.8	1,082.2	1,064.7	998.9	1,007.4	1,017.5	1,009.3	1,102.0	1,085.2	1,220.7	13,475.0
	therms/hr	2.4	2.8	1.8	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.6	2.0	2.8
Monthly Totals therms		6,443.8	5,503.5	4,951.4	4,505.3	4,481.3	4,129.8	4,180.1	4,227.7	4,193.8	4,493.3	4,431.6	5,366.1	56,907.7
Monthly Peak therm/hr		11.3	10.9	8.0	6.6	6.5	6.2	6.1	6.1	6.3	6.5	6.6	9.3	11.3

Peak BTU/hr output (83.3% eff.)	941,290.0	907,970.0	666,400.0	549,780.0	541,450.0	516,460.0	508,130.0	508,130.0	524,790.0	541,450.0	549,780.0	774,690.0	941,290.0
Monthly Total Consumed by CGT for steam (BTU)	958,515,250	818,645,625	736,520,750	670,163,375	666,593,375	614,307,750	621,789,875	628,870,375	623,827,750	668,378,375	659,200,500	798,207,375	8,465,020,375

AHU 9 Monthly Heating Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	therms	811.3	628.1	497.8	415.3	422.5	398.8	406.7	405.6	395.4	418.2	410.1	597.5	5,807.3
	therms/hr	1.5	1.3	0.9	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	1.1	1.5
Level 3	therms	772.0	632.9	589.7	543.0	541.6	483.2	486.4	499.1	501.7	523.1	517.4	634.1	6,724.2
	therms/hr	1.4	1.3	1.0	0.8	0.8	0.8	0.7	0.7	0.8	0.8	0.8	1.1	1.4
Level 4	therms	1,184.4	1,015.1	1,059.2	1,016.6	1,021.9	949.4	965.3	969.8	954.7	1,019.1	1,004.4	1,081.2	12,241.1
	therms/hr	1.9	1.8	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.5	1.5	1.6	1.9
Level 5	therms	660.8	535.0	485.4	443.0	423.2	370.5	370.7	383.2	390.1	427.0	425.6	532.7	5,447.2
	therms/hr	1.2	1.1	0.8	0.7	0.6	0.6	0.6	0.6	0.6	0.7	0.7	1.0	1.2
Level 6	therms	373.3	391.6	317.7	272.6	248.0	221.2	214.0	220.0	227.5	272.7	276.3	329.9	3,364.8
	therms/hr	0.7	0.9	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.6	0.9
Monthly Totals therms		3,801.8	3,202.7	2,949.8	2,690.5	2,657.2	2,423.1	2,443.1	2,477.7	2,469.4	2,660.1	2,633.8	3,175.4	33,584.6
Monthly Peak therm/hr		6.7	6.4	4.7	4.1	3.9	3.8	3.7	3.7	3.8	4.1	4.1	5.4	6.7

Peak BTU/hr output (83.3% eff.)	558,110.0	533,120.0	391,510.0	341,530.0	324,870.0	316,540.0	308,210.0	308,210.0	316,540.0	341,530.0	341,530.0	449,820.0	558,110.0
Monthly Total Consumed by CGT for steam (BTU)	565,517,750	476,401,625	438,782,750	400,211,875	395,262,963	360,436,125	363,411,125	368,557,875	367,323,250	395,689,875	391,777,750	472,340,750	4,995,713,713

AHU 10 Monthly Heating Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	therms	866.5	678.6	551.0	461.3	449.7	399.7	398.1	402.4	406.8	452.2	454.5	655.8	6,176.6
	therms/hr	1.6	1.4	1.0	0.7	0.7	0.6	0.6	0.6	0.6	0.7	0.7	1.2	1.6
Level 3	therms	1,145.8	941.6	883.4	820.0	827.0	755.3	765.9	778.6	771.8	801.3	786.6	947.3	10,224.6
	therms/hr	2.0	1.8	1.4	1.2	1.2	1.1	1.1	1.1	1.2	1.2	1.2	1.6	2.0
Level 4	therms	817.5	691.8	710.1	680.1	673.4	609.0	612.4	615.4	610.1	663.6	659.6	725.8	8,068.8
	therms/hr	1.4	1.3	1.0	1.0	1.0	8.0	0.9	0.9	0.9	1.0	1.0	1.1	8.0
Level 5	therms	933.9	758.7	695.4	641.9	628.5	567.7	573.6	585.1	583.3	624.5	615.1	755.8	7,963.5
	therms/hr	1.7	1.5	1.1	1.0	0.9	0.9	0.8	0.9	0.9	0.9	1.0	1.3	1.7
Level 6	therms	717.9	748.5	610.8	536.3	503.9	457.4	447.5	455.8	464.1	539.3	541.3	636.8	6,659.6
	therms/hr	1.4	1.6	1.0	0.9	0.8	0.7	0.7	0.7	0.8	0.9	0.9	1.2	1.6
Monthly Totals therms		4,481.6	3,819.2	3,450.7	3,139.6	3,082.5	2,789.1	2,797.5	2,837.3	2,836.1	3,080.9	3,057.1	3,721.5	39,093.1
Monthly Peak therm/hr		8.1	7.6	5.5	4.8	4.6	11.3	4.1	4.2	4.4	4.7	4.8	6.4	11.3

Peak BTU/hr output (83.3% eff.)	674,730.0	633,080.0	458,150.0	399,840.0	383,180.0	941,290.0	341,530.0	349,860.0	366,520.0	391,510.0	399,840.0	533,120.0	941,290.0
Monthly Total Consumed by CGT for steam (BTU)	666,638,000	568,106,000	513,291,625	467,015,500	458,521,875	414,878,625	416,128,125	422,048,375	421,869,875	458,283,875	454,743,625	553,573,125	5,815,098,625

AHU 11 Monthly Heating Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	therms	1,077.8	840.7	674.7	562.1	552.4	496.1	495.7	499.3	501.1	552.5	553.1	807.7	7,613.2
	therms/hr	1.9	1.8	1.3	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.9	1.5	1.9
Level 3	therms	1,362.6	1,112.3	1,029.5	947.3	949.5	857.2	866.0	885.0	887.0	927.8	917.0	1,118.1	11,859.3
	therms/hr	2.4	2.2	1.6	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.4	1.9	2.4
Level 4	therms	2,143.1	1,758.3	1,648.8	1,531.5	1,543.9	1,440.3	1,467.4	1,473.1	1,446.5	1,537.7	1,511.3	1,797.1	19,299.0
	therms/hr	3.6	3.3	2.6	2.2	2.2	2.1	2.1	2.1	2.1	2.2	2.2	3.0	3.6
Level 5	therms	1,283.8	1,043.5	956.6	877.7	857.6	774.8	784.6	803.0	807.3	872.2	863.0	1,050.4	10,974.5
	therms/hr	2.2	2.0	1.5	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.8	2.2
Level 6	therms	951.9	990.8	805.5	706.1	663.2	603.1	591.0	603.2	615.2	715.4	719.4	845.0	8,809.8
	therms/hr	1.8	2.2	1.3	1.1	1.1	1.0	1.0	1.0	1.0	1.1	1.2	1.5	2.2
Monthly Totals therms		6,819.2	5,745.6	5,115.1	4,624.7	4,566.6	4,171.5	4,204.7	4,263.6	4,257.1	4,605.6	4,563.8	5,618.3	58,555.8
Monthly Peak therm/hr		11.9	11.5	8.3	6.9	6.7	6.4	6.4	6.4	6.4	6.8	7.0	9.7	11.9

Peak BTU/hr output (83.3% eff.)	991,270.0	957,950.0	691,390.0	574,770.0	558,110.0	533,120.0	533,120.0	533,120.0	533,120.0	566,440.0	583,100.0	808,010.0	991,270.0
Monthly Total Consumed by CGT for steam (BTU)	1,014,356,000	854,658,000	760,871,125	687,924,125	679,281,750	620,510,625	625,449,125	634,210,500	633,243,625	685,083,000	678,865,250	835,722,125	8,710,175,250

AHU 12 Monthly Heating Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	therms	489.2	390.9	345.1	318.5	300.4	256.7	253.1	260.3	271.8	312.6	319.1	392.5	3,910.2
	therms/hr	0.9	0.8	0.6	0.5	0.5	0.4	0.4	0.4	0.5	0.5	0.5	0.7	0.9
Level 3	therms	875.7	712.4	653.3	594.5	591.3	525.4	528.3	544.0	554.5	590.8	591.6	724.4	7,486.2
	therms/hr	1.5	1.4	1.1	0.9	0.9	0.8	0.8	0.8	0.9	0.9	0.9	1.2	1.5
Level 4	therms	754.0	607.6	547.0	498.1	484.7	430.1	430.7	437.6	441.3	488.0	489.1	612.4	6,220.6
	therms/hr	1.3	1.2	0.9	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.8	1.1	1.3
Level 5	therms	714.6	579.9	528.5	480.3	459.6	404.4	406.2	420.5	430.8	475.1	475.0	585.5	5,960.4
	therms/hr	1.3	1.1	0.9	0.7	0.7	0.7	0.6	0.6	0.7	0.7	0.7	1.0	1.3
Level 6	therms	454.5	469.3	374.2	316.8	290.3	259.2	246.6	251.1	261.2	325.6	336.7	404.2	3,989.7
	therms/hr	0.9	1.1	0.7	0.6	0.5	0.5	0.4	0.4	0.5	0.6	0.6	0.8	1.1
Monthly Totals therms		3,288.0	2,760.1	2,448.1	2,208.2	2,126.3	1,875.8	1,864.9	1,913.5	1,959.6	2,192.1	2,211.5	2,719.0	27,567.1
Monthly Peak therm/hr		5.9	5.6	4.2	3.5	3.3	3.1	2.9	2.9	3.3	3.4	3.5	4.8	5.9

Peak BTU/hr output (83.3% eff.)	491,470.0	466,480.0	349,860.0	291,550.0	274,890.0	258,230.0	241,570.0	241,570.0	274,890.0	283,220.0	291,550.0	399,840.0	491,470.0
Monthly Total Consumed by CGT for steam (BTU)	489,090,000	410,564,875	364,154,875	328,469,750	316,287,125	279,025,250	277,403,875	284,633,125	291,490,500	326,074,875	328,960,625	404,451,250	4,100,606,125

AHU 13 Monthly Heating Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	therms	678.2	533.2	435.9	364.5	353.6	313.6	312.7	318.0	323.3	360.4	362.7	518.2	4,874.3
	therms/hr	1.2	1.1	0.8	0.6	0.5	0.5	0.5	0.5	0.5	0.6	0.6	1.0	1.2
Level 3	therms	757.0	618.5	572.6	525.2	525.1	472.6	477.4	489.2	492.6	517.2	512.5	623.7	6,583.6
	therms/hr	1.3	1.2	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8	1.1	1.3
Level 4	therms	681.1	553.4	506.9	464.8	455.6	408.7	410.6	416.1	417.5	458.0	457.6	562.3	5,792.6
	therms/hr	1.2	1.1	0.8	0.7	0.7	0.6	0.6	0.6	0.7	0.7	0.7	1.0	1.2
Level 5	therms	675.2	550.1	506.4	464.4	451.3	405.1	409.0	419.8	423.6	458.9	455.1	554.7	5,773.6
	therms/hr	1.2	1.1	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.7	0.7	1.0	1.2
Level 6	therms	685.8	704.0	590.9	536.0	523.8	489.4	491.2	496.4	494.5	546.8	541.3	617.2	6,717.3
	therms/hr	1.3	1.5	0.9	0.8	0.8	0.8	0.7	0.7	0.8	0.8	0.8	1.1	1.5
Monthly Totals therms		3,477.3	2,959.2	2,612.7	2,354.9	2,309.4	2,089.4	2,097.0	2,128.7	2,147.7	2,306.0	2,333.0	2,876.1	29,691.4
Monthly Peak therm/hr		6.2	6.0	4.2	3.6	3.5	3.2	3.1	3.1	3.3	3.5	3.6	5.2	6.2

Peak BTU/hr output (83.3% eff.)	516,460.0	499,800.0	349,860.0	299,880.0	291,550.0	266,560.0	258,230.0	258,230.0	274,890.0	291,550.0	299,880.0	433,160.0	516,460.0
Monthly Total Consumed by CGT for steam (BTU)	517,248,375	440,181,000	388,639,125	350,291,375	343,523,250	310,798,250	311,928,750	316,644,125	319,470,375	343,017,500	347,033,750	427,819,875	4,416,595,750

AHU 14 Monthly Heating Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	therms	2,204.2	1,727.5	1,421.7	1,207.4	1,227.9	1,146.7	1,171.7	1,181.2	1,168.2	1,228.1	1,209.1	1,673.3	16,567.0
	therms/hr	3.9	3.5	2.5	1.8	1.7	1.7	1.7	1.7	1.7	1.7	1.8	3.1	3.9
Level 2	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 3	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 4	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 5	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 6	therms	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	therms/hr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monthly Totals therms		2,204.2	1,727.5	1,421.7	1,207.4	1,227.9	1,146.7	1,171.7	1,181.2	1,168.2	1,228.1	1,209.1	1,673.3	16,567.0
Monthly Peak therm/hr		3.9	3.5	2.5	1.8	1.7	1.7	1.7	1.7	1.7	1.7	1.8	3.1	3.9

Peak BTU/hr output (83.3% eff.)	324,870.0	291,550.0	208,250.0	149,940.0	141,610.0	141,610.0	141,610.0	141,610.0	141,610.0	141,610.0	149,940.0	258,230.0	324,870.0
Monthly Total Consumed by CGT for steam (BTU)	327,874,750	256,965,625	211,477,875	179,600,750	182,650,125	170,571,625	174,290,375	175,703,500	173,769,750	182,679,875	179,853,625	248,903,375	2,464,341,250

Constituent Tables for Cooling Energy Consumption and Peak Values

AHU 7 Monthly Cooling Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	kWh	0.0	0.0	0.0	167.8	5,052.4	18,816.6	26,474.9	25,767.9	13,281.8	2,773.3	318.8	0.0	92,653.5
	Kw	0.0	0.0	0.0	2.2	37.9	51.3	61.7	57.8	50.7	11.9	3.5	0.0	61.7
Level 3	kWh	0.0	0.0	0.0	156.9	1,783.7	11,003.4	16,313.9	15,034.4	6,198.8	2,267.7	292.8	0.0	53,051.6
	Kw	0.0	0.0	0.0	2.0	8.7	30.6	38.0	33.8	18.2	9.4	3.1	0.0	38.0
Level 4	kWh	0.0	0.0	0.0	373.6	2,963.7	7,060.4	9,127.4	9,383.5	5,752.4	1,792.3	534.0	0.0	36,987.3
	Kw	0.0	0.0	0.0	4.3	7.4	15.0	17.5	17.5	11.4	5.8	4.3	0.0	17.5
Level 5	kWh	0.0	0.0	0.0	110.2	3,130.4	11,814.2	16,606.9	16,303.9	8,488.7	1,723.7	205.7	0.0	58,383.7
	Kw	0.0	0.0	0.0	1.4	10.7	29.4	35.1	33.3	19.1	7.4	2.2	0.0	35.1
Level 6	kWh	0.0	0.0	1.4	2,617.9	8,081.2	17,425.8	25,588.5	26,901.5	14,886.4	2,136.7	166.0	0.0	97,805.4
	Kw	0.0	0.0	1.4	18.0	30.9	49.0	66.2	68.1	43.7	14.4	4.8	0.0	68.1
Monthly Totals kWh		0.0	0.0	1.4	3,426.4	21,011.4	66,120.4	94,111.6	93,391.2	48,608.1	10,693.7	1,517.3	0.0	338,881.5
Monthly Peak kW		0.0	0.0	1.4	27.9	95.6	175.3	218.5	210.5	143.1	48.9	17.9	0.0	218.5

Monthly BTU (1.1089kW/Ton)	0.0	0.0	15,150.1	301,920.8	1,034,538.7	1,897,015.1	2,364,505.4	2,277,933.1	1,548,561.7	529,173.1	193,705.5	0.0	2,364,505.4
Monthly Energy consumed by A.C. (BTUH)	0.0	0.0	16,117.2	39,445,645.8	241,888,933.4	761,195,971.5	1,083,438,254.9	1,075,144,814.8	559,589,625.9	123,108,773.7	17,467,569.0	0.0	3,901,295,706.1

AHU 8 Monthly Cooling Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	kWh	0.0	0.0	0.0	212.5	6,936.1	26,037.3	36,682.1	35,767.1	18,534.9	3,699.3	403.8	0.0	128,273.1
	Kw	0.0	0.0	0.0	2.8	52.0	71.4	83.9	79.2	70.8	16.9	4.4	0.0	83.9
Level 3	kWh	0.0	0.0	0.0	182.6	2,090.1	13,048.9	19,366.1	17,827.7	7,332.9	2,678.5	340.7	0.0	62,867.5
	Kw	0.0	0.0	0.0	2.3	10.4	36.3	45.0	40.2	21.7	11.1	3.6	0.0	45.0
Level 4	kWh	0.0	0.0	0.0	163.2	4,638.2	17,507.6	24,610.3	24,162.7	12,581.0	2,553.2	304.5	0.0	86,520.7
	Kw	0.0	0.0	0.0	2.0	15.9	43.5	51.9	49.3	28.3	11.0	3.2	0.0	51.9
Level 5	kWh	0.0	0.0	0.0	135.8	3,850.1	14,487.6	20,343.5	20,000.6	10,431.4	2,120.8	253.4	0.0	71,623.2
	Kw	0.0	0.0	0.0	1.7	13.2	35.9	42.8	40.7	23.5	9.1	2.7	0.0	42.8
Level 6	kWh	0.0	0.0	3.9	3,629.8	10,703.7	22,664.9	31,743.4	33,730.8	19,405.0	2,987.0	248.1	0.0	125,116.6
	Kw	0.0	0.0	2.0	24.5	38.8	60.3	79.2	82.0	53.1	19.7	6.6	0.0	82.0
Monthly Totals kWh		0.0	0.0	3.9	4,323.9	28,218.2	93,746.3	132,745.4	131,488.9	68,285.2	14,038.8	1,550.5	0.0	474,401.1
Monthly Peak kW		0.0	0.0	2.0	33.3	130.3	247.4	302.8	291.4	197.4	67.8	20.5	0.0	302.8

Monthly BTU (1.1089kW/Ton)	0.0	0.0	21,643.1	360,357.1	1,410,046.0	2,677,247.8	3,276,760.8	3,153,395.3	2,136,171.0	733,700.1	221,841.5	0.0	3,276,760.8
Monthly Energy consumed by A.C. (BTUH)	0.0	0.0	44,897.9	49,777,909.1	324,855,569.0	1,079,232,822.3	1,528,201,035.0	1,513,735,866.3	786,117,736.0	161,618,471.8	17,849,776.4	0.0	5,461,434,083.6

AHU 9 Monthly Cooling Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	kWh	0.0	0.0	0.0	110.0	3,615.5	13,585.6	19,139.6	18,663.7	9,675.5	1,919.2	209.0	0.0	66,918.1
	Kw	0.0	0.0	0.0	1.5	27.1	37.3	43.8	41.4	36.9	8.8	2.3	0.0	43.8
Level 3	kWh	0.0	0.0	0.0	104.9	1,200.3	7,494.6	11,123.0	10,239.4	4,211.5	1,538.3	195.7	0.0	36,107.7
	Kw	0.0	0.0	0.0	1.3	6.0	20.9	25.9	23.1	12.5	6.4	2.1	0.0	25.9
Level 4	kWh	0.0	0.0	0.0	154.4	4,331.9	16,291.9	22,891.4	22,464.2	11,693.1	2,388.9	288.0	0.0	80,503.8
	Kw	0.0	0.0	0.0	1.9	14.8	40.5	48.5	46.0	26.4	10.2	3.1	0.0	48.5
Level 5	kWh	0.0	0.0	0.0	91.1	2,562.2	9,649.7	13,560.3	13,306.9	6,925.8	1,412.7	170.0	0.0	47,678.7
	Kw	0.0	0.0	0.0	1.1	8.8	24.0	28.7	27.2	15.6	6.0	1.8	0.0	28.7
Level 6	kWh	0.0	0.0	1.2	1,152.6	3,412.3	7,223.1	10,123.1	10,751.1	6,182.3	947.0	78.6	0.0	39,871.3
	Kw	0.0	0.0	0.6	7.8	12.4	19.3	25.3	26.2	17.0	6.3	2.1	0.0	26.2
Monthly Totals kWh		0.0	0.0	1.2	1,613.0	15,122.2	54,244.9	76,837.4	75,425.3	38,688.2	8,206.1	941.3	0.0	271,079.6
Monthly Peak kW		0.0	0.0	0.6	13.6	69.1	142.0	172.2	163.9	108.4	37.7	11.4	0.0	172.2

