University Medical Center of Princeton

Plainsboro, NJ

Technical Report Three

Mechanical System Existing Conditions Evaluation

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Executive Summary

The University Medical Center of Princeton consists of a very complex and well planned mechanical system. Princeton Healthcare Systems (the owner) has set forth to "Design for Healing" and have spared no cost to ensure that the quality of care will not be undermined by the performance of the mechanical system.

The use of various energy generation and recovery methods help to reduce cost and provide excellent care. Princeton Healthcare Systems has contracted NRG to design and construct a central utility plant (CUP) on site to generate steam, chilled water and electricity. The CUP allows for both steam and electricity to be generated with the same fuel (natural gas), thus increasing efficiency and reducing emissions. The use of eight heat recovery units will reduce the cost to preheat and precool the ventilation air, again cutting cost and improving efficiency. A chilled water thermal storage unit will also be used to cut peak cooling loads thus reducing cost and allowing the chillers to operate at a more consistent level. The installation of photovoltaic panels will generate and estimated 225kW of clean energy.

To install and operate such a complex mechanical system a lot of money must be spent up front, but will pay off with reduced operating costs. It is estimated that the total first cost of the mechanical system will be just over $79 million; the annual operating cost is estimated to be $1.5 million. This breaks down to an installation cost of $124 per square foot and $5.51 per square foot for annual operation.

With every building currently constructed, LEED serves as a guideline for building efficiency and sustainability. Although this building is not listed with a LEED rating, it is very possible for this building to be certified. It was found that one of the prerequisites was not met within the Energy and Atmosphere category. This prerequisite pertains to the power density of the lighting system and power consumption per air flow rate prescribed in ASHRAE Standard 90.1. These non-compliances are understandable with the understanding that the ASHRAE standard is not focused on hospital equipment and lighting needs. The UMCP is designed with high efficient lighting and electrical systems to help reduce energy consumption while providing the necessary light and equipment to provide a healing environment for patients.

Design Objectives

The University Medical Center of Princeton has multiple design objectives such as architectural design, patient experience, improved operating performance, and environmental responsibility. To achieve these and other goals, the design is well integrated and comprised of state-of-the-art equipment. The result of the collaboration of the design teams produced a complex building that meets the specific needs of operating, exam, imaging and patient rooms as well as office, educational and general use spaces.

Every interior space is laid out in a way to improve efficiency. Extensive analysis of the patient/doctor routes were performed to minimize the distance traveled providing faster and more efficient care. By segmenting the hospital into separate portals based on major type of care (ie. maternity, cancer, etc.) transportation time will be decreased. 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 created the well planned hospital. The partnership between HOK and RMJM Hillier brought together experience of over 260 hospital designs. Syska Hennessay worked hard to provide a mechanical system that provides all of the environmental needs maintaining a strong LEED initiative. RTKL Associates is an industry leader in healthcare technologies who provided 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 is bringing 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 and the other members of the project team are collaborating to bring one of the most advanced healing facilities to New Jersey.

Energy Sources and 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, the total utility rates are 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

To help reduce the cost of electricity, the UMCP has commissioned the construction of a central utility plant. The CUP will also provide high pressure steam and chilled water. A list of exact equipment has not yet been made available for use on this report. Assumptions have been made as to the efficiencies of the equipment used for steam and chilled water generation. Table 1 below details the assumed equipment and efficiencies, these assumptions are found to be a reasonable for equipment of this size across industry.

Equipment Information				
Chiller Information			Boiler Information	
Brand:	Carrier		Brand:	Brunham
Model:	19XRV		Model:	C series
Nominal Tons:	1450		Output (MBh):	6695
IPLV kW/ton:	0.35		Efficiency:	0.82

Table 1 Equipment assumptions and efficiencies

Indoor and Outdoor Design Conditions

Indoor design requirements for the UMCP vary based on space usage. For the majority of the building the cooling and heating design temperatures are 72.3^{o}F and 68^{o}F respectively. Operating rooms are required to be kept at 68^{o}F year round. Keeping the operating rooms at this temperature keep surgeons and other staff members comfortable while wearing sterile gowns and working under the intense operating lights.

ASHRAE weather data for Newark, New Jersey was used for load estimations. Newark is located approximately 40 miles NNE of Plainsboro. The 0.4% cooling and 99.6% heating design temperatures were used in accordance with the requirements of Technical Report Two. The specifics of the weather data and internal design requirements are summarized below in table 2.

Indoor and Outdoor Design Conditions			
		Common Space	Operating Room
Interior Design Temps	Cooling	72.3 °F	68.0 °F
	Heating	72.0 °F	68.0 °F
Exterior Design Temps	Cooling	91.0 °F	
	Heating	14.0 °F	

Table 2 Indoor and Outdoor Design Conditions

System Design

The mechanical system at the University Medical Center of Princeton can be discussed in four parts. The first is ventilation; a very important aspect for a hospital. The second is the calculated heating and cooling loads. From this one can estimate the energy usage. Finally, every system must consist of major components such as air handlers and pumps.

Ventilation Air

As a design object of Princeton Healthcare System to provide a healthy environment for patients, ventilation air becomes a major issue. To prevent possible spread of disease and bacteria, as well as provide a comfortable and fresh environment, every operating, exam, and patient room is supplied with 100% outside air. To reduce energy cost, some spaces such as the main lobby, classrooms, and office space are provided with a minimum of 25% outside air. Table 3 shows the summary results of the calculated required outside air for areas served by air handling units 1, 2 and 4 (the non-100% outside air units) vs. the current design values.

Calculated vs. Designed Percent Outside Air		
AHU	Calculated Ventilation Requirement	Designed Maximum ventilation
1	22%	25%
2	25%	50%
4	18%	40%

Table 3 Calculated Percent Outside Air vs. Designed

The calculated ventilation requirements were determined using section 6.2 of ASHRAE standard 62.1. This calculation method takes into account the square footage of each zone, the estimated population, and the airflow rates required per square foot and per person.

Heating and Cooling Loads

Heating and cooling loads were calculated using Trane Trace700 with a simplified block model of UMCP. This model consisted of groups of rooms modeled to be a single space. These groups consist of similar room types with comparable occupancies and the same exterior wall orientation. The assumed system for the majority of the building is constant volume non-mixing with terminal reheat. The basement, first and part of the second level were modeled constant volume with mixing and terminal reheat and are air handling units 1, 2 and 4 with UMCP. The calculated values are tabulated in table 4 below and are presented against the loads designed for by the mechanical engineering firm Syska Hennessay.

Modeled vs. Syska Design Building Loads by Floor								
Floor - % Outside Air	Cooling (ft²/tons)		Heating (Btuh/ft²)		Total Supply (cfm/ft²)		Ventilation Air (cfm/ft²)	
	Modeled	Syska Designed	Modeled	Syska Designed	Modeled	Syska Designed	Modeled	Syska Designed
Level 0 -31% OA	330	253	19	25	0.85	1.11	0.26	0.36
Level 1 -33% OA	345	210	44	34	2.15	1	0.66	1
Level 1 -100% OA	89	146	78	54	1.79	1.24	1.79	1.24
Level 2 -100% OA	104	118	73	67	1.43	1.37	1.43	1.37
Level 3 -100% OA	131	137	69	63	1.24	1.17	1.24	1.17
Level 4 -100% OA	131	123	69	67	1.24	1.25	1.24	1.25
Level 5 - 100%OA	131	141	69	57	1.24	1.06	1.24	1.06
Level 6 -100% OA	78	106	150	71	1.81	1.37	1.81	1.37

Table 4 Calculated Cooling Loads vs. Syska Hennessay Design Cooling Loads

The values in black are within 20% plus or minus of the Syska values. The red numbers are more than 20% over and the green are more than 20% under. This comparison shows that the block model, although not exact, provides a reasonable estimate of the heating and cooling loads. More details and possible reasons for these deviations are listed in Technical Report Two.