Monthly BTU (1.1089kW/Ton)	0.0	0.0	6,492.9	147,172.9	747,768.1	1,536,658.0	1,863,468.3	1,773,649.6	1,173,054.4	407,971.9	123,365.5	0.0	1,863,468.3
Monthly Energy consumed by A.C. (BTUH)	0.0	0.0	13,814.7	18,569,293.3	174,090,866.4	624,481,995.8	884,572,981.1	868,316,503.0	445,389,047.6	94,470,848.1	10,836,500.8	0.0	3,120,741,850.8

AHU 10 Monthly Cooling Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	kWh	0.0	0.0	0.0	115.4	3,448.8	12,827.3	18,038.9	17,555.3	9,050.0	1,892.9	219.3	0.0	63,147.9
	Kw	0.0	0.0	0.0	1.5	25.9	34.9	42.1	39.5	34.6	8.1	2.4	0.0	42.1
Level 3	kWh	0.0	0.0	0.0	156.8	1,794.8	11,206.1	16,631.3	15,310.0	6,296.9	2,300.1	292.6	0.0	53,988.6
	Kw	0.0	0.0	0.0	2.0	8.9	31.2	38.7	34.5	18.6	9.6	3.1	0.0	38.7
Level 4	kWh	0.0	0.0	0.0	130.6	3,688.6	13,836.9	19,408.5	19,106.1	9,980.8	2,032.8	243.6	0.0	68,427.9
	Kw	0.0	0.0	0.0	1.6	12.6	34.2	40.7	38.8	22.4	8.7	2.6	0.0	40.7
Level 5	kWh	0.0	0.0	0.0	126.9	3,605.7	13,609.0	19,129.8	18,781.2	9,778.6	1,985.2	236.8	0.0	67,253.2
	Kw	0.0	0.0	0.0	1.6	12.4	33.8	40.4	38.3	22.0	8.5	2.5	0.0	40.4
Level 6	kWh	0.0	0.0	2.3	2,201.7	6,528.4	13,816.2	19,354.2	20,556.5	11,823.7	1,807.0	150.1	0.0	76,240.1
	Kw	0.0	0.0	1.2	14.9	23.8	36.9	48.4	50.1	32.5	12.0	4.0	0.0	50.1
Monthly Totals kWh		0.0	0.0	2.3	2,731.4	19,066.3	65,295.5	92,562.7	91,309.1	46,930.0	10,018.0	1,142.4	0.0	329,057.7
Monthly Peak kW		0.0	0.0	1.2	21.6	83.6	171.0	210.3	201.2	130.1	46.9	14.6	0.0	210.3

Monthly BTU (1.1089kW/Ton)	0.0	0.0	12,985.8	233,745.2	904,680.3	1,850,482.5	2,275,768.8	2,177,292.8	1,407,881.7	507,530.0	157,994.4	0.0	2,275,768.8
Monthly Energy consumed by A.C. (BTUH)	0.0	0.0	26,478.2	31,444,617.3	219,496,414.9	751,699,499.0	1,065,606,898.2	1,051,175,115.1	540,270,883.7	115,329,932.1	13,151,618.5	0.0	3,788,201,457.1

AHU 11 Monthly Cooling Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	kWh	0.0	0.0	0.0	148.8	4,453.2	16,563.5	23,296.7	22,673.8	11,689.7	2,445.0	282.7	0.0	81,553.4
	Kw	0.0	0.0	0.0	2.0	33.4	45.1	54.4	50.9	44.7	10.5	3.1	0.0	54.4
Level 3	kWh	0.0	0.0	0.0	190.1	2,175.2	13,582.9	20,158.8	18,557.2	7,632.0	2,787.7	354.6	0.0	65,438.5
	Kw	0.0	0.0	0.0	2.4	10.8	37.8	46.9	41.8	22.6	11.6	3.8	0.0	46.9
Level 4	kWh	0.0	0.0	0.0	234.8	6,660.1	25,117.2	35,305.6	34,662.7	18,048.7	3,668.3	438.0	0.0	124,135.4
	Kw	0.0	0.0	0.0	2.9	22.8	62.4	74.6	70.7	40.6	15.8	4.6	0.0	74.6
Level 5	kWh	0.0	0.0	0.0	166.6	4,727.2	17,839.4	25,075.7	24,617.8	12,817.0	2,603.4	310.8	0.0	88,157.9
	Kw	0.0	0.0	0.0	2.1	16.2	44.4	52.9	50.2	28.9	11.2	3.3	0.0	52.9
Level 6	kWh	0.0	0.0	3.1	2,963.1	8,786.7	18,594.5	26,053.9	27,671.4	15,913.3	2,432.6	202.0	0.0	102,620.6
	Kw	0.0	0.0	1.7	20.0	32.0	49.6	65.1	67.4	43.8	16.1	5.4	0.0	67.4
Monthly Totals kWh		0.0	0.0	3.1	3,703.4	26,802.4	91,697.5	129,890.7	128,182.9	66,100.7	13,937.0	1,588.1	0.0	461,905.8
Monthly Peak kW		0.0	0.0	1.7	29.4	115.2	239.3	293.9	281.0	180.6	65.2	20.2	0.0	293.9

Monthly BTU (1.1089kW/Ton)	0.0	0.0	18,396.6	318,153.1	1,246,640.8	2,589,593.3	3,180,449.1	3,040,851.3	1,954,369.2	705,564.1	218,595.0	0.0	3,180,449.1
Monthly Energy consumed by A.C. (BTUH)	0.0	0.0	35,688.0	42,634,544.9	308,556,495.5	1,055,646,481.2	1,495,336,954.6	1,475,676,298.0	760,969,179.7	160,446,522.6	18,282,637.8	0.0	5,317,584,802.3

AHU 12 Monthly Cooling Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	kWh	0.0	0.0	0.0	96.1	2,655.4	9,103.7	12,508.4	12,530.8	6,707.9	1,464.7	185.6	0.0	45,252.6
	Kw	0.0	0.0	0.0	1.3	17.4	23.6	28.1	26.7	24.1	6.1	2.0	0.0	28.1
Level 3	kWh	0.0	0.0	0.0	114.7	1,307.1	8,093.2	12,008.8	11,056.2	4,552.6	1,664.7	214.0	0.0	39,011.3
	Kw	0.0	0.0	0.0	1.4	6.4	22.5	28.0	24.9	13.4	6.9	2.3	0.0	28.0
Level 4	kWh	0.0	0.0	0.0	89.7	2,526.6	9,471.9	13,284.6	13,075.0	6,828.9	1,392.9	167.4	0.0	46,837.0
	Kw	0.0	0.0	0.0	1.1	8.6	23.4	27.9	26.6	15.4	6.0	1.8	0.0	27.9
Level 5	kWh	0.0	0.0	0.0	100.5	2,577.5	9,554.6	13,309.3	13,132.9	6,800.5	1,431.3	187.5	0.0	47,094.1
	Kw	0.0	0.0	0.0	1.3	8.7	23.4	28.5	26.9	15.7	5.9	2.0	0.0	28.5
Level 6	kWh	0.0	0.0	1.4	1,347.6	3,991.8	8,484.9	11,864.4	12,602.7	7,254.2	1,097.2	91.1	0.0	46,735.3
	Kw	0.0	0.0	0.7	9.2	14.5	22.6	29.7	30.7	19.9	7.4	2.4	0.0	30.7
Monthly Totals kWh		0.0	0.0	1.4	1,748.6	13,058.4	44,708.3	62,975.5	62,397.6	32,144.1	7,050.8	845.6	0.0	224,930.3
Monthly Peak kW		0.0	0.0	0.7	14.3	55.6	115.5	142.2	135.8	88.5	32.3	10.5	0.0	142.2

Monthly BTU (1.1089kW/Ton)	0.0	0.0	7,575.1	154,748.0	601,677.3	1,249,887.3	1,538,822.3	1,469,564.5	957,705.8	349,535.6	113,626.1	0.0	1,538,822.3
Monthly Energy consumed by A.C. (BTUH)	0.0	0.0	16,117.2	20,130,357.3	150,331,841.2	514,694,071.0	724,991,030.0	718,338,088.5	370,051,594.2	81,170,721.2	9,734,776.5	0.0	2,589,458,597.1

AHU 13 Monthly Cooling Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 2	kWh	0.0	0.0	0.0	86.9	2,594.6	9,648.3	13,569.5	13,205.1	6,806.6	1,424.8	165.1	0.0	47,500.9
	Kw	0.0	0.0	0.0	1.2	19.5	26.3	31.7	29.7	26.0	6.1	1.8	0.0	31.7
Level 3	kWh	0.0	0.0	0.0	104.9	1,200.3	7,494.6	11,123.0	10,239.4	4,211.5	1,538.3	195.7	0.0	36,107.7
	Kw	0.0	0.0	0.0	1.3	6.0	20.9	25.9	23.1	12.5	6.4	2.1	0.0	25.9
Level 4	kWh	0.0	0.0	0.0	83.5	2,346.3	8,836.0	12,416.3	12,183.6	6,340.7	1,293.7	155.8	0.0	43,655.9
	Kw	0.0	0.0	0.0	1.0	8.0	22.0	26.3	24.9	14.3	5.5	1.7	0.0	26.3
Level 5	kWh	0.0	0.0	0.0	86.1	2,421.5	9,118.2	12,813.0	12,573.4	6,543.9	1,335.1	160.7	0.0	45,051.9
	Kw	0.0	0.0	0.0	1.1	8.3	22.7	27.1	25.7	14.8	5.7	1.7	0.0	27.1
Level 6	kWh	0.0	0.0	2.2	2,022.9	5,983.4	12,663.9	17,739.0	18,844.2	10,839.3	1,662.6	138.1	0.0	69,895.6
	Kw	0.0	0.0	1.1	13.7	21.8	33.8	44.3	45.9	29.8	11.0	3.7	0.0	45.9
Monthly Totals kWh		0.0	0.0	2.2	2,384.3	14,546.1	47,761.0	63,966.0	67,285.3	40,771.5	12,463.3	1,989.8	0.0	251,169.5
Monthly Peak kW		0.0	0.0	1.1	18.3	63.6	125.7	150.9	150.7	108.3	43.8	15.0	0.0	150.9

Monthly BTU (1.1089kW/Ton)	0.0	0.0	11,903.7	198,034.1	688,249.6	1,360,266.9	1,632,969.6	1,630,805.3	1,171,972.2	473,983.2	162,323.0	0.0	1,632,969.6
Monthly Energy consumed by A.C. (BTUH)	0.0	0.0	25,327.0	27,448,708.0	167,458,647.0	549,837,581.0	736,393,934.6	774,606,616.1	469,372,562.0	143,480,888.7	22,907,117.1	0.0	2,891,531,381.5

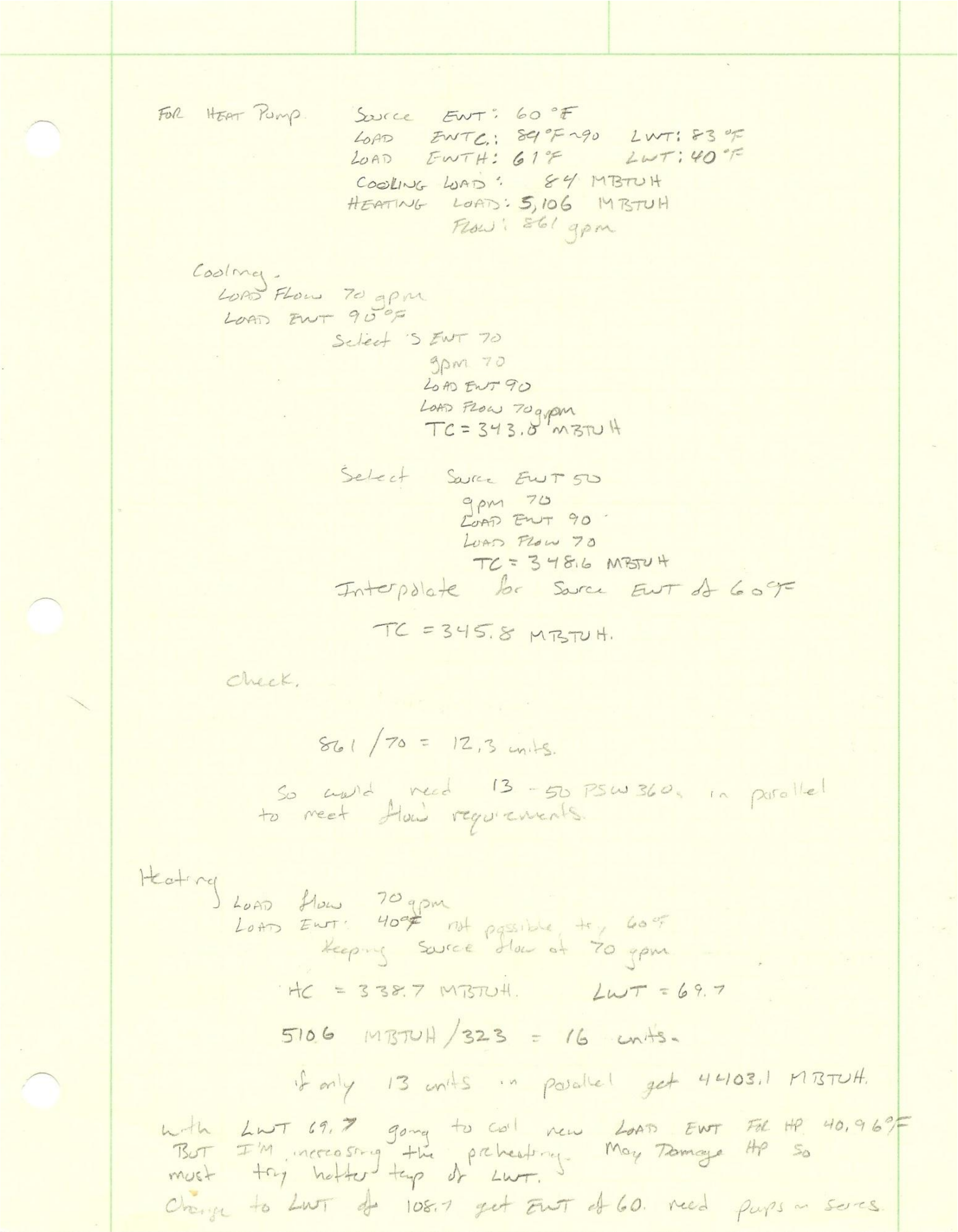
AHU 14 Monthly Cooling Coil Energy Consumption

		Jan	Feb	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Level 1	kWh	0.0	0.0	0.0	402.7	4,256.9	25,190.8	37,365.2	34,525.3	14,450.0	5,320.4	743.9	0.0	122,255.2
	Kw	0.0	0.0	0.0	5.1	19.8	69.9	88.7	77.9	41.4	21.4	7.8	0.0	88.7
Level 2	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 3	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 4	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 5	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Level 6	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monthly Totals kWh		0.0	0.0	0.0	402.7	4,256.9	25,190.8	37,365.2	34,525.3	14,450.0	5,320.4	743.9	0.0	122,255.2
Monthly Peak kW		0.0	0.0	0.0	5.1	19.8	69.9	88.7	77.9	41.4	21.4	7.8	0.0	88.7

Monthly BTU (1.1089kW/Ton)	0.0	0.0	0.0	55,189.8	214,266.4	756,425.3	959,870.2	842,997.6	448,011.5	231,580.8	84,408.0	0.0	959,870.2
Monthly Energy consumed by A.C. (BTUH)	0.0	0.0	0.0	4,635,991.6	49,006,586.9	290,003,319.4	430,158,312.9	397,464,614.2	166,352,317.7	61,249,887.3	8,563,978.5	0.0	1,407,435,008.4

Appendix E

Heat Pump Selection calculations



FOR HEAT PUMP.
SOURCE EWT: 60 °F
LOAD EWTC.: 89 °F ~90 LWT: 83 °F
LOAD EWTH: 61 °F LWT: 40 °F
COOLING LOAD: 84 MBTUH
HEATING LOAD: 5,106 MBTUH
FLOW: 861 gpm

Cooling.
LOAD FLOW 70 gpm
LOAD EWT 90 °F
Select S EWT 70
gpm 70
LOAD EWT 90
LOAD FLOW 70 gpm
TC = 343.0 MBTUH

Select Source EWT 50
gpm 70
LOAD EWT 90
LOAD FLOW 70
TC = 348.6 MBTUH
Interpolate for Source EWT of 60 °F

TC = 345.8 MBTUH.

Check.

861 / 70 = 12,3 units.

So would need 13 - 50 PSW 360s in parallel
to meet flow requirements.

Heating
LOAD flow 70 gpm
LOAD EWT: 40 °F not possible, try 60 °F
Keeping Source flow at 70 gpm

HC = 338.7 MBTUH. LWT = 69.7

5106 MBTUH / 323 = 16 units.

if only 13 units in parallel get 4403.1 MBTUH.

with LWT 69.7 going to coil new LOAD EWT FOR HP 40.96 °F
BUT I'M increasing the preheating. May Damage HP So
must try hotter temp of LWT.
Change to LWT of 108.7 get EWT of 60. need pumps in series.

Size GHx based on cooling with heat pump.

70 gpm for each loop.

water temp entering HP/leaving ground 60°F

water temp leaving HP/entering ground. 69.9°F

$$q = 500(\text{gpm})(\Delta T)$$

$$\Delta T = \frac{q}{500(\text{gpm})} = 9.88\,°F + 60°F$$

using 1½ in utube. SDR 9

$R_p = .11$ h ft °F/BTU

$R_s = 1/1.33$ BTU/h ft °F $= .7519$

$F = 1$

$$L_c = q_{d\,cool}\left[\frac{\frac{(COP_c+1)}{COP_c}(R_p + R_s F_c)}{(T_{EWT\,max} - T_{g\,max})}\right]$$

EER = 24.75

COP = (.2928) EER.

COP = 7.25

$$L_c = 345800\left[\frac{\left(\frac{8.25}{7.25}\right)(.11 + .75)}{(69.9 - 56.7)}\right] = 25{,}637\ '/\text{HP}$$

(25,637)(13) = 333,281 ' => 1,111 wells @ 300' depth

So if each Hp had this setup of wells, heating potential is.

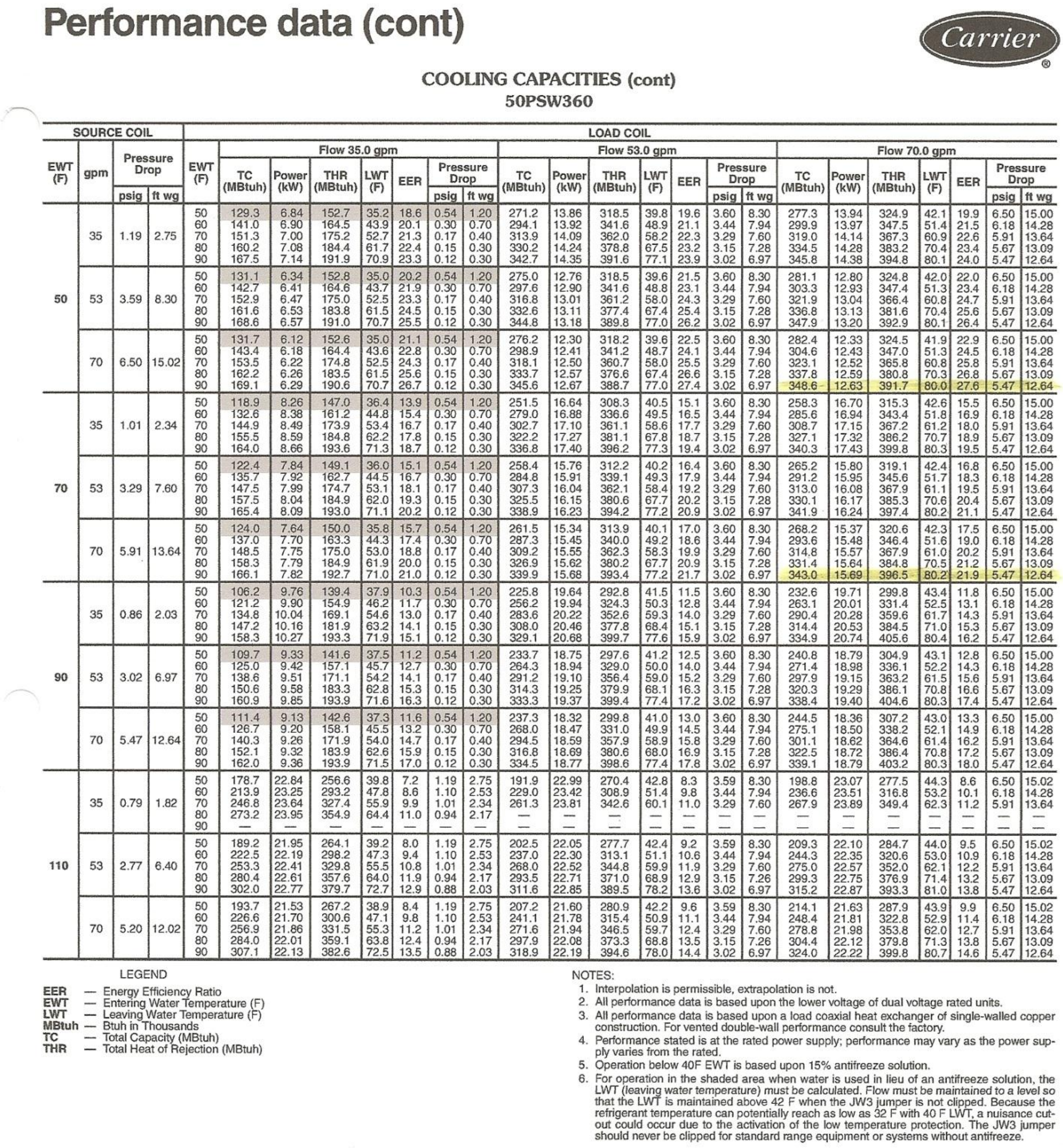
$$q_{d\,heat} = L_c\left[\frac{(T_{g\,min} - T_{EWT\,min})}{\frac{COP_h-1}{COP_h}(R_p + R_s F_h)}\right]$$

* assume no COP because no HP

$$= 25637\left[\frac{(56.7 - 36.04)}{1\,(.11 + .75)}\right] = 616 \text{ MBTUH.}$$

616 (13) = 8 008 MBTUH almost equal to current heating load of 9,379 MBTUH

Carrier Heat Pump Performance Data for 50SWP360



Performance data (cont)

COOLING CAPACITIES (cont)

50PSW360

SOURCE COIL				LOAD COIL																											
					Flow 35.0 gpm							Flow 53.0 gpm							Flow 70.0 gpm						
EWT (F)	gpm	Pressure Drop		EWT (F)	TC (MBtuh)	Power (kW)	THR (MBtuh)	LWT (F)	EER	Pressure Drop		TC (MBtuh)	Power (kW)	THR (MBtuh)	LWT (F)	EER	Pressure Drop		TC (MBtuh)	Power (kW)	THR (MBtuh)	LWT (F)	EER	Pressure Drop	
		psig	ft wg							psig	ft wg						psig	ft wg						psig	ft wg
50	35	1.19	2.75	50	129.3	6.84	152.7	35.2	18.6	0.54	1.20	271.2	13.86	318.5	39.8	19.6	3.60	8.30	277.3	13.94	324.9	42.1	19.9	6.50	15.00
				60	141.0	6.90	164.5	43.9	20.1	0.30	0.70	294.1	13.92	341.6	48.9	21.1	3.44	7.94	299.9	13.97	347.5	51.4	21.5	6.18	14.28
				70	151.3	7.00	175.2	52.7	21.3	0.17	0.40	313.9	14.09	362.0	58.2	22.3	3.29	7.60	319.0	14.14	367.3	60.9	22.6	5.91	13.64
				80	160.2	7.08	184.4	61.7	22.4	0.15	0.30	330.2	14.24	378.8	67.5	23.2	3.15	7.28	334.5	14.28	383.2	70.4	23.4	5.67	13.09
				90	167.5	7.14	191.9	70.9	23.3	0.12	0.30	342.7	14.35	391.6	77.1	23.9	3.02	6.97	345.8	14.38	394.8	80.1	24.0	5.47	12.64
	53	3.59	8.30	50	131.1	6.34	152.8	35.0	20.2	0.54	1.20	275.0	12.76	318.5	39.6	21.5	3.60	8.30	281.1	12.80	324.8	42.0	22.0	6.50	15.00
				60	142.7	6.41	164.6	43.7	21.9	0.30	0.70	297.6	12.90	341.6	48.8	23.1	3.44	7.94	303.3	12.93	347.4	51.3	23.4	6.18	14.28
				70	152.9	6.47	175.0	52.5	23.3	0.17	0.40	316.8	13.01	361.2	58.0	24.3	3.29	7.60	321.9	13.04	366.4	60.8	24.7	5.91	13.64
				80	161.6	6.53	183.8	61.5	24.5	0.15	0.30	332.6	13.11	377.4	67.4	25.4	3.15	7.28	336.8	13.13	381.6	70.4	25.6	5.67	13.09
				90	168.6	6.57	191.0	70.7	25.5	0.12	0.30	344.8	13.18	389.8	77.0	26.2	3.02	6.97	347.9	13.20	392.9	80.1	26.4	5.47	12.64
	70	6.50	15.02	50	131.7	6.12	152.6	35.0	21.1	0.54	1.20	276.2	12.30	318.2	39.6	22.5	3.60	8.30	282.4	12.33	324.5	41.9	22.9	6.50	15.00
				60	143.4	6.18	164.4	43.6	22.8	0.30	0.70	298.9	12.41	341.2	48.7	24.1	3.44	7.94	304.6	12.43	347.0	51.3	24.5	6.18	14.28
				70	153.5	6.22	174.8	52.5	24.3	0.17	0.40	318.1	12.50	360.7	58.0	25.5	3.29	7.60	323.1	12.52	365.8	60.8	25.8	5.91	13.64
				80	162.2	6.26	183.5	61.5	25.6	0.15	0.30	333.7	12.57	376.6	67.4	26.6	3.15	7.28	337.8	12.59	380.8	70.3	26.8	5.67	13.09
				90	169.1	6.29	190.6	70.7	26.7	0.12	0.30	345.6	12.67	388.7	77.0	27.4	3.02	6.97	348.6	12.63	391.7	80.0	27.6	5.47	12.64
70	35	1.01	2.34	50	118.9	8.26	147.0	36.4	13.9	0.54	1.20	251.5	16.64	308.3	40.5	15.1	3.60	8.30	258.3	16.70	315.3	42.6	15.5	6.50	15.00
				60	132.6	8.38	161.2	44.8	15.4	0.30	0.70	279.0	16.88	336.6	49.5	16.5	3.44	7.94	285.6	16.94	343.4	51.8	16.9	6.18	14.28
				70	144.9	8.49	173.9	53.4	16.7	0.17	0.40	302.7	17.10	361.1	58.6	17.7	3.29	7.60	308.7	17.15	367.2	61.2	18.0	5.91	13.64
				80	155.5	8.59	184.8	62.2	17.8	0.15	0.30	322.2	17.27	381.1	67.8	18.7	3.15	7.28	327.1	17.32	386.2	70.7	18.9	5.67	13.09
				90	164.0	8.66	193.6	71.3	18.7	0.12	0.30	336.8	17.40	396.2	77.3	19.4	3.02	6.97	340.3	17.43	399.8	80.3	19.5	5.47	12.64
	53	3.29	7.60	50	122.4	7.84	149.1	36.0	15.1	0.54	1.20	258.4	15.76	312.2	40.2	16.4	3.60	8.30	265.2	15.80	319.1	42.4	16.8	6.50	15.00
				60	135.7	7.92	162.7	44.5	16.7	0.30	0.70	284.8	15.91	339.1	49.3	17.9	3.44	7.94	291.2	15.95	345.6	51.7	18.3	6.18	14.28
				70	147.5	7.99	174.7	53.1	18.1	0.17	0.40	307.3	16.04	362.1	58.4	19.2	3.29	7.60	313.0	16.08	367.9	61.1	19.5	5.91	13.64
				80	157.5	8.04	184.9	62.0	19.3	0.15	0.30	325.5	16.15	380.6	67.7	20.2	3.15	7.28	330.1	16.17	385.3	70.6	20.4	5.67	13.09
				90	165.4	8.09	193.0	71.1	20.2	0.12	0.30	338.9	16.23	394.2	77.2	20.9	3.02	6.97	341.9	16.24	397.4	80.2	21.1	5.47	12.64
	70	5.91	13.64	50	124.0	7.64	150.0	35.8	15.7	0.54	1.20	261.5	15.34	313.9	40.1	17.0	3.60	8.30	268.2	15.37	320.6	42.3	17.5	6.50	15.00
				60	137.0	7.70	163.3	44.3	17.4	0.30	0.70	287.3	15.45	340.0	49.2	18.6	3.44	7.94	293.6	15.48	346.4	51.6	19.0	6.18	14.28
				70	148.5	7.75	175.0	53.0	18.8	0.17	0.40	309.2	15.55	362.3	58.3	19.9	3.29	7.60	314.8	15.57	367.9	61.0	20.2	5.91	13.64
				80	158.3	7.79	184.9	61.9	20.0	0.15	0.30	326.9	15.62	380.2	67.7	20.9	3.15	7.28	331.4	15.64	384.8	70.5	21.2	5.67	13.09
				90	166.1	7.82	192.7	71.0	21.0	0.12	0.30	339.9	15.68	393.4	77.2	21.7	3.02	6.97	343.0	15.69	396.5	80.2	21.9	5.47	12.64
90	35	0.86	2.03	50	106.2	9.76	139.4	37.9	10.3	0.54	1.20	225.8	19.64	292.8	41.5	11.5	3.60	8.30	232.6	19.71	299.8	43.4	11.8	6.50	15.00
				60	121.2	9.90	154.9	46.2	11.7	0.30	0.70	256.2	19.94	324.3	50.3	12.8	3.44	7.94	263.1	20.01	331.4	52.5	13.1	6.18	14.28
				70	134.8	10.04	169.1	54.6	13.0	0.17	0.40	283.6	20.22	352.6	59.3	14.0	3.29	7.60	290.4	20.28	359.6	61.7	14.3	5.91	13.64
				80	147.2	10.16	181.9	63.2	14.1	0.15	0.30	308.0	20.46	377.8	68.4	15.1	3.15	7.28	314.4	20.53	384.5	71.0	15.3	5.67	13.09
				90	158.3	10.27	193.3	71.9	15.1	0.12	0.30	329.1	20.68	399.7	77.6	15.9	3.02	6.97	334.9	20.74	405.6	80.4	16.2	5.47	12.64
	53	3.02	6.97	50	109.7	9.33	141.6	37.5	11.2	0.54	1.20	233.7	18.75	297.6	41.2	12.5	3.60	8.30	240.8	18.79	304.9	43.1	12.8	6.50	15.00
				60	125.0	9.42	157.1	45.7	12.7	0.30	0.70	264.3	18.94	329.0	50.0	14.0	3.44	7.94	271.4	18.98	336.1	52.2	14.3	6.18	14.28
				70	138.6	9.51	171.1	54.2	14.1	0.17	0.40	291.2	19.10	356.4	59.0	15.2	3.29	7.60	297.9	19.15	363.2	61.5	15.6	5.91	13.64
				80	150.6	9.58	183.3	62.8	15.3	0.15	0.30	314.3	19.25	379.9	68.1	16.3	3.15	7.28	320.3	19.29	386.1	70.8	16.6	5.67	13.09
				90	160.9	9.85	193.9	71.6	16.3	0.12	0.30	333.3	19.37	399.4	77.4	17.2	3.02	6.97	338.4	19.40	404.6	80.3	17.4	5.47	12.64
	70	5.47	12.64	50	111.4	9.13	142.6	37.3	11.6	0.54	1.20	237.3	18.32	299.8	41.0	13.0	3.60	8.30	244.5	18.36	307.2	43.0	13.3	6.50	15.00
				60	126.7	9.20	158.1	45.5	13.2	0.30	0.70	268.0	18.47	331.0	49.9	14.5	3.44	7.94	275.1	18.50	338.2	52.1	14.9	6.18	14.28
				70	140.3	9.26	171.9	54.0	14.7	0.17	0.40	294.5	18.59	357.9	58.9	15.8	3.29	7.60	301.1	18.62	364.6	61.4	16.2	5.91	13.64
				80	152.1	9.32	183.9	62.6	15.9	0.15	0.30	316.8	18.69	380.6	68.0	16.9	3.15	7.28	322.5	18.72	386.4	70.8	17.2	5.67	13.09
				90	162.0	9.36	193.9	71.5	17.0	0.12	0.30	334.5	18.77	398.6	77.4	17.8	3.02	6.97	339.1	18.79	403.2	80.3	18.0	5.47	12.64
110	35	0.79	1.82	50	178.7	22.84	256.6	39.8	7.2	1.19	2.75	191.9	22.99	270.4	42.8	8.3	3.59	8.30	198.8	23.07	277.5	44.3	8.6	6.50	15.02
				60	213.9	23.25	293.2	47.8	8.6	1.10	2.53	229.0	23.42	308.9	51.4	9.8	3.44	7.94	236.6	23.51	316.8	53.2	10.1	6.18	14.28
				70	246.8	23.64	327.4	55.9	9.9	1.01	2.34	261.3	23.81	342.6	60.1	11.0	3.29	7.60	267.9	23.89	349.4	62.3	11.2	5.91	13.64
				80	273.2	23.95	354.9	64.4	11.0	0.94	2.17	—	—	—	—	—	—	—	—	—	—	—	—	—	—
				90	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	53	2.77	6.40	50	189.2	21.95	264.1	39.2	8.0	1.19	2.75	202.5	22.05	277.7	42.4	9.2	3.59	8.30	209.3	22.10	284.7	44.0	9.5	6.50	15.02
				60	222.5	22.19	298.2	47.3	9.4	1.10	2.53	237.0	22.30	313.1	51.1	10.6	3.44	7.94	244.3	22.35	320.6	53.0	10.9	6.18	14.28
				70	253.3	22.41	329.8	55.5	10.8	1.01	2.34	268.0	22.52	344.8	59.9	11.9	3.29	7.60	275.0	22.57	352.0	62.1	12.2	5.91	13.64
				80	280.4	22.61	357.6	64.0	11.9	0.94	2.17	293.5	22.71	371.0	68.9	12.9	3.15	7.26	299.3	22.75	376.9	71.4	13.2	5.67	13.09
				90	302.0	22.77	379.7	72.7	12.9	0.88	2.03	311.6	22.85	389.5	78.2	13.6	3.02	6.97	315.2	22.87	393.3	81.0	13.8	5.47	12.64
	70	5.20	12.02	50	193.7	21.53	267.2	38.9	8.4	1.19	2.75	207.2	21.60	280.9	42.2	9.6	3.59	8.30	214.1	21.63	287.9	43.9	9.9	6.50	15.02
				60	226.6	21.70	300.6	47.1	9.8	1.10	2.53	241.1	21.78	315.4	50.9	11.1	3.44	7.94	248.4	21.81	322.8	52.9	11.4	6.18	14.28
				70	256.9	21.86	331.5	55.3	11.2	1.01	2.34	271.6	21.94	346.5	59.7	12.4	3.29	7.60	278.8	21.98	353.8	62.0	12.7	5.91	13.64
				80	284.0	22.01	359.1	63.8	12.4	0.94	2.17	297.9	22.08	373.3	68.8	13.5	3.15	7.26	304.4	22.12	379.8	71.3	13.8	5.67	13.09
				90	307.1	22.13	382.6	72.5	13.5	0.88	2.03	318.9	22.19	394.6	78.0	14.4	3.02	6.97	324.0	22.22	399.8	80.7	14.6	5.47	12.64

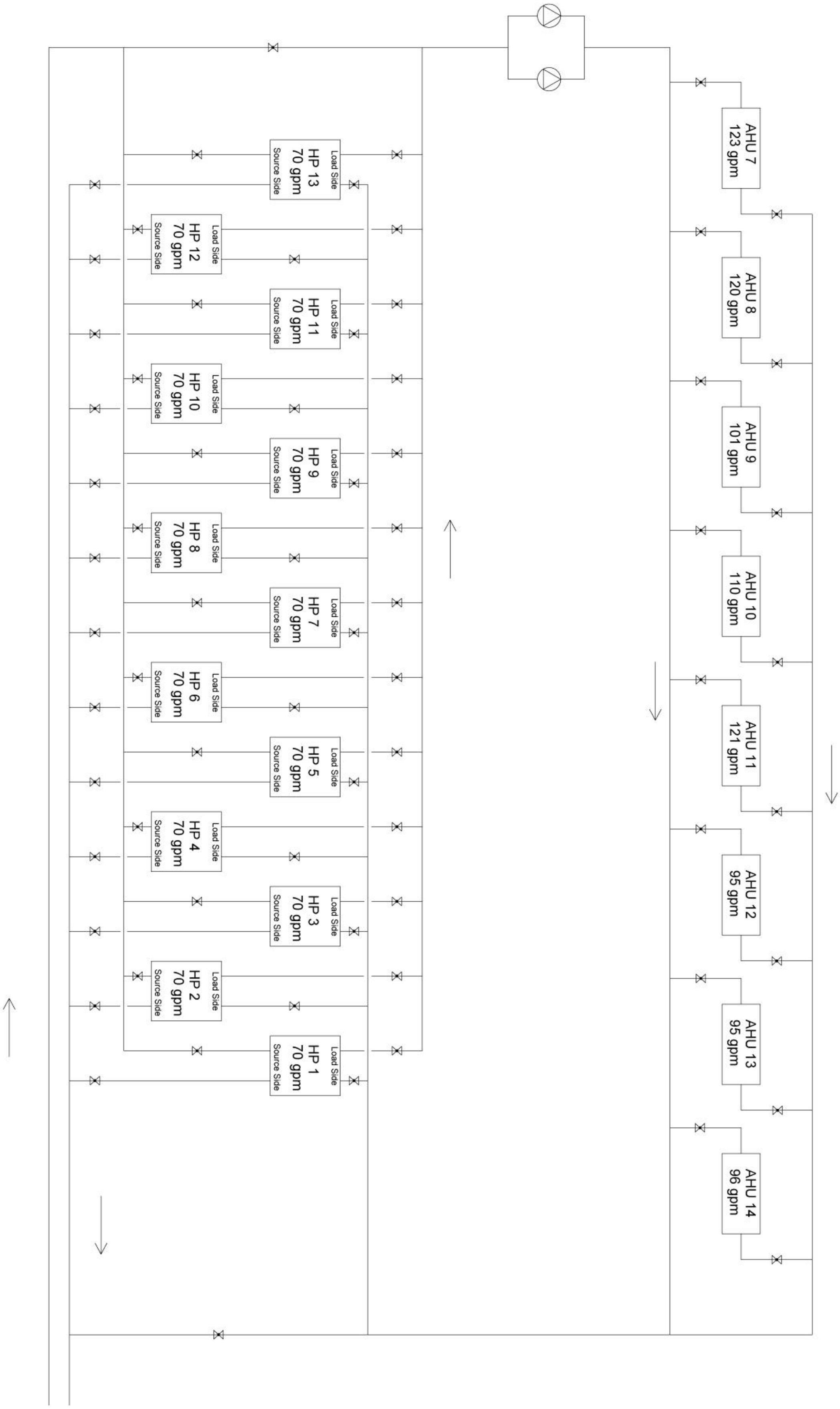
LEGEND

EER — Energy Efficiency Ratio
EWT — Entering Water Temperature (F)
LWT — Leaving Water Temperature (F)
MBtuh — Btuh in Thousands
TC — Total Capacity (MBtuh)
THR — Total Heat of Rejection (MBtuh)

NOTES:

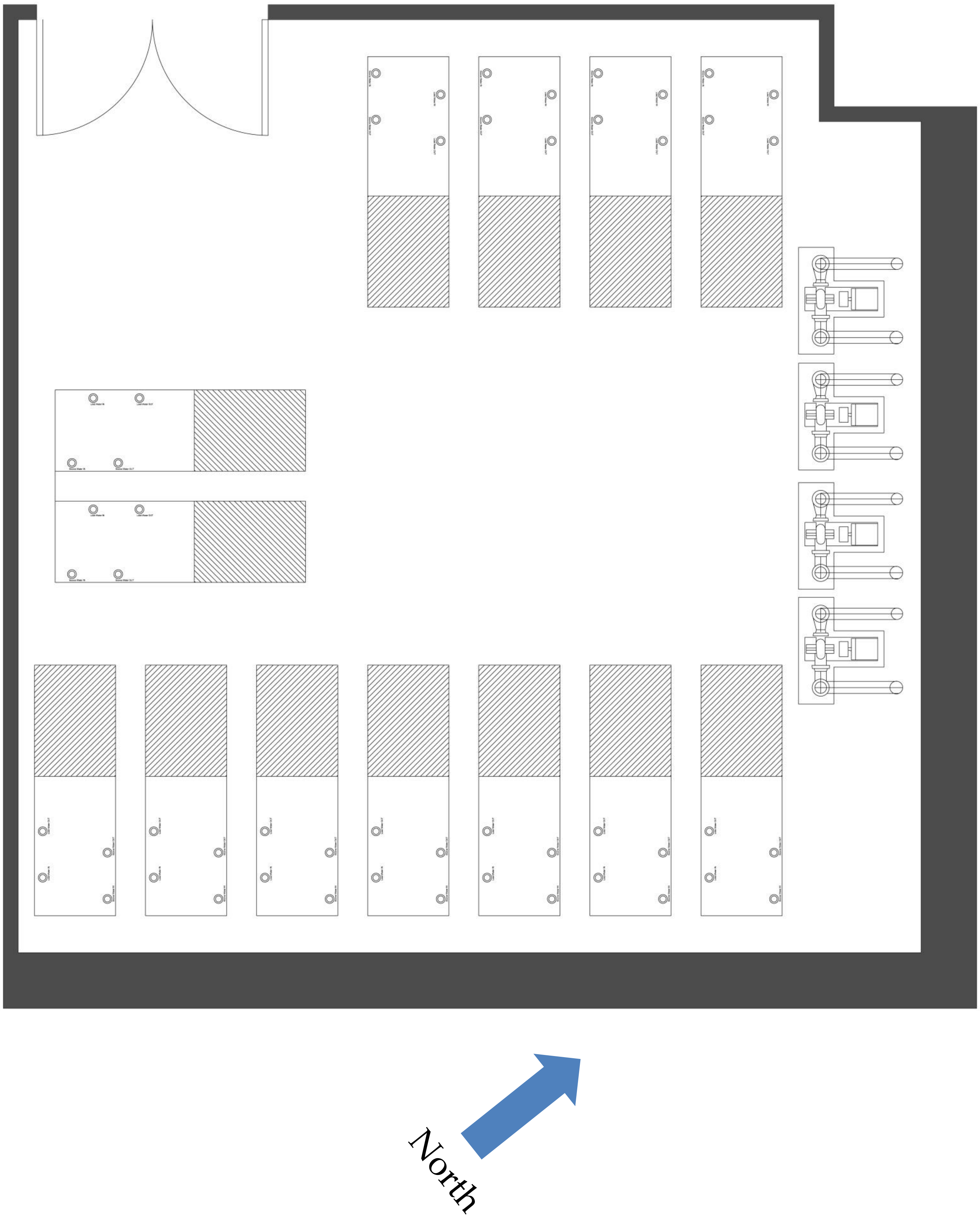
1. Interpolation is permissible, extrapolation is not.
2. All performance data is based upon the lower voltage of dual voltage rated units.
3. All performance data is based upon a load coaxial heat exchanger of single-walled copper construction. For vented double-wall performance consult the factory.
4. Performance stated is at the rated power supply; performance may vary as the power supply varies from the rated.
5. Operation below 40F EWT is based upon 15% antifreeze solution.
6. For operation in the shaded area when water is used in lieu of an antifreeze solution, the LWT (leaving water temperature) *must* be calculated. Flow must be maintained to a level so that the LWT is maintained above 42 F when the JW3 jumper is not clipped. Because the refrigerant temperature can potentially reach as low as 32 F with 40 F LWT, a nuisance cutout could occur due to the activation of the low temperature protection. The JW3 jumper should never be clipped for standard range equipment or systems without antifreeze.

Appendix F

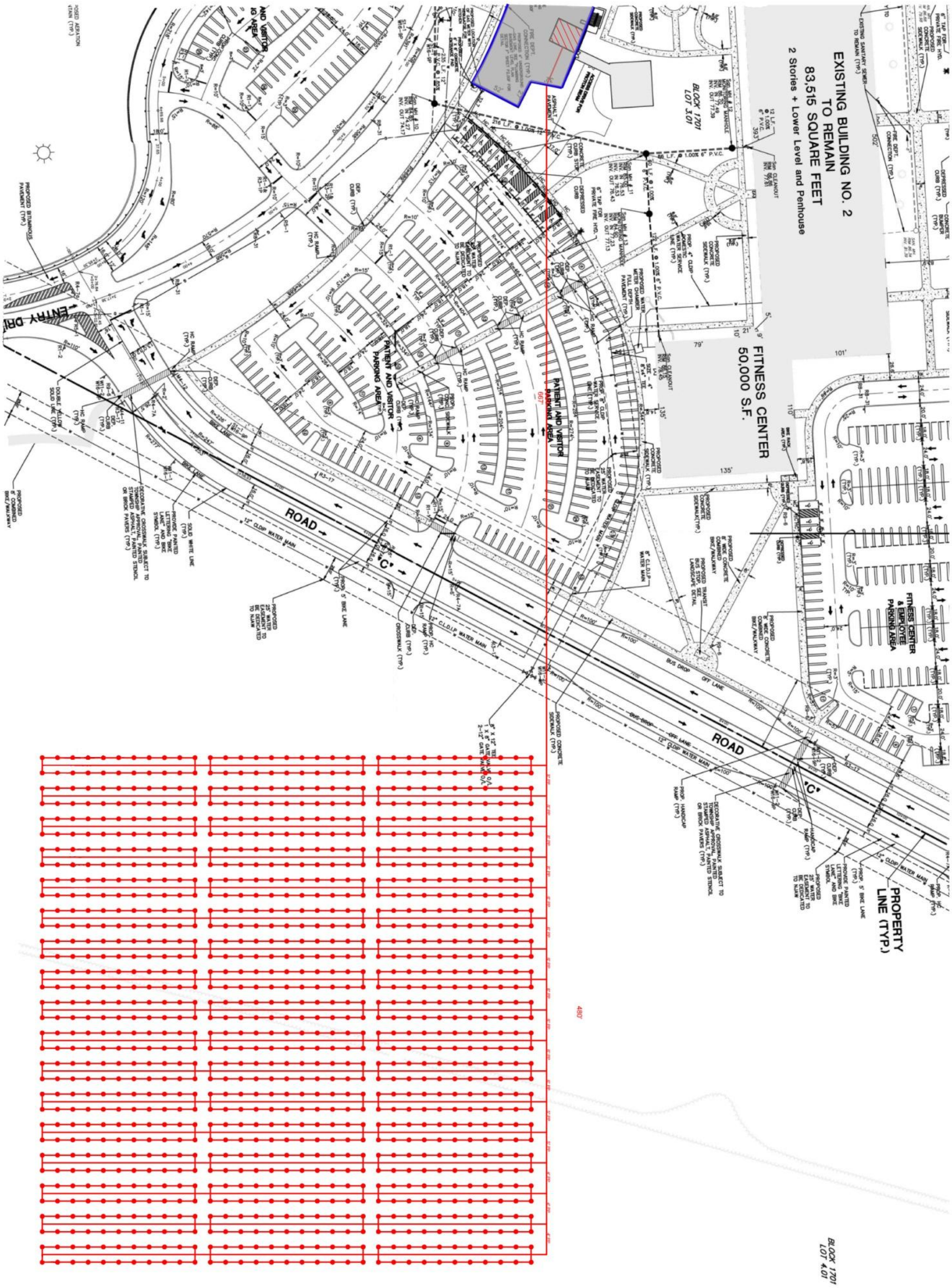

HP 13
70 gpm
HP 12
70 gpm
HP 11
70 gpm
HP 10
70 gpm
HP 9
70 gpm
HP 8
70 gpm
HP 7
70 gpm
HP 6
70 gpm
HP 5
70 gpm
HP 4
70 gpm
HP 3
70 gpm
HP 2
70 gpm
HP 1
70 gpm
Load Side
Source Side
AHU 7
123 gpm
AHU 8
120 gpm
AHU 9
101 gpm
AHU 10
110 gpm
AHU 11
121 gpm
AHU 12
95 gpm
AHU 13
95 gpm
AHU 14
96 gpm

Appendix G

Heat Pump Room Layout

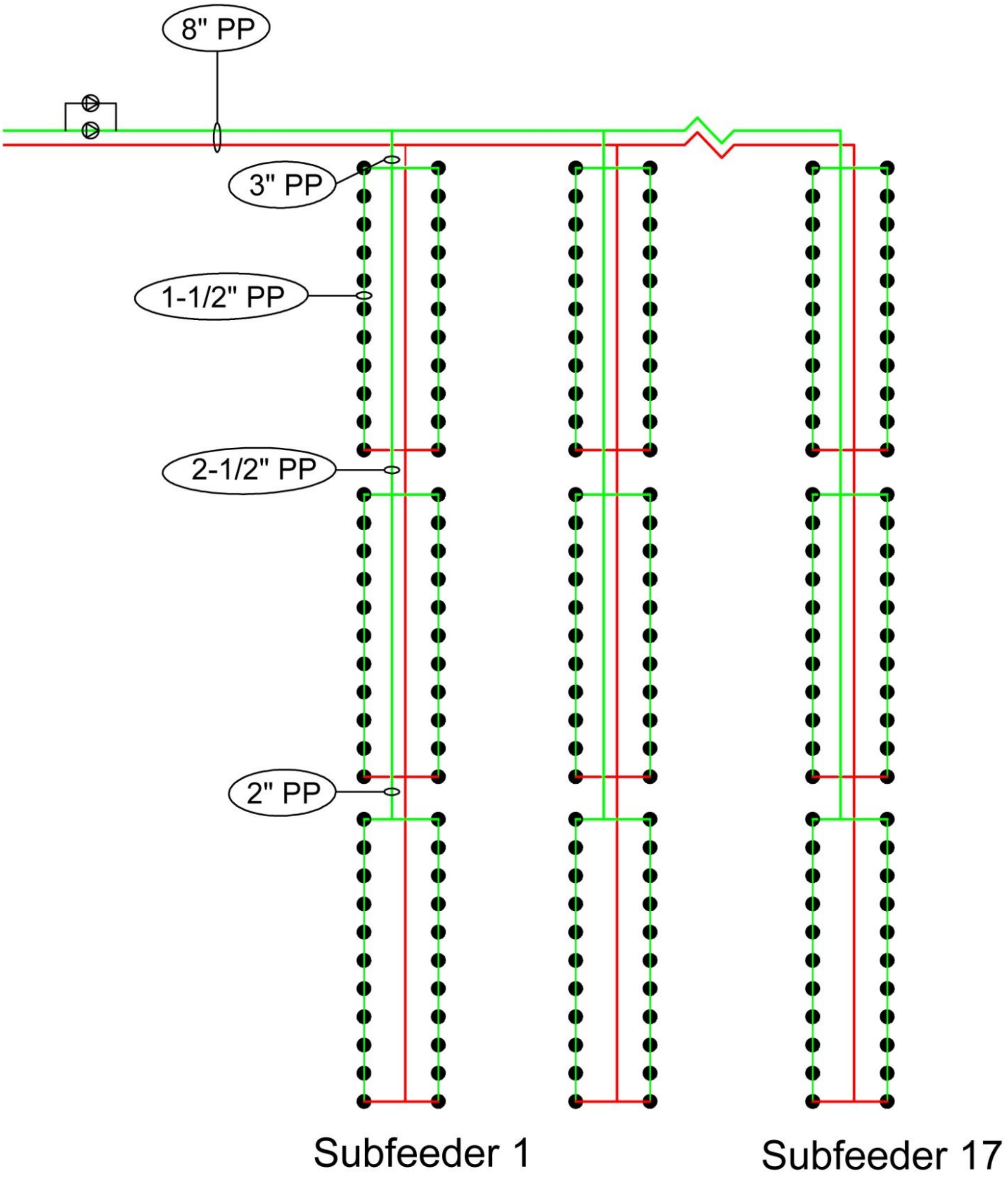

North

Well Field Layout



Well Field Single Line Diagram

*Pipe Design Criteria Shown on Next Page

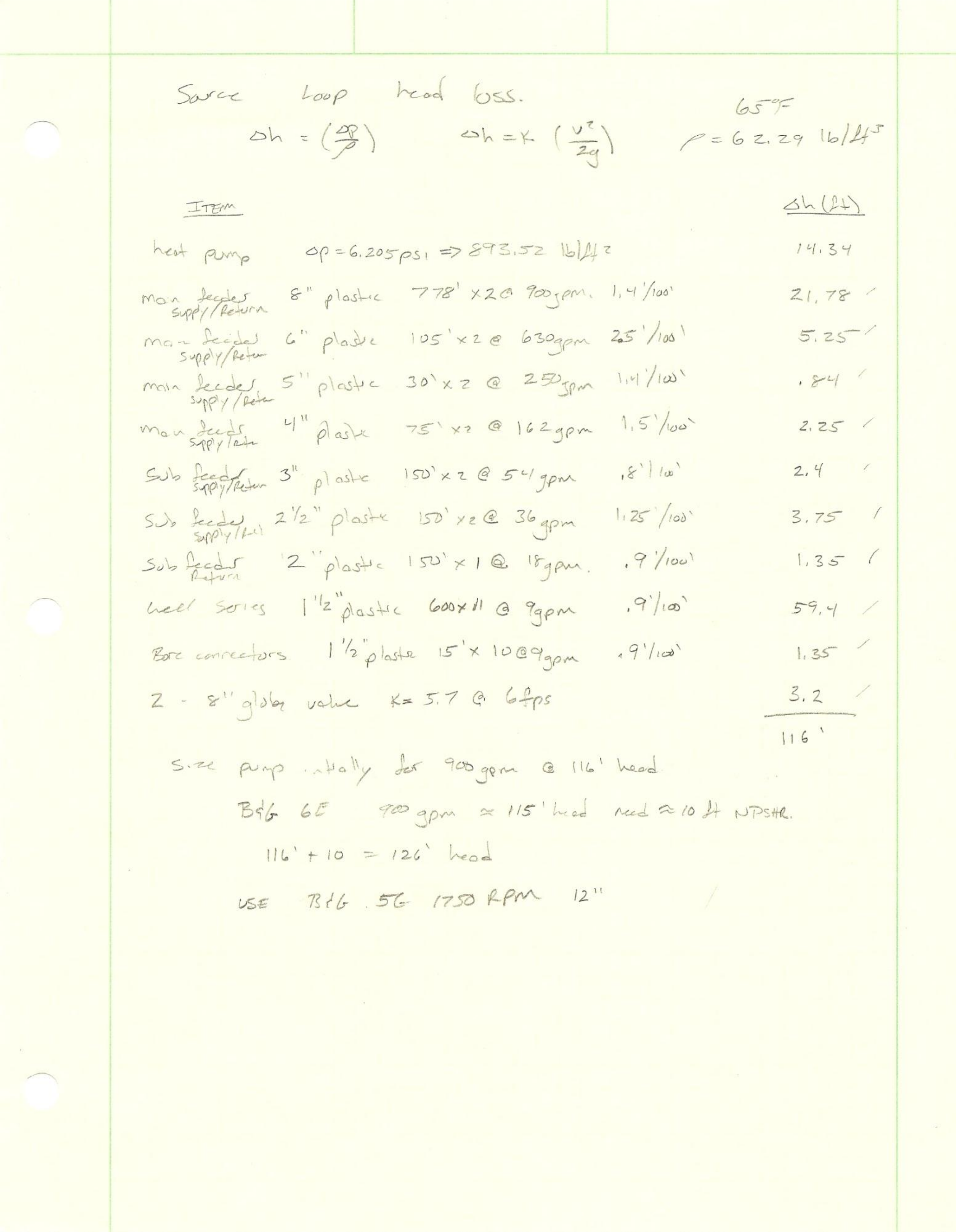


Pipe Sizing Criteria

Pipe Selection Schedule					
Designation	**Nominal Diameter (in)**	**Flow Rate (gpm)**	**Total Length (ft)**	**Head Loss (ft/100ft)**	**Velocity (fps)**
8" SP	8	900	1,073	1.25	5.75
4" SP	4	95-123		0.6-0.8	2.5
2" SP	2	70		9	6
8" PP	8	900	1,556	1.4	6
6" PP	6	630	210	2.5	8
5" PP	5	250	60	1.4	5
4" PP	4	162	150	1.5	4.5
3" PP	3	54	300	0.8	2.5
2-1/2" PP	2.5	36	5,100	1.25	2.5
2" PP	2	18	2,550	0.9	1.8
1-1/2" PP	1.5	9	666,600	0.9	1.6

Appendix H

Head Loss Calculations



Source Loop head loss.

65°F

$\Delta h = \left(\frac{\Delta p}{\rho}\right)$ $\Delta h = K\left(\frac{v^2}{2g}\right)$ $\rho = 62.29\ lb/ft^3$

ITEM					Δh (ft)
heat pump	Δp = 6.205 psi ⇒ 893.52 lb/ft²				14.34
main feeder supply/Return	8" plastic	778' x 2	@ 900 gpm.	1.4'/100'	21.78 ✓
main feeder supply/Retn	6" plastic	105' x 2	@ 630 gpm	2.5'/100'	5.25 ✓
main feeder supply/Retn	5" plastic	30' x 2	@ 250 gpm	1.4'/100'	.84 ✓
main feeder supply/Retn	4" plastic	75' x 2	@ 162 gpm	1.5'/100'	2.25 ✓
Sub feeder supply/Return	3" plastic	150' x 2	@ 54 gpm	.8'/100'	2.4 ✓
Sub feeder supply/Ret	2 1/2" plastic	150' x 2	@ 36 gpm	1.25'/100'	3.75 ✓
Sub feeder Return	2" plastic	150' x 1	@ 18 gpm.	.9'/100'	1.35 ✓
well series	1 1/2" plastic	600 x 11	@ 9 gpm	.9'/100'	59.4 ✓
Bore connectors	1 1/2" plastic	15' x 10	@ 9 gpm	.9'/100'	1.35 ✓
2 - 8" globe valve	K = 5.7 @ 6 fps				3.2 ✓
					116'

Size pump initially for 900 gpm @ 116' head

B&G 6E 900 gpm ≈ 115' head need ≈ 10 ft NPSHR.

116' + 10 = 126' head

USE B&G 5G 1750 RPM 12"

Head loss Through System.

Because in parallel find longest equivalent Run.

Fitting 4" globe — K factor 5.7

Elevation change:
From lower level 72.15'
to 119" above Roof 178.15 + 119/12

heat pump. pressure Drop of 5.7 psig.