Energy Use and Cost

Every building consumes energy to move air, pump water, and provide light. The size of the University Medical Center of Princeton creates a large demand for energy. The energy consumption can be attributed to four categories: boilers, chillers, fan/motors and lighting/misc. The boilers and chillers are located in the central utility plant and the exact information on the equipment is not known at this time. The assumed equipment listed in table 1 is sized based on the calculated heating and cooling loads. Table 5a below compares the energy use for the four categories. The results in terms of energy units consumed can be found in Appendix B as "Energy Consumption Summary".

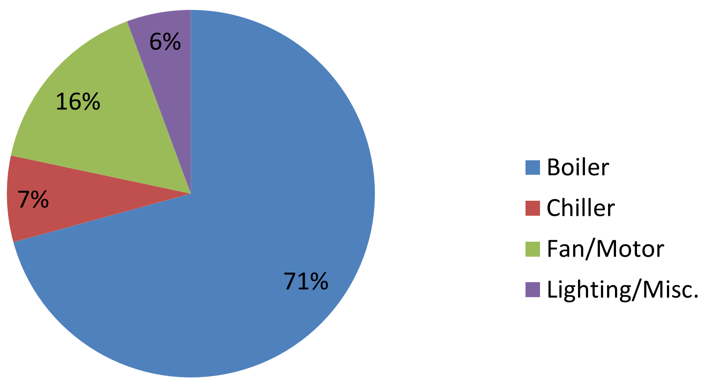

Table 5a Energy Use Summary

Using the PSE&G utility rates listed earlier, the annual cost to operate the patient tower is $1.47 Million or $5.51 per square foot. A breakdown of cost in the four categories listed is shown in table 5b.

Energy Cost Summary		
Equipment	Fuel	Total Cost per year
Boiler	Nat. Gas	$397,425.48
Chiller	Electricity	$279,006.16
Fan/motor	Electricity	$583,761.20
Lighting and Misc.	Electricity	$208,523.97
Total Cost		$1,468,716.82

Table 5b Energy Cost Summary

For an analysis on CO_2 and other emissions, please see the section titled "Emissions Analysis" in Technical Report Two.

Major Equipment

The University Medical Center of Princeton has a large amount of equipment which has been simplified into the following three tables. Table 6a is a schedule of the air handling units, the area they service, CFM supplied, and the heating/cooling loads. Table 6b lists the heat exchangers located throughout the patient tower, what is serviced, the type of heat exchanger and the total load. Table 6c is a schedule of the heat recovery units, the air volume and water flow rate.

Air Handling Unit Schedule				
Unit Number	Serviced Space	Total CFM	Total Cooling Load (MBH)	Total Heating Load (MBH)
AHU -1	Lobby	60,000	3,033	
AHU -2	Imaging Department	35,000	2,125	
AHU -4	Basement East	33,000	1,814	
AHU -7	Bed Tower Sector 1	46,000	3,391	
AHU -8	Bed Tower Sector 2	50,000	3,806	
AHU -9	Bed Tower Sector 3	35,000	2,560	
AHU -10	Bed Tower Sector 4	42,000	3,064	
AHU -11	Bed Tower Sector 5	50,000	3,667	
AHU -12	Bed Tower Sector 7	30,000	2,195	
AHU -13	Bed Tower Sector 6	30,000	2,195	
AHU -14	Cancer Center	20,000	1,470	
MUH -1	Kitchen Basement	22,000	1,197	580

Table 6a Air Handler Schedule

Heat Exchanger Schedule			
Unit Number	Service	Type	Total Load (MBH)
HX 1&2	Reheat/Perimeter Heating	Shell & Tube	9,070
HX 3&4	Perimeter Heating