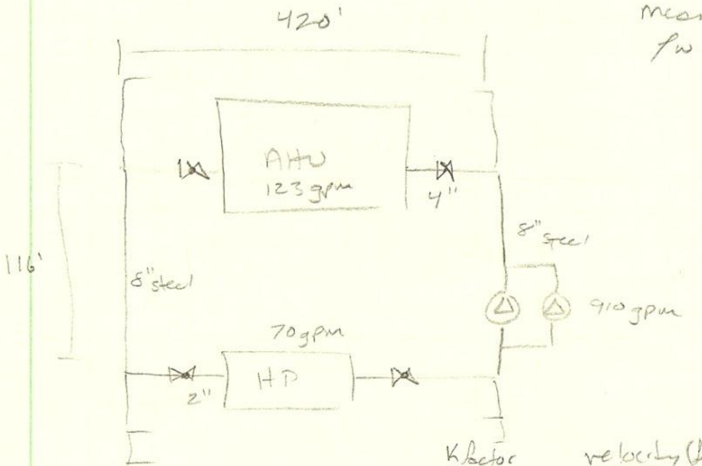
$(178.15 + (19/12)) - 72.15 = 115.92'$

8" steel pipe @ 900 gpm 1.25 ft/100ft head loss

mean water temp 85°F
$\rho_w = 62.16$ lb/ft³

$$\Delta h = K\left(\frac{v^2}{2g}\right)$$

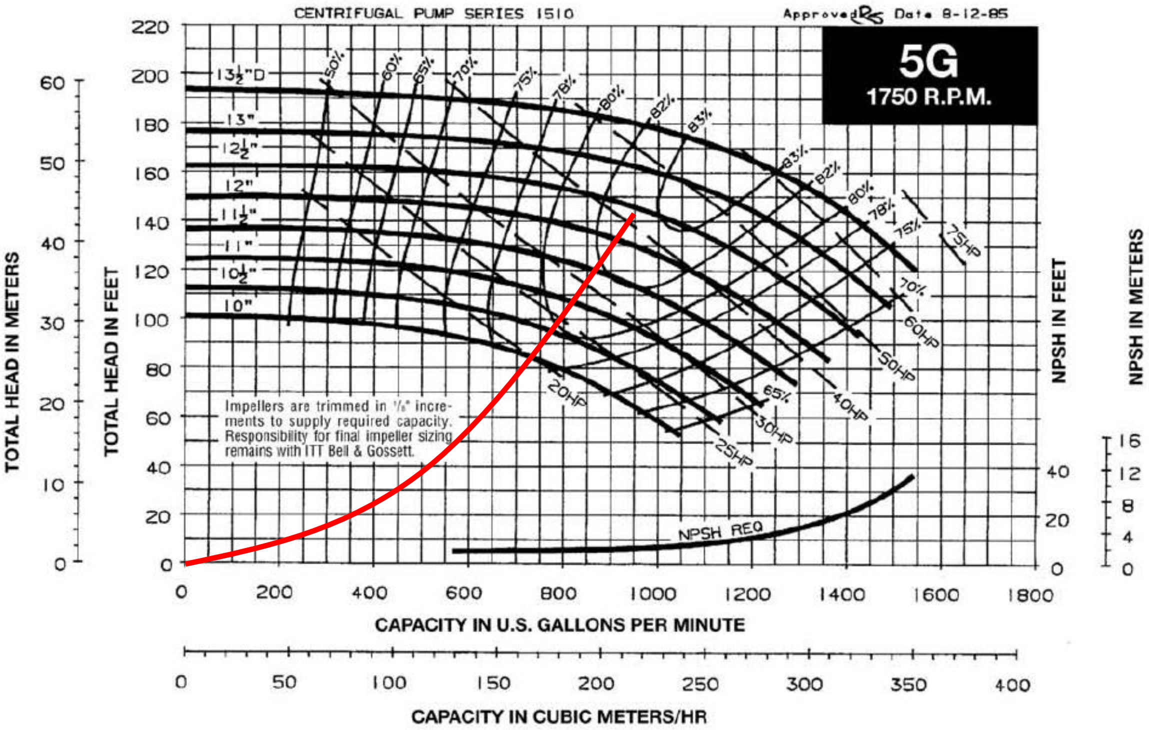
$$\Delta h = \left(\frac{\Delta P}{\rho}\right)\left(\frac{\cancelto{1}{g_c}}{g}\right)$$



	K factor	velocity (fps)	Δh (ft)	
2-4" globe valves	5.7	4	1.425	✓
2-2" globe valves	7	7	5.36	
70 gpm heat pump	ΔP 5.7 psi ⇒ 820.8 lb/ft²		13.2	
123 gpm AHU.	13 ft wg (.433) ⇒ 5.63 psi ⇒ 810.6		13.0	✓
420' 8" steel pipe sply 1.25 ft/100ft			5.25'	✓
420' 8" steel pipe return 1.25 ft/100ft			5.25'	✓
116' 8" steel pipe supply 1.25 ft/100ft			1.45'	✓
116' 8" steel pipe return			1.45'	✓

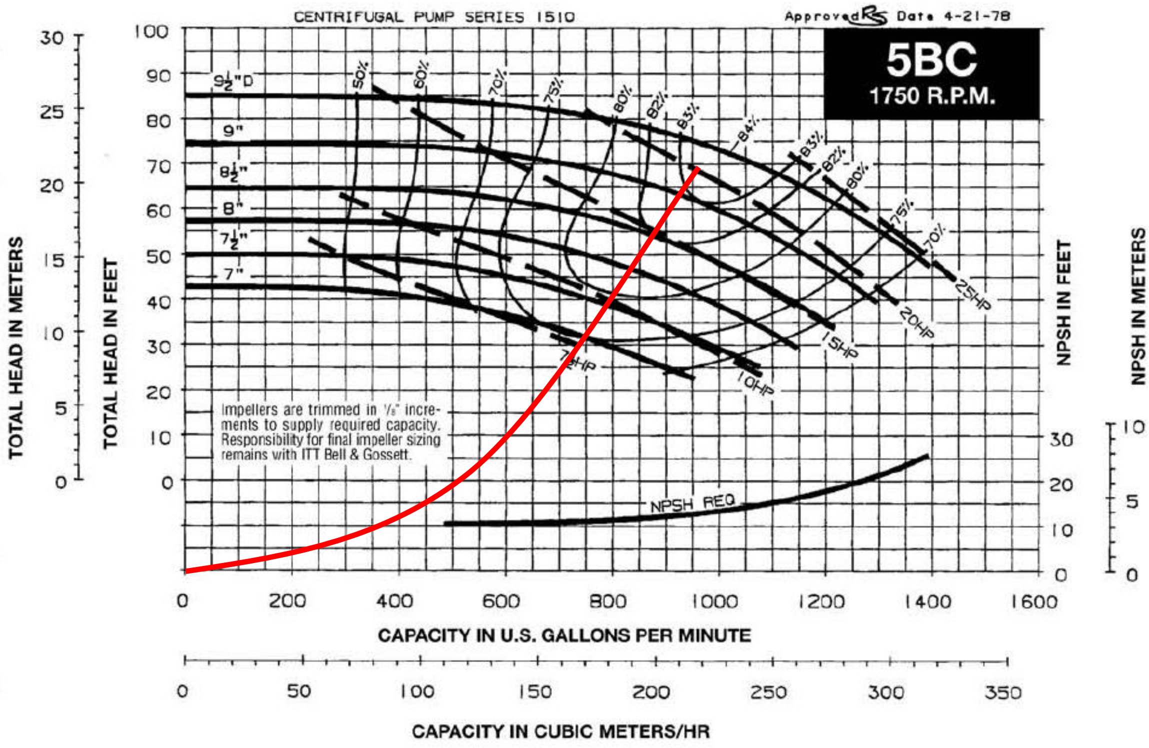
46.39'
NPSHR 12
58.39

Select the B&G 1510 Series 5BC 8"
NPSHR = 12 feet. requires to make to 9" $4515.66
17 HP 82% efficient. 16 HP. @statesupply.com


CENTRIFUGAL PUMP SERIES 1510

Approved RS Date 8-12-85

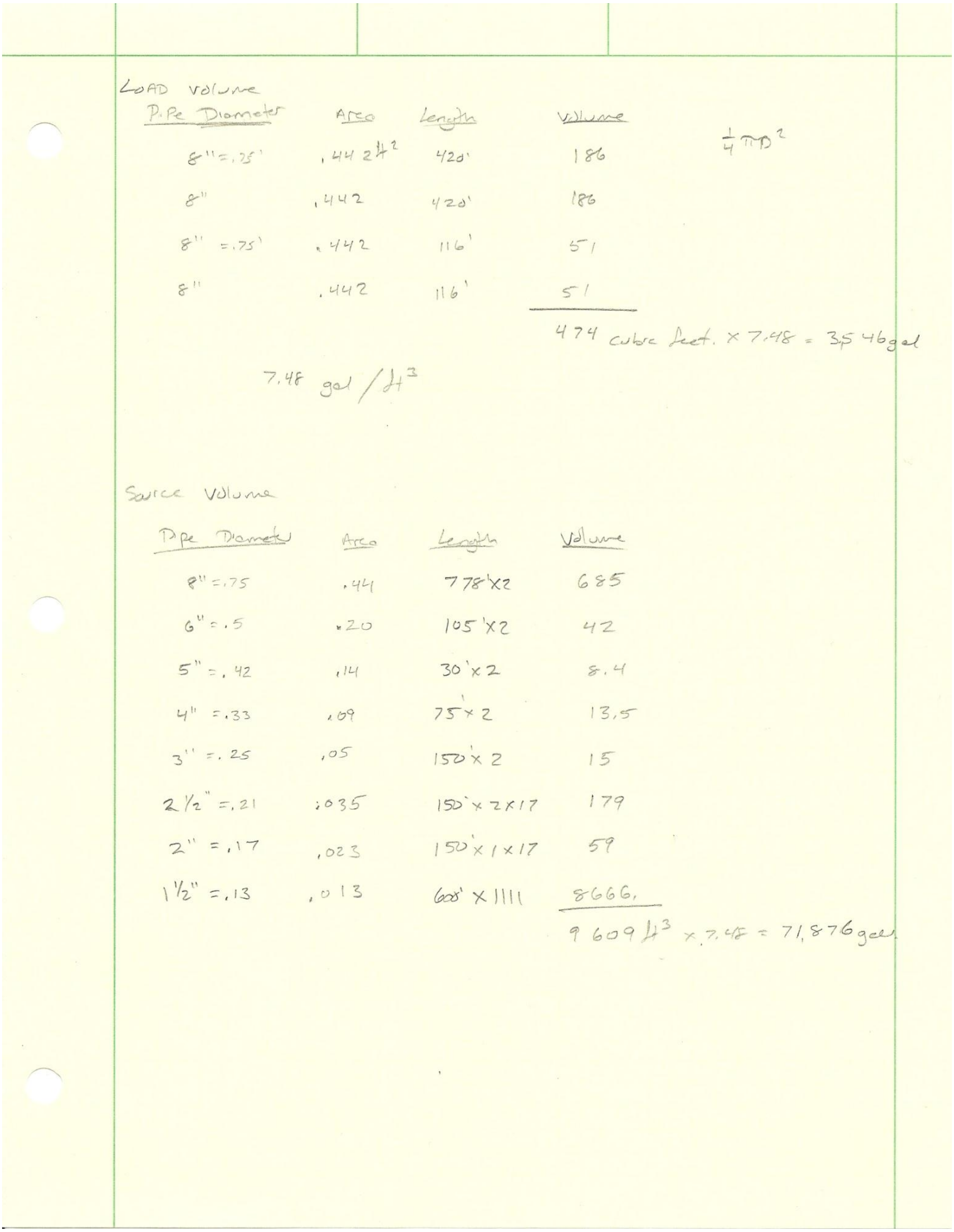
Impellers are trimmed in 1/8" increments to supply required capacity. Responsibility for final impeller sizing remains with ITT Bell & Gossett.


CENTRIFUGAL PUMP SERIES 1510

Approved RS Date 4-21-78

Impellers are trimmed in 1/8" increments to supply required capacity. Responsibility for final impeller sizing remains with ITT Bell & Gossett.

Expansion Tank Calculations



LOAD volume

Pipe Diameter	Area	Length	Volume
8" = .75'	.442 ft²	420'	186
8"	.442	420'	186
8" = .75'	.442	116'	51
8"	.442	116'	51

$\frac{1}{4}\pi D^2$

474 cubic feet. × 7.48 = 3,546 gal

7.48 gal / ft³

Source Volume

Pipe Diameter	Area	Length	Volume
8" = .75	.44	778' × 2	685
6" = .5	.20	105' × 2	42
5" = .42	.14	30' × 2	8.4
4" = .33	.09	75' × 2	13.5
3" = .25	.05	150' × 2	15
2 1/2" = .21	.035	150' × 2 × 17	179
2" = .17	.023	150' × 1 × 17	59
1 1/2" = .13	.013	600' × 1111	8666.

9609 ft³ × 7.48 = 71,876 gal

Net Positive Suction Head Requirement Check for Pumps in Series

NPSH Check for Pumps in Series	
Equipment	**Δh (ft wg)**
Head Provided by Load Side Pump	62.5
2 - 4" Globe Vales	-1.42
8" Steel Pipe 420' Long	-5.25
8" Steel Pipe 420' Long	-5.25
8" Steel Pipe 116' Long	-1.45
8" Steel Pipe 116' Long	-1.45
123 gpm AHU Heat Recovery Coil	-13
NPSH Available for Source Side Pump	34.68
NPSH Required for Source Side Pump	10
Head Provided by Source Side Pump	132
8" Plastic Pipe 1556' Long	-21.78
6" Plastic Pipe 210' Long	-5.25
5" Plastic Pipe 60' Long	-0.84
4" Plastic Pipe 150' Long	-2.25
3" Plastic Pipe 300' Long	-2.4
2-1/2" Plastic Pipe 300' Long	-3.75
2" Plastic Pipe 300' Long	-1.35
1-1/2" Plastic Pipe 6600' Long	-59.4
1-1/2" Plastic Pipe 150' Long	-1.35
8" Globe Valve	-3.2
NPSH Avalalbe for Load Side Pump	30.43
NPSH Required for Load Side Pump	12

LOAD LOOP E.T.

$$V_T = V_W \left[\left(\frac{v_2}{v_1} - 1 \right) - 3\alpha \Delta T \right.$$

$V_W = 3546$ gal

$v_1 = .01602$ ft³/lbm $\quad T_1 = 36$ °F - from coils in winter

$v_2 = .01610$ ft³/lbm $\quad T_2 = 90$ °F - from coils in summer

$\Delta T = 50$ °F

$\alpha = 6.8 \times 10^{-6}$

$$V_T = 3546 \left[\left(\frac{.01610}{.01602} - 1 \right) - 3(6.8 \times 10^{-6})(50) \right]$$

$V_T = 1.4$ gal.

Source Loop E.T.

$V_W = 71876$ gal.

$T_1 = 36$ - from coils in winter

$T_2 = 70$ - from hp in summer

$v_1 = .01602$

$v_2 = .01605$

$\Delta T = 34$ °F

$\alpha = 6.8 \times 10^{-6}$

$$V_T = 71,876 \left[\left(\frac{.01605}{.01602} - 1 \right) - 3(6.8 \times 10^{-6})(34) \right]$$

$V_T = 85$ gal.

Appendix I

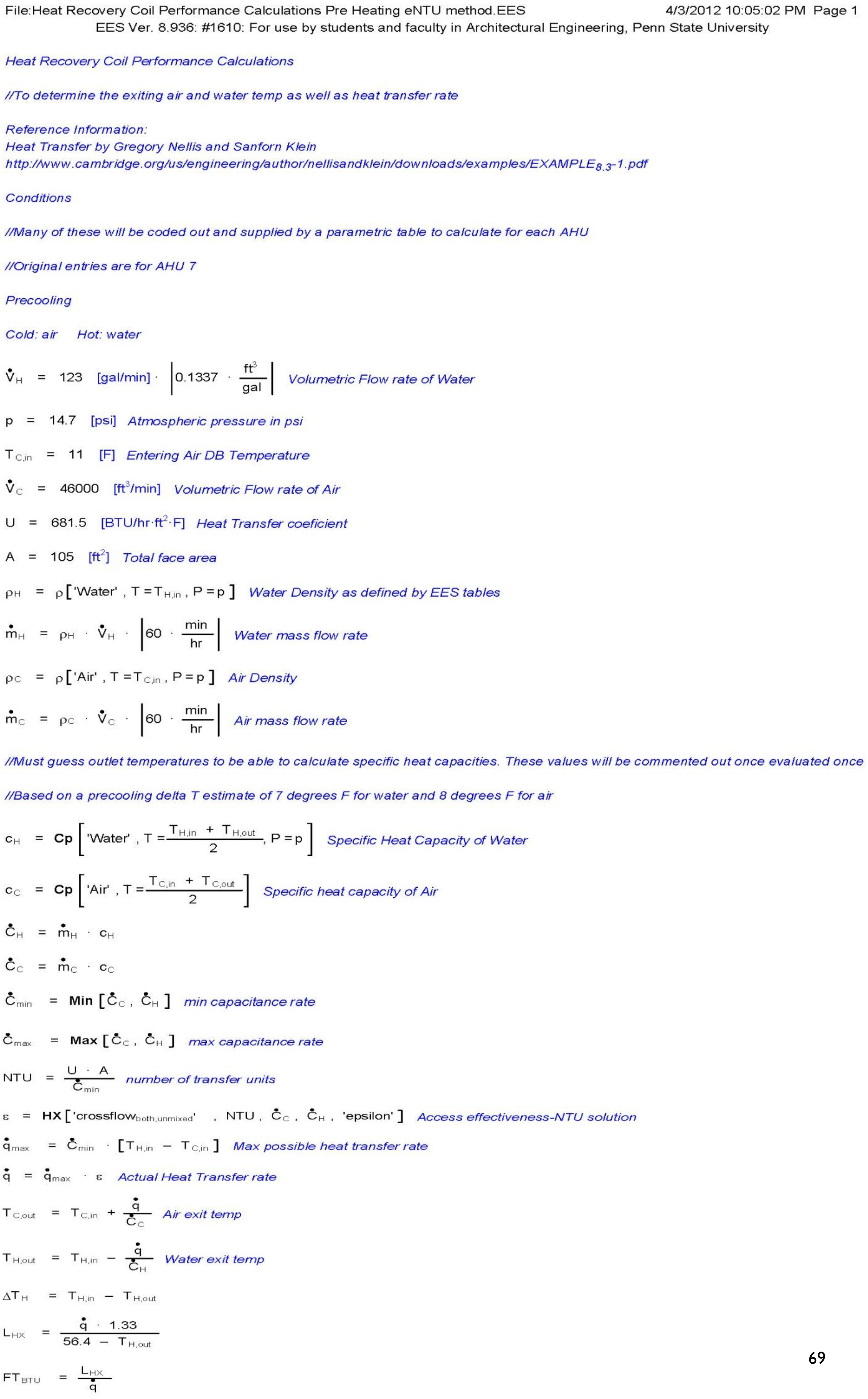
U Value Calculations

Cooling U Value Calcuations for Heat Recovery Coils Using LMTD Method

AHU		Cooling Heat Rate (BTU/hr)		Cooling EWT (°F)	Cooling LWT (°F)	Water Flow Rate (gpm)	Design Outdoor Air Temp (°F)	Leaving DB Temp (°F)	Air Flow Rate (cfm)	Face Area (SF)	F Value		T1	T2	Tlm		Calculated U Value (BTU/hr-ft2-°F)
7		396104		82.2	88.9	123	93	85.2	46000	105	0.7343		4.1	3	3.52141		1458.9
8		436579		81.7	89.3	120	93	85.1	50000	116.25	0.7343		3.7	3.4	3.54789		1441.5
9		282006		83.1	88.9	101	93	85.7	35000	79.15	0.7343		4.1	2.6	3.29326		1473.4
10		349630		82.5	89.2	110	93	85.5	42000	95.81	0.7343		3.8	3	3.38426		1468.5
11		418942		82.2	89.5	121	93	85.4	50000	116.25	0.7343		3.5	3.2	3.34776		1466.0
12		248095		83.1	88.6	95	93	85.5	30000	70	0.7343		4.4	2.4	3.29959		1462.8
13		248095		83.1	88.6	95	93	85.5	30000	70	0.7343		4.4	2.4	3.29959		1462.8
14		161346		84.1	87.6	96	93	87.6	20000	48.75	0.7343		5.4	3.5	4.38156		1028.7

Cooling U Value Calcuations for Heat Recovery Coils Using LMTD Method

AHU		Heating Heat Rate (BTU/hr)		Heaitng EWT (°F)	Heating LWT (°F)	Water Flow Rate (gpm)	Design Outdoor Air Temp (°F)	Leaving DB Temp (°F)	Air Flow Rate (cfm)	Face Area (SF)	F Value		T1	T2	Tlm		Calculated U Value (BTU/hr-ft2-°F)
7		1441504		61.1	36.7	123	11	39.9	46000	105	0.8617		21.2	25.7	23.37786		681.5
8		1569503		62.5	35.3	120	11	39.9	50000	116.25	0.8617		22.6	24.3	23.43973		668.4
9		1057792		58.6	36.8	101	11	38.9	35000	79.15	0.8617		19.7	25.8	22.61304		685.9
10		1273115		60.3	36.2	110	11	39	42000	95.81	0.8617		21.3	25.2	23.19538		664.8
11		1523919		61.2	35	121	11	39.1	50000	116.25	0.8617		22.1	24	23.03694		660.4
12		936480		58.5	38	95	11	39.8	30000	70	0.8617		18.7	27	22.59651		687.1
13		936480		58.5	38	95	11	39.8	30000	70	0.8617		18.7	27	22.59651		687.1
14		640098		54.5	40.6	96	11	40.5	20000	48.75	0.8617		14	29.6	20.83564		731.3



File:Heat Recovery Coil Performance Calculations Pre Heating eNTU method.EES 4/3/2012 10:05:02 PM Page 1
EES Ver. 8.936: #1610: For use by students and faculty in Architectural Engineering, Penn State University

Heat Recovery Coil Performance Calculations

//To determine the exiting air and water temp as well as heat transfer rate

Reference Information:
Heat Transfer by Gregory Nellis and Sanforn Klein
http://www.cambridge.org/us/engineering/author/nellisandklein/downloads/examples/EXAMPLE$_{8.3}$-1.pdf

Conditions

//Many of these will be coded out and supplied by a parametric table to calculate for each AHU

//Original entries are for AHU 7

Precooling

Cold: air *Hot: water*

$\dot{V}_H = 123\ [\text{gal/min}] \cdot \left| 0.1337 \cdot \frac{\text{ft}^3}{\text{gal}} \right|$ *Volumetric Flow rate of Water*

$p = 14.7\ [\text{psi}]$ *Atmospheric pressure in psi*

$T_{C,in} = 11\ [\text{F}]$ *Entering Air DB Temperature*

$\dot{V}_C = 46000\ [\text{ft}^3/\text{min}]$ *Volumetric Flow rate of Air*

$U = 681.5\ [\text{BTU/hr} \cdot \text{ft}^2 \cdot \text{F}]$ *Heat Transfer coeficient*

$A = 105\ [\text{ft}^2]$ *Total face area*

$\rho_H = \rho\left[\text{'Water'}, T = T_{H,in}, P = p\right]$ *Water Density as defined by EES tables*

$\dot{m}_H = \rho_H \cdot \dot{V}_H \cdot \left| 60 \cdot \frac{\text{min}}{\text{hr}} \right|$ *Water mass flow rate*

$\rho_C = \rho\left[\text{'Air'}, T = T_{C,in}, P = p\right]$ *Air Density*

$\dot{m}_C = \rho_C \cdot \dot{V}_C \cdot \left| 60 \cdot \frac{\text{min}}{\text{hr}} \right|$ *Air mass flow rate*

//Must guess outlet temperatures to be able to calculate specific heat capacities. These values will be commented out once evaluated once

//Based on a precooling delta T estimate of 7 degrees F for water and 8 degrees F for air

$c_H = \mathbf{Cp}\left[\text{'Water'}, T = \frac{T_{H,in} + T_{H,out}}{2}, P = p\right]$ *Specific Heat Capacity of Water*

$c_C = \mathbf{Cp}\left[\text{'Air'}, T = \frac{T_{C,in} + T_{C,out}}{2}\right]$ *Specific heat capacity of Air*

$\dot{C}_H = \dot{m}_H \cdot c_H$

$\dot{C}_C = \dot{m}_C \cdot c_C$

$\dot{C}_{min} = \mathbf{Min}\left[\dot{C}_C, \dot{C}_H\right]$ *min capacitance rate*

$\dot{C}_{max} = \mathbf{Max}\left[\dot{C}_C, \dot{C}_H\right]$ *max capacitance rate*

$NTU = \frac{U \cdot A}{\dot{C}_{min}}$ *number of transfer units*

$\varepsilon = \mathbf{HX}\left[\text{'crossflow}_{\text{both,unmixed}}\text{'}, NTU, \dot{C}_C, \dot{C}_H, \text{'epsilon'}\right]$ *Access effectiveness-NTU solution*

$\dot{q}_{max} = \dot{C}_{min} \cdot \left[T_{H,in} - T_{C,in}\right]$ *Max possible heat transfer rate*

$\dot{q} = \dot{q}_{max} \cdot \varepsilon$ *Actual Heat Transfer rate*

$T_{C,out} = T_{C,in} + \frac{\dot{q}}{\dot{C}_C}$ *Air exit temp*

$T_{H,out} = T_{H,in} - \frac{\dot{q}}{\dot{C}_H}$ *Water exit temp*

$\Delta T_H = T_{H,in} - T_{H,out}$

$L_{HX} = \frac{\dot{q} \cdot 1.33}{56.4 - T_{H,out}}$

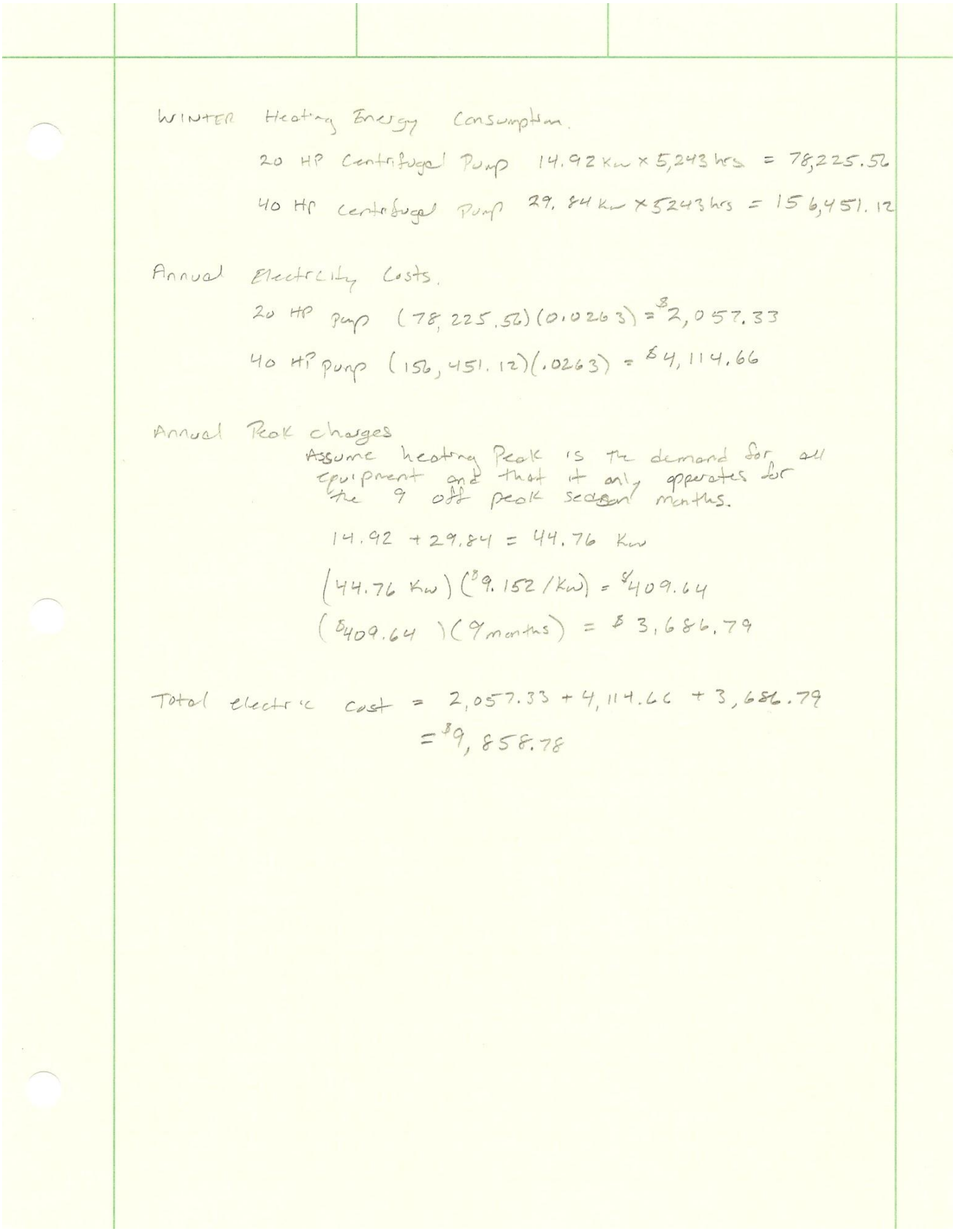
$FT_{BTU} = \frac{L_{HX}}{\dot{q}}$

Parametric Table: Table 1

	$T_{H,in}$ [F]	L_{HX}	FT_{BTU}	$T_{H,out}$ [F]	ΔT_H	$\dot{q}$ [BTU/hr]	$T_{C,out}$ [F]
Run 1	20	6088	0.03055	12.87	7.133	199279.0	14.57
Run 2	22	7527	0.03085	13.29	8.707	243972.3	15.38
Run 3	24	9001	0.03117	13.72	10.28	288819.3	16.18
Run 4	26	10511	0.03149	14.16	11.84	333822.5	16.99
Run 5	28	12059	0.03182	14.6	13.4	378984.5	17.8
Run 6	30	13646	0.03216	15.04	14.96	424308.3	18.61
Run 7	32	16263	0.03306	16.17	15.83	491930.8	19.82
Run 8	34	18080	0.0335	16.69	17.31	539763.9	20.68
Run 9	36	19954	0.03395	17.22	18.78	587773.6	21.54
Run 10	38	21888	0.03442	17.76	20.24	635962.1	22.41
Run 11	40	23888	0.03491	18.3	21.7	684332.1	23.27
Run 12	42	25955	0.03541	18.85	23.15	732886.4	24.14
Run 13	44	28095	0.03594	19.4	24.6	781628.3	25.02
Run 14	46	51130	0.04846	28.95	17.05	1055172.8	29.92
Run 15	48	56106	0.05031	29.97	18.03	1115134.7	31
Run 16	50	61479	0.05232	30.98	19.02	1175098.2	32.07
Run 17	52	67298	0.05449	31.99	20.01	1235061.7	33.15
Run 18	54	73621	0.05685	33	21	1295029.7	34.22
Run 19	56	80518	0.05942	34.02	21.98	1355000.2	35.3
Run 20	58	88068	0.06224	35.03	22.97	1414973.6	36.37
Run 21	60	96371	0.06534	36.04	23.96	1474947.6	37.45
Run 22	62	105544	0.06876	37.06	24.94	1534922.8	38.52
Run 23	64	115731	0.07256	38.07	25.93	1594901.3	39.6
Run 24	66	127110	0.07681	39.08	26.92	1654876.1	40.67
Run 25	68	139904	0.08158	40.1	27.9	1714851.3	41.75
Run 26	70	154391	0.08699	41.11	28.89	1774821.9	42.82
Run 27	72	170932	0.09316	42.12	29.88	1834790.0	43.9
Run 28	74	189995	0.1003	43.14	30.86	1894751.4	44.97
Run 29	76	212204	0.1086	44.15	31.85	1954705.5	46.05
Run 30	78	238406	0.1183	45.16	32.84	2014650.7	47.12
Run 31	80	269781	0.13	46.17	33.83	2074586.2	48.2
Run 32	82	308028	0.1443	47.18	34.82	2134509.9	49.27
Run 33	84	355677	0.1621	48.19	35.81	2194421.3	50.35
Run 34	86	416673	0.1848	49.2	36.8	2254316.6	51.42
Run 35	88	497547	0.215	50.21	37.79	2314199.6	52.49
Run 36	90	609864	0.2569	51.22	38.78	2374061.6	53.57
Run 37	92	776417	0.319	52.23	39.77	2433907.9	54.64
Run 38	94	1.049E+06	0.4206	53.24	40.76	2493735.3	55.71
Run 39	96	1.576E+06	0.6171	54.24	41.76	2553542.0	56.78
Run 40	98	3.023E+06	1.157	55.25	42.75	2613327.0	57.85
Run 41	100	2.455E+07	9.184	56.26	43.74	2673089.5	58.92
Run 42	102	-4.230E+06	-1.548	57.26	44.74	2732830.4	60
Run 43	104	-1.994E+06	-0.7142	58.26	45.74	2792546.9	61.07
Run 44	106	-1.324E+06	-0.4643	59.26	46.74	2852238.7	62.14
Run 45	108	-1.001E+06	-0.3441	60.27	47.73	2911904.4	63.2
Run 46	110	-812284	-0.2734	61.27	48.73	2971546.6	64.27
Run 47	112	-687423	-0.2268	62.26	49.74	3031161.7	65.34
Run 48	114	-599002	-0.1938	63.26	50.74	3090748.5	66.41
Run 49	116	-533106	-0.1692	64.26	51.74	3150306.0	67.48
Run 50	118	-482094	-0.1502	65.26	52.74	3209838.1	68.54
Run 51	120	-441439	-0.135	66.25	53.75	3269343.1	69.61
Run 52	122	-408283	-0.1227	67.24	54.76	3328818.4	70.67
Run 53	124	-380727	-0.1124	68.24	55.76	3388264.2	71.74
Run 54	126	-357461	-0.1037	69.23	56.77	3447682.7	72.8
Run 55	128	-337559	-0.09625	70.22	57.78	3507070.4	73.87
Run 56	130	-320339	-0.08982	71.21	58.79	3566432.2	74.93
Run 57	132	-305298	-0.0842	72.2	59.8	3625759.2	75.99
Run 58	134	-292044	-0.07925	73.18	60.82	3685061.0	77.06
Run 59	136	-280279	-0.07485	74.17	61.83	3744329.9	78.12
Run 60	138	-269765	-0.07092	75.15	62.85	3803570.6	79.18

Appendix J

GHX Electrical Cost Calculations



WINTER Heating Energy Consumption.

20 HP Centrifugal Pump 14.92 Kw × 5,243 hrs = 78,225.56

40 HP centrifugal Pump 29.84 Kw × 5243 hrs = 156,451.12

Annual Electricity Costs.

20 HP pump (78,225.56)(0.0263) = \$2,057.33

40 HP pump (156,451.12)(.0263) = \$4,114.66

Annual Peak charges

Assume heating Peak is the demand for all equipment and that it only opperates for the 9 off peak season months.

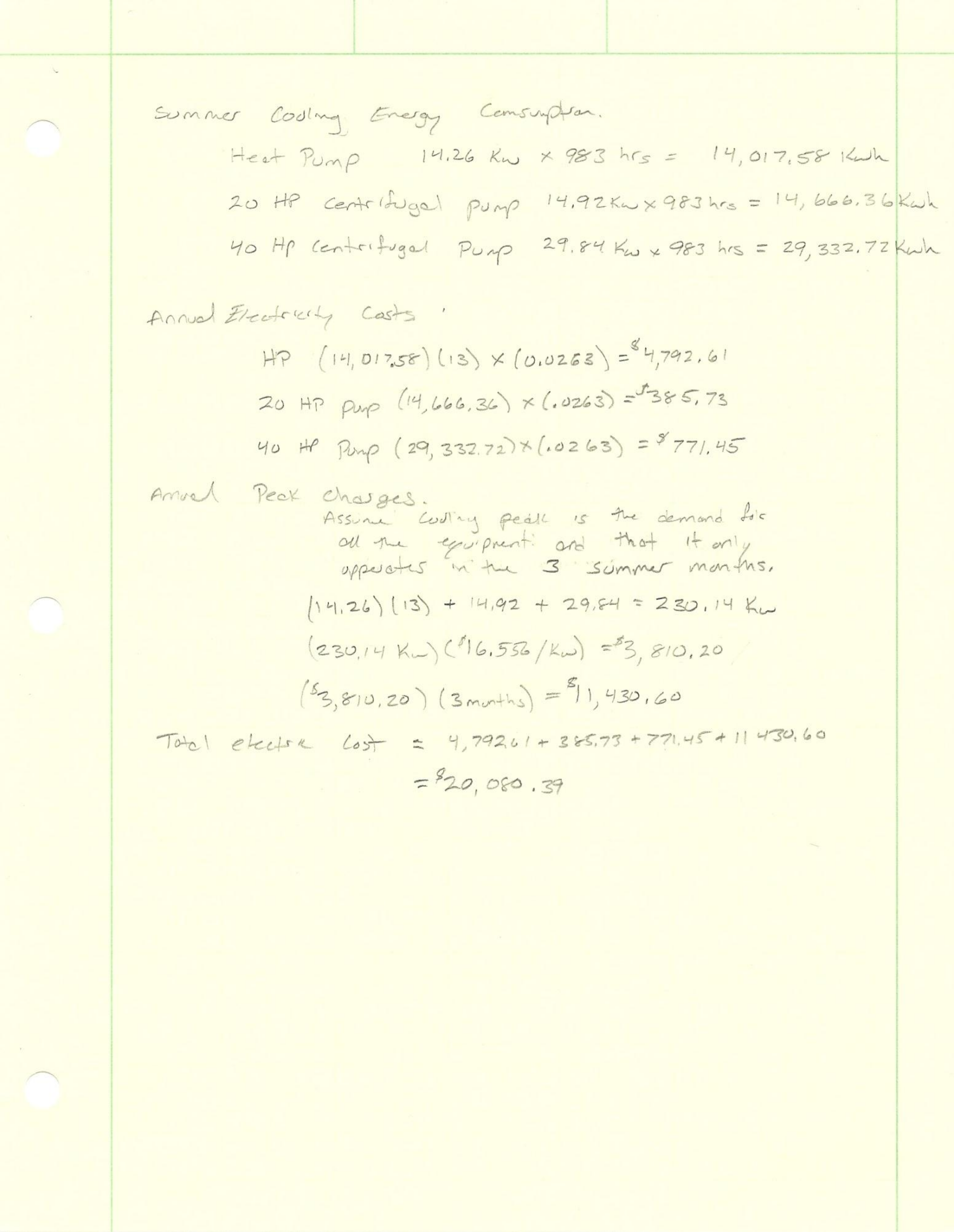
14.92 + 29.84 = 44.76 Kw

(44.76 Kw)(\$9.152/Kw) = \$409.64

(\$409.64)(9 months) = \$3,686.79

Total electric cost = 2,057.33 + 4,114.66 + 3,686.79
= \$9,858.78

GSHP Electrical Cost Data



Summer Cooling Energy Consumption.

Heat Pump $14.26\ \text{Kw} \times 983\ \text{hrs} = 14{,}017.58\ \text{Kwh}$

20 HP Centrifugal pump $14.92\ \text{Kw} \times 983\ \text{hrs} = 14{,}666.36\ \text{Kwh}$

40 Hp Centrifugal Pump $29.84\ \text{Kw} \times 983\ \text{hrs} = 29{,}332.72\ \text{Kwh}$

Annual Electricity Costs

HP $(14{,}017.58)(13) \times (0.0263) = \$4{,}792.61$

20 HP Pump $(14{,}666.36) \times (.0263) = \$385.73$

40 HP Pump $(29{,}332.72) \times (.0263) = \$771.45$

Annual Peak Charges.

Assume cooling peak is the demand for all the equipment and that it only opperates in the 3 summer months.

$(14.26)(13) + 14.92 + 29.84 = 230.14\ \text{Kw}$

$(230.14\ \text{Kw})(\$16.556/\text{Kw}) = \$3{,}810.20$

$(\$3{,}810.20)(3\ \text{months}) = \$11{,}430.60$

Total electric cost $= 4{,}792.61 + 385.73 + 771.45 + 11\,430.60$

$= \$20{,}080.39$

Appendix K

GSHP Cost Estimate Details

Cost Estimate for GSHP and GHX Alternative: Pluming and Electrical				
Item	**Units**	**QTY**	**Price/unit with Labor, Overhead and Profit**	**Total Cost**
Carrier 50 PSW 360 Heat Pump	Each	13	$33,100	$430,300
15 Gallon Expansion Tank	Each	1	$683	$683
40 Gallon Expansion Tank	Each	2	$915	$1,830
Bell and Gossett Series 1510 5G Pump*	Each	2	$10,613	$21,226
Bell and Gossett Series 1510 5BC Pump*	Each	2	$4,516	$9,032
8" Globe Valve	Each	2	$6,000	$12,000
4" Globe Valve	Each	16	$2,225	$35,600
2" Globe Valve	Each	26	$1,075	$27,950
8" Steel Pipe	LF	1072	$166	$177,952
4" Steel Pipe	LF	320	$74	$23,680
2" Steel Pipe	LF	130	$41	$5,330
8" Globe Valve	Each	2	$6,000	$12,000
8" Schedule 40 Plastic Pipe	LF	1556	$77	$119,812
6" Schedule 40 Plastic Pipe	LF	210	$57	$11,970
5" Schedule 40 Plastic Pipe	LF	60	$48	$2,880
4" Schedule 40 Plastic Pipe	LF	150	$40	$6,000
3" Shcedule 40 Plastic Pipe	LF	5100	$34	$173,400
2-1/2" Schedule 40 Plastic Pipe	LF	5100	$31	$158,100
2" Schedule 40 Plastic Pipe	LF	2550	$27	$68,850
Drill, plumb, grout Bore Wholes	LF	333300	$15	$4,999,500
800 Amp automatic Transfer Switch	Each	1	$5,500	$5,500
800 Amp Nema 1 Panel Board **	Each	1	$1,500	$1,500
2 sets (4 - 500 kcmil)	CLF	33.6	$1,625	$54,600

Total Cost	$6,359,695

Appendix L

Microsteam Turbine Selection and Performance Data

Selecting Microsteam Turbine.

PRV 1 stage 1

41, 400 lb/hr 150 psi - 70 psi

Temp: 365.87°F

stage 2

41, 400 lb/hr 70 psi - 15 psi

Temp 365.87°F

Can get 3 units. with 13 800 lb/hr.

to get 275 KW each

275 (3) = 825 KW

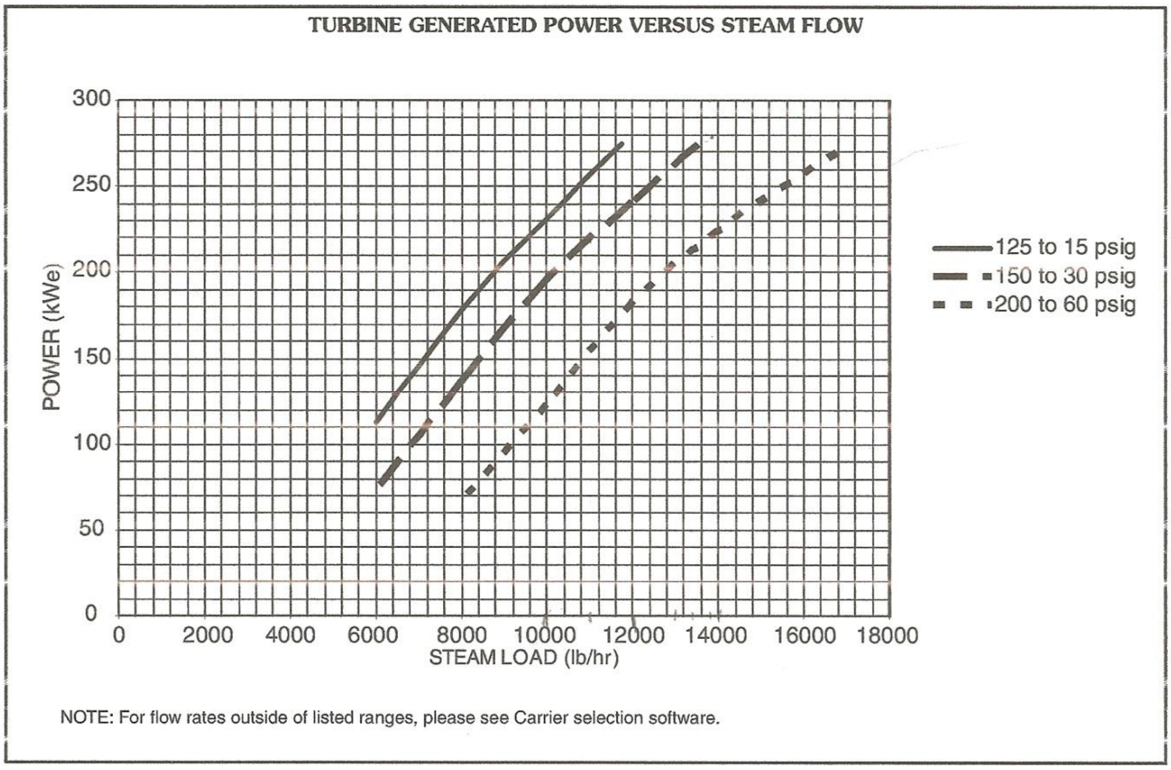
Basement so no structural concerns.

PRV 3 - maybe not replace because. would need to look at structural. 520. lb/SF.

Typical floor only designed for 150 lb/SF

* Basement designed for 275 lb/SF but easy to restructure with raised slab and reinforcement.

Performance data



NOTE: For flow rates outside of listed ranges, please see Carrier selection software.

TURBINE PERFORMANCE

INLET STEAM PRESSURE (PSIG)	INLET STEAM TEMPERATURE (F)	SUPERHEAT (F)	EXHAUST STEAM PRESSURE					
			15 psig		30 psig		60 psig	
			Steam Required (lb/hr)	kWe Generated	Steam Required (lb/hr)	kWe Generated	Steam Required (lb/hr)	kWe Generated
125	353.2	0.0	12,828	275	13,502	241	13,972	118
	400.0	46.8	11,021	275	13,063	249	13,550	122
	450.0	96.8	10,294	275	12,587	257	13,091	126
	500.0	146.8	9,608	275	12,108	265	12,626	130
150	366.3	0.0	11,150	275	13,532	275	16,212	154
	400.0	33.7	10,661	275	12,942	275	15,856	193
	450.0	83.7	9,967	275	12,106	275	15,319	199
	500.0	133.7	9,312	275	11,315	275	14,773	206
200	387.9	0.0	10,779	275	12,041	275	16,759	275
	400.0	12.1	10,618	275	11,866	275	16,502	275
	450.0	62.1	9,973	275	11,166	275	15,470	275
	500.0	112.1	9,364	275	10,506	275	14,490	275

NOTE: Super-heated steam has a temperature higher than the evaporating temperature at a given pressure. For example, steam at 100 psig has a evaporating or saturation temperature of 337.9 F (170 C). A superheat of 50° F (27.8° C) means that the steam temperature is 50° F (27.8° C) above the saturation temperature or 337.9 + 50 = 387.9° F (197.8° C).

Appendix M

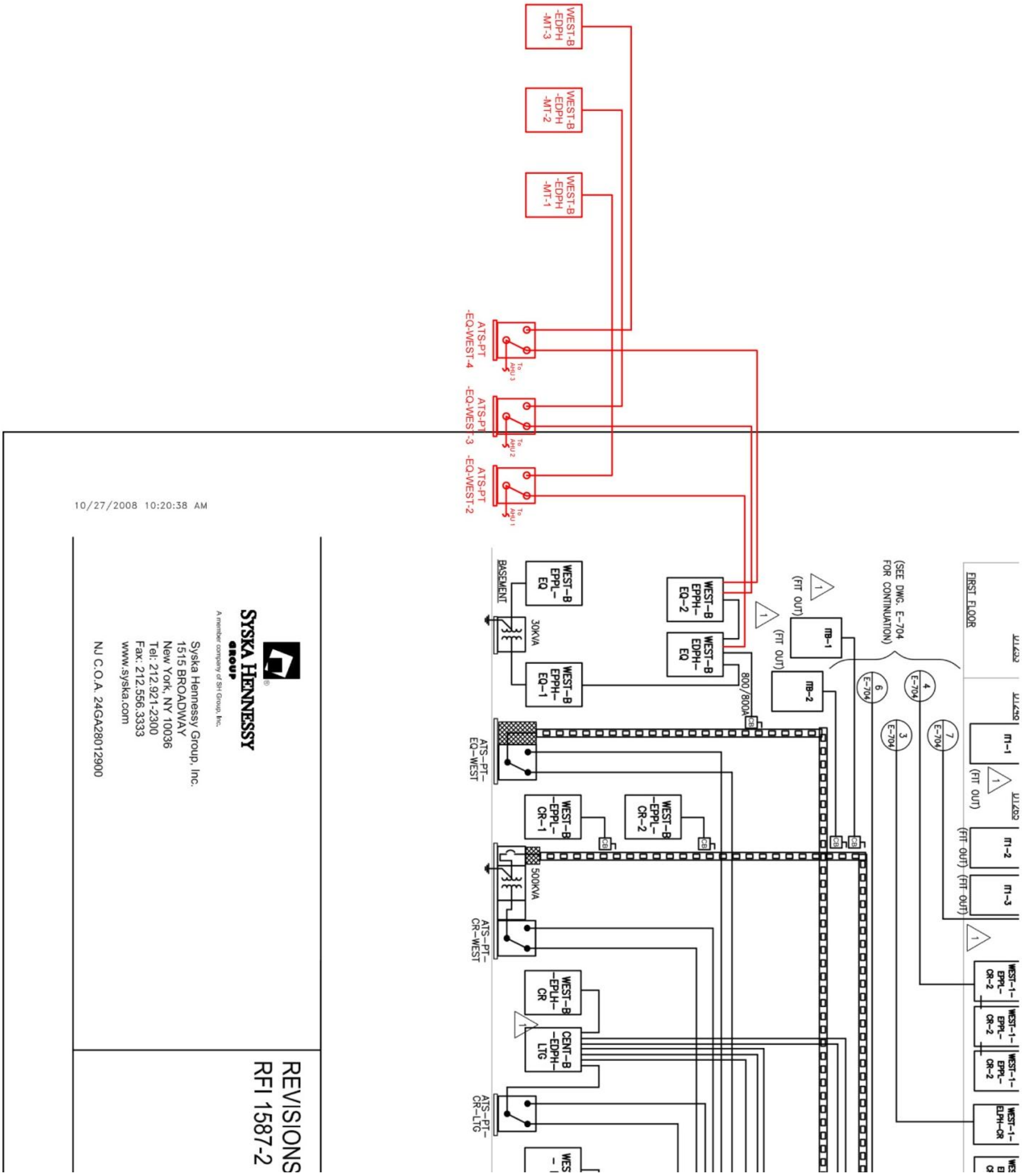
GSHP Panel Board Schedule

EMERGENCY EQUIPMENT SWITCHBOARD
EAST-B-EPPH-EQ-3

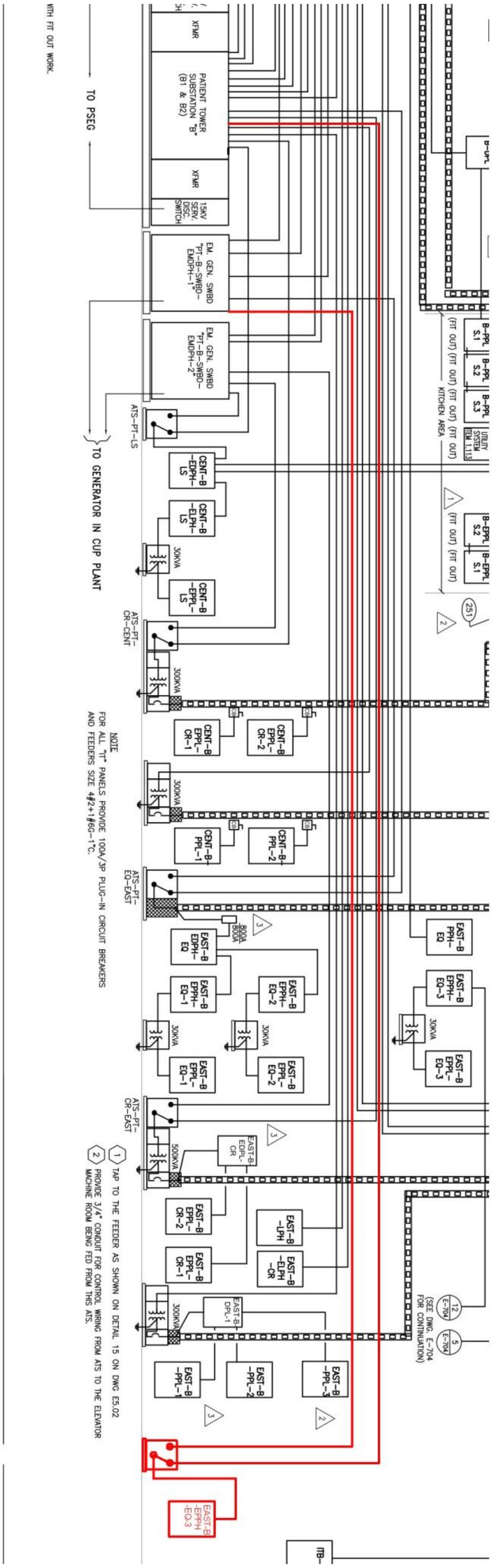
VOLTAGE: 480/277V, 3Φ 4W+G BUS: 600 A

ITEM NO.	EQUIPMENT	H.P.	KVA	FULL LOAD AMPS	CIRCUIT BREAKER			REMARKS	CONDUIT & WIRESIZE
					FRAME	TRIP	POLES		
	INCOMING SECTION MAIN C/B				800	800	3		2 sets (3#500kcmil +1/0G - 3 1/2"C)
1	HP-1	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
2	HP-2	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
3	HP-3	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
4	HP-4	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
5	HP-5	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
6	HP-6	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
7	HP-7	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
8	HP-8	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
9	HP-9	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
10	HP-10	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
11	HP-11	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
12	HP-12	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
13	HP-13	-	35	42	100	60	3		3#6 + 1#10G - 3/4"C
14	HPP-1	20	23	27	225	50	3		3#8 + 1#10G - 3/4"C
15	HPP-2 (Standby)	20	23	27	225	50	3		3#8 + 1#10G - 3/4"C
16	GHXP-1	40	44	52	225	125	3		3#8 + 1#6G - 3/4"C
17	GHXP-2 (Standby)	40	44	52	225	125	3		3#8 + 1#6G - 3/4"C
18	Spare	-	-	-					
19	Spare	-	-	-					
20	Spare	-	-	-					
21	Spare	-	-	-					
22	Spare	-	-	-					
23	Spare	-	-	-					
24	Spare	-	-	-					
25	Spare	-	-	-					
26	Spare	-	-	-					
27	Spare	-	-	-					
28	Spare	-	-	-					
29	Spare	-	-	-					
30	Spare	-	-	-					
31	Spare	-	-	-					
32	Spare	-	-	-					
33	Spare	-	-	-					
34	Spare	-	-	-					
35	Spare	-	-	-					
36	Spare	-	-	-					

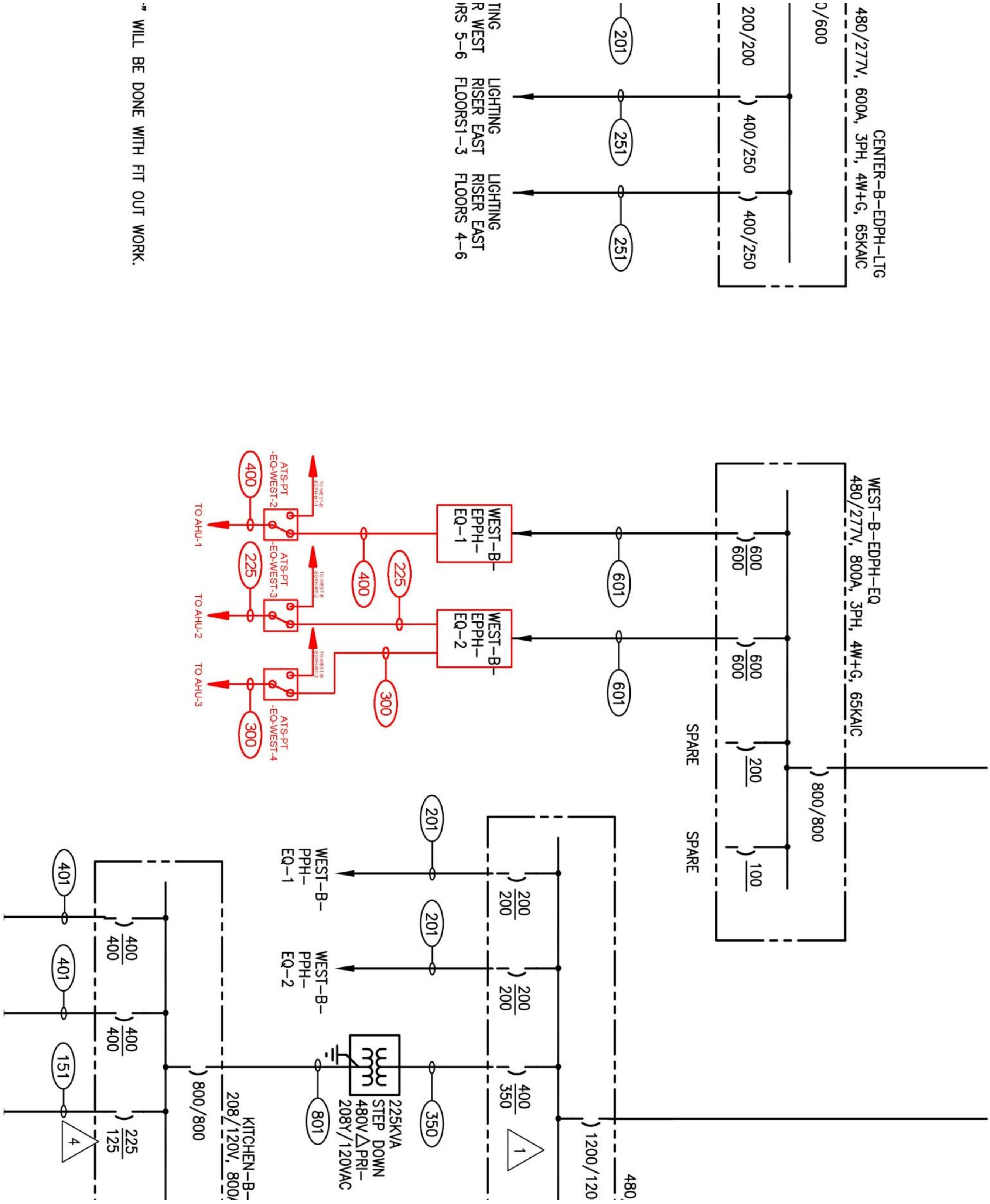
Microsteam Turbine Riser Drawing E7.05



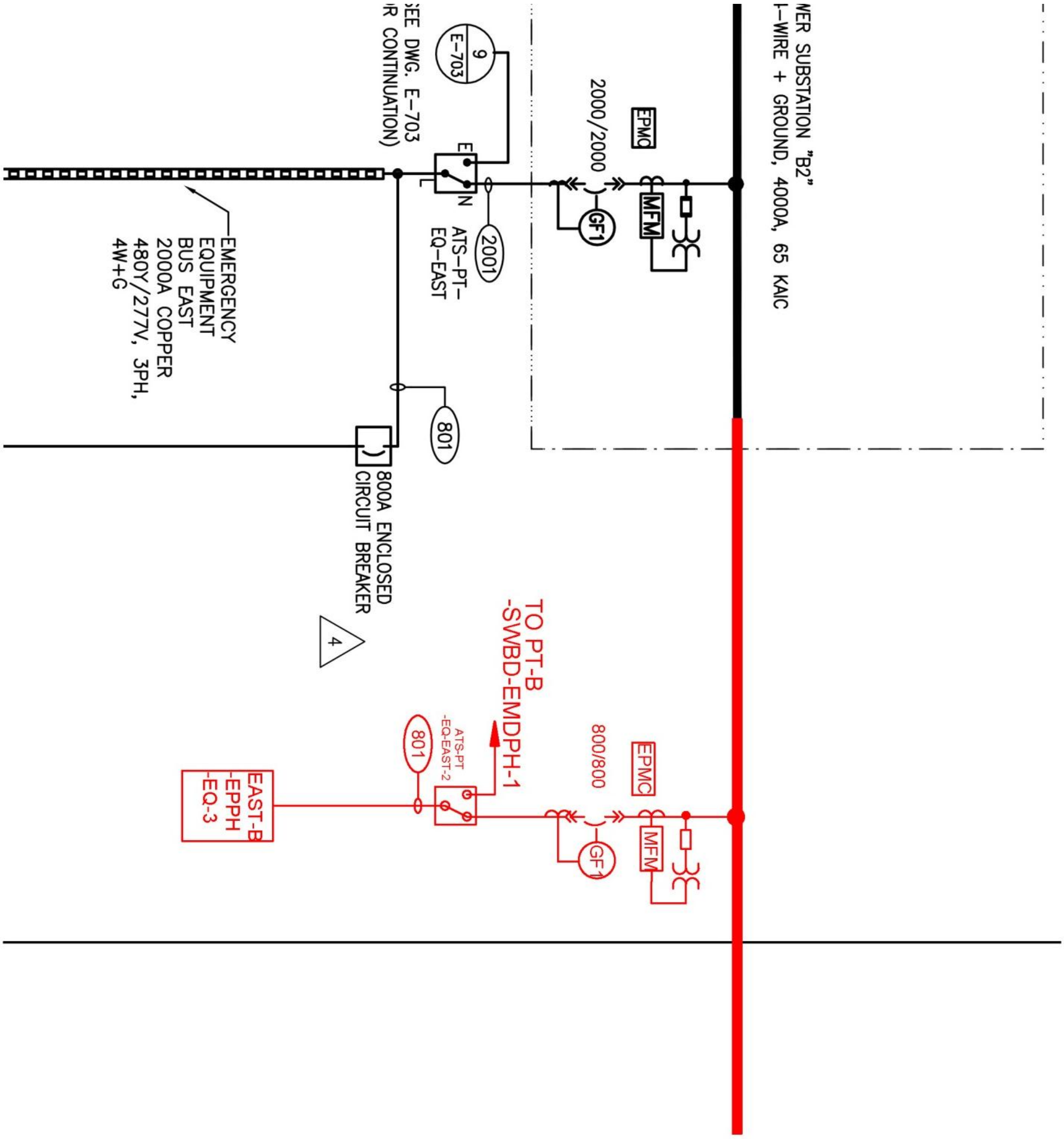
GSHP Panel Board Riser Drawing E7.05



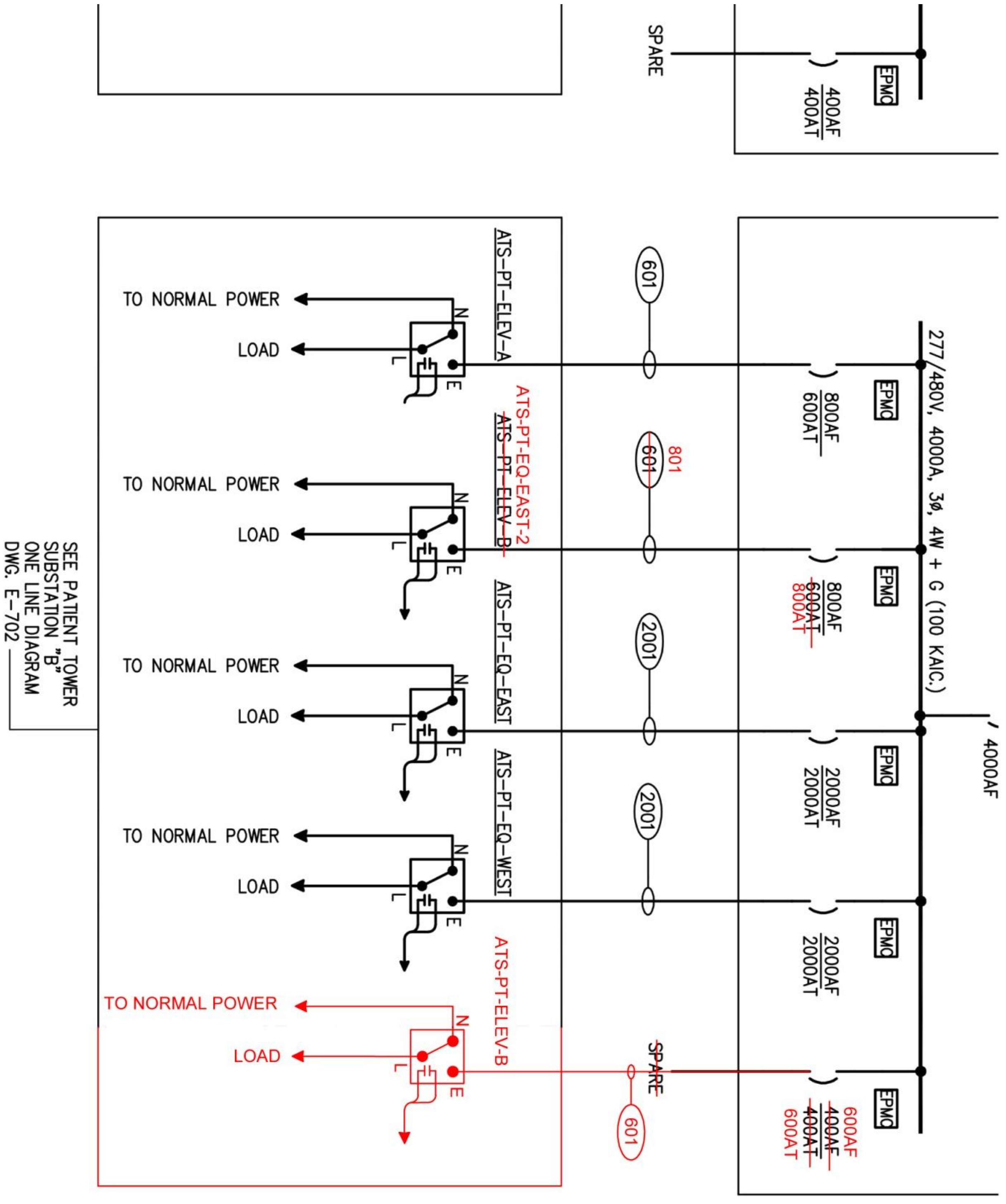
Mircosteam Turbine Single Line Drawing E7.02



GSHP Single Line Drawing E5.02

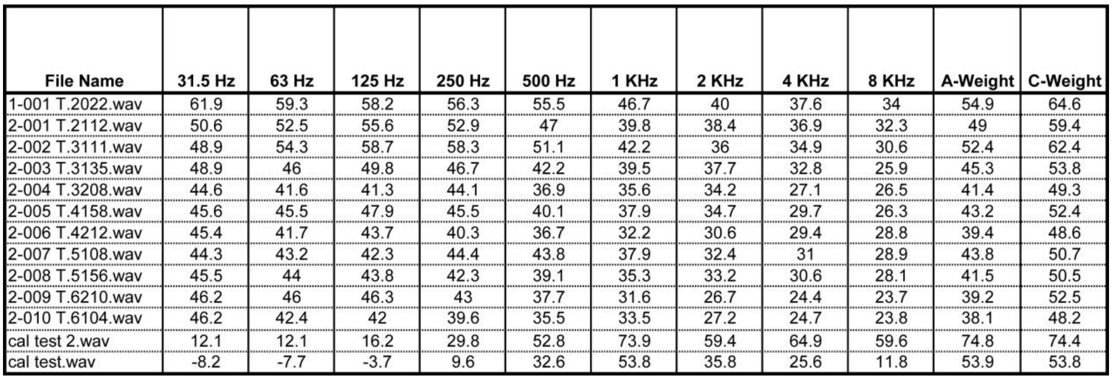


GSHP Emergency Power Single Line Drawing E7.03



Appendix N

Matlab Export to Excel



File Name	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1 KHz	2 KHz	4 KHz	8 KHz	A-Weight	C-Weight
1-001 T.2022.wav	61.9	59.3	58.2	56.3	55.5	46.7	40	37.6	34	54.9	64.6
2-001 T.2112.wav	50.6	52.5	55.6	52.9	47	39.8	38.4	36.9	32.3	49	59.4
2-002 T.3111.wav	48.9	54.3	58.7	58.3	51.1	42.2	36	34.9	30.6	52.4	62.4
2-003 T.3135.wav	48.9	46	49.8	46.7	42.2	39.5	37.7	32.8	25.9	45.3	53.8
2-004 T.3208.wav	44.6	41.6	41.3	44.1	36.9	35.6	34.2	27.1	26.5	41.4	49.3
2-005 T.4158.wav	45.6	45.5	47.9	45.5	40.1	37.9	34.7	29.7	26.3	43.2	52.4
2-006 T.4212.wav	45.4	41.7	43.7	40.3	36.7	32.2	30.6	29.4	28.8	39.4	48.6
2-007 T.5108.wav	44.3	43.2	42.3	44.4	43.8	37.9	32.4	31	28.9	43.8	50.7
2-008 T.5156.wav	45.5	44	43.8	42.3	39.1	35.3	33.2	30.6	28.1	41.5	50.5
2-009 T.6210.wav	46.2	46	46.3	43	37.7	31.6	26.7	24.4	23.7	39.2	52.5
2-010 T.6104.wav	46.2	42.4	42	39.6	35.5	33.5	27.2	24.7	23.8	38.1	48.2
cal test 2.wav	12.1	12.1	16.2	29.8	52.8	73.9	59.4	64.9	59.6	74.8	74.4
cal test.wav	-8.2	-7.7	-3.7	9.6	32.6	53.8	35.8	25.6	11.8	53.9	53.8

T_{60} Calculation Excel Spreadsheet for Room T.3111

Full Audience

Full Audience

Full Audience

Areas		
	Description	Surface Area
Ceiling 1	GWB	91.4
Ceiling 2	2x2 Tile	145.3
Floor 1	Linoleum Floor	237
Floor 2		
Wall 1	GWB	0.73
Wall 2	Door	25.67
Wall 3	DuPont Panel	483
Misc		
Glass	Regular Window	101.2
People		

483.73

Reverberation Time									
a=Sα	Select Material	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz	16000 Hz
Ceiling 1	G.W.B 5/8 inch	50.27	12.80	7.31	3.66	10.97	10.05	0.00	0.00
Ceiling 2	A.T.C	110.43	135.13	120.60	143.85	143.85	136.58	0.00	0.00
Floor 1	Linoleum, Rubber or asphalt tile on conc	4.74	7.11	7.11	7.11	7.11	4.74	0.00	0.00
Floor 2	Carpet, Indoor-Outdoor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wall 1	G.W.B 2 X 5/8 inch	0.20	0.09	0.07	0.05	0.09	0.07	0.00	0.00
Wall 2	Wood, 1/4-in peneling, with airspace beh	10.78	5.39	2.57	2.05	1.54	1.54	0.00	0.00
Wall 3	DuPont Audio Comfort Panels	96.60	391.23	560.28	507.15	429.87	333.27	0.00	0.00
Misc	Fabric well upholstered seats with perfora	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glass	Glass heavy	18.22	6.07	4.05	3.04	2.02	2.02	0.00	0.00
People	Audience seated in uphoslstered seats	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total a	291.24	557.82	701.99	666.90	595.45	488.28	0.00	0.00
	Reverberation time T=.05(V/a)	**0.36**	**0.19**	**0.15**	**0.16**	**0.17**	**0.21**	**#DIV/0!**	**#DIV/0!**

Volumes		
Volume 1		2073.75
Volume 2		
Volume 3		
Volume 4		
	Total	2073.75

	Original absorption (a1)	329.88	224.55	190.01	193.56	228.37	198.48	0.00
	New absorption (a2)	291.24	557.82	701.99	666.90	595.45	488.28	0.00
	NR = 10 log (a2/a1)	-0.54	3.95	5.68	5.37	4.16	3.91	0.00
	Original dB level 2-002 T.3111.wav	58.70	58.30	51.10	42.20	36.00	34.90	30.60
	New dB level with DuPont Panels	59	54	45	37	32	31	31
	NC-45	60	54	49	46	44	43	42
	Compliant	Yes	No	Yes	Yes	Yes	Yes	Yes
	A wighting	-15	-8	-3	0	1	1	-1
dB A		44	46	42	37	33	32	30
			44	45				

DuPont AudioComfort Panel Brochure

Provides proven performance—in the lab and in hospitals

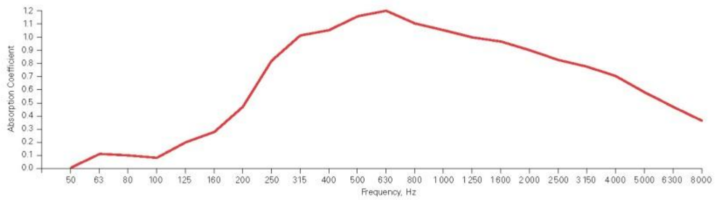
Tests were conducted by an independent laboratory to evaluate the acoustic performance of DuPont™ AudioComfort™ panels. As shown in Table I, AudioComfort™ panels provide excellent sound absorption across a range of frequencies, including low frequencies.

Table I. Acoustic Performance of DuPont™ AudioComfort™ Panels per ASTM C423-08a, specimen mounting A*

Sample	Absorption Coefficient at Frequency, Hz						NRC	SAA
	125 Hz	250 Hz	500 Hz	1 000 Hz	2000 Hz	4000 Hz		
DuPont™ AudioComfort™ Panel	0.20	0.81	1.16	1.05	0.89	0.69	1.00	0.96

*Data from ATI Test Report 91780.01-113-11 (6/12/09) 3 pcf glass fiber board. Complete lab reports are available upon request to DuPont.

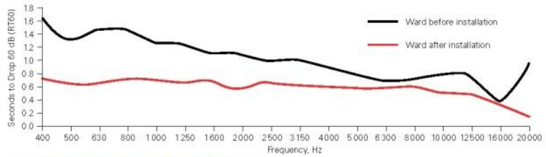
Figure 1. Sound Absorption Coefficients



Independent acoustic tests were also conducted in a hospital. The elapsed time (in seconds) to achieve a drop of 60 decibels at frequencies ranging from 400 hertz to 20000 hertz (reverberation time RT60) was measured in the same hospital ward before and after installation of the AudioComfort™ panels. As shown in Figure 2, there was an average 46% sound absorption improvement in the voice frequency range (between 400 hertz and 3150 hertz) after installation of the AudioComfort™ panels.

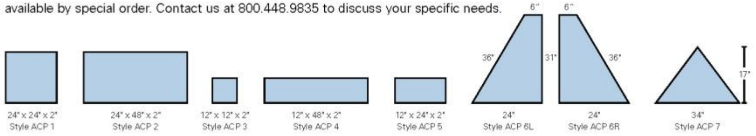
Figure 2. Acoustic Performance Before and After Installation of DuPont™ AudioComfort™ Panels in a Hospital Ward

Panel area installed is ~28% coverage/ft² of available ceiling space



Available in a variety of sizes and shapes

AudioComfort™ panels are available in a variety of sizes and shapes* to meet a wide range of installation needs, from fitting around existing fixtures for retrofit projects to meeting the design needs for new construction. All panels are white. Custom sizes are also available by special order. Contact us at 800.448.9835 to discuss your specific needs.



*The values shown above are nominal.

For more information about new DuPont™ AudioComfort™ panels with DuPont™ Tyvek® facing, call 800.448.9835 or visit our website at www.acoustics.dupont.com

The miracles of science™

DuPont™ AudioComfort™ Acoustic Panels

Sound absorbing panels with DuPont™ Tyvek® facing provide enhanced comfort for hospital patients and staff.

Tyvek.

New DuPont™ AudioComfort™ panels with DuPont™ Tyvek® facing provide facility managers and architects with a superior sound control solution for today's hospitals and healthcare facilities. AudioComfort™ panels combine excellent sound absorption, cleanability, and high light reflectance.

DuPont™ AudioComfort™ panels are available in a variety of shapes to fit around existing fixtures and their high light reflection helps spread diffuse reflection of natural and artificial lighting.

DuPont™ AudioComfort™ panels provide a superior sound control solution across a number of key hospital areas, including emergency rooms and surgical suites.

What makes these panels unique?

The glass fiber wool interior of an AudioComfort™ panel is completely encapsulated with Tyvek®. Tyvek® is a functional membrane that not only provides a safe barrier between the glass fiber wool and clean environment, it also facilitates the sound absorption of human voice frequency ranges within the acoustical material. Unlike other panel materials, Tyvek® does not support the growth of microorganisms.

AudioComfort™ panels come in a variety of sizes and shapes, and are easily retrofitted within existing interior spaces. AudioComfort™ panels provide the only solution that can be installed in most restricted hospital areas while they continue to operate. They can also be specified for new construction as a supplemental sound absorbing system.

Ideal for locations where noise management and cleanliness are required

Hospitals and healthcare facilities have strict requirements for surface cleanliness to control the spread of infections. Generally, the solid surfaces designed for regular cleaning and disinfecting allow facilities to meet strict cleanliness requirements, but do not absorb sound energy well.

AudioComfort™ panels with Tyvek® facing offer excellent sound absorption and provide users with an aesthetically pleasing, cleanable surface and interior that do not promote the growth of mold. They are particularly well suited for retrofit solutions in existing facilities that have hard ceiling and wall surfaces, such as painted drywall.

AudioComfort™ panels are ideal for locations where noise interferes with patient comfort, impedes staff performance or is noncompliant with HIPAA guidelines. These areas include nurse stations, patient rooms, surgical suites, intensive care and neonatal units, hallways, and common areas.

AudioComfort™ with DuPont™ Tyvek® facing delivers superior benefits facility managers look for, including:

- excellent sound absorption without space needed for drop ceilings (NRC 1)
- cleanability: water and stain resistance
- lint and loose fiber-free surface does not support mold growth
- lightweight solution engineered for easy installation in most restricted areas without disrupting normal operating activities
- high diffuse light reflectance (>0.89 in average)
- a minimum of 25% recycled glass content of which 20% is post-consumer recycled glass
- outer covering that is highly resistant to particle penetration and is fully recyclable
- meets Class A flammability ratings (ASTM E84)
- available in a variety of sizes and shapes to accommodate most spaces
- can be installed in new or existing buildings

Installation

AudioComfort™ panels are non-linting, lightweight, and easy to install. They can be mounted on walls, ceilings or room partitions using a variety of means, including adhesives, Velcro® tape, and mechanical or impaling clips. They can also be suspended using eye hooks and cable. Care must be taken to ensure that each panel is securely attached to the desired surface. The panels are not designed for installation in high-abuse areas, such as walls below shoulder level or in elevators. Panels should be replaced if the Tyvek® cover is punctured or damaged.

Meets most current hospital design standards

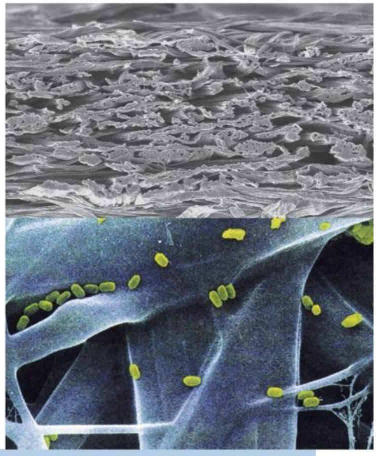
AudioComfort™ panels can help meet HIPAA, 2010 FGI-ASHE Guidelines for Design and Construction of Health Care Facilities, and Sound & Vibration for Health Care Facilities January 1, 2010, Version 2.0, including New Guidelines for NICUs, which were adopted as the sole reference standard for two LEED® "Environmental Quality" credits by the Green Guide for Health Care and LEED® for Healthcare (in draft).

Product data

AudioComfort™ panels feature a unique combination of a 2"-thick glass fiber wool panel completely encapsulated with a Tyvek® membrane. The nominal density is approximately 3 lb/ft^3.

Tyvek® facing

Tyvek® is a high-density polyethylene (HDPE) microporous barrier made by a flash spun process with a typical pore size between 2 and 15 microns. Tyvek® has 76% penetration resistance for particles greater than 0.1 micron at a face velocity of 0.248 cm/second.



The unique structure of DuPont™ Tyvek® creates a tortuous path with substantial lateral movement (top). Tyvek® delivers a superior barrier to microbial assault (bottom).

Various styles of Tyvek® are already the standard for microbial barrier in medical device packaging and sterile single use garments. The unique, inherent properties of Tyvek® are leveraged in the DuPont™ AudioComfort™ panels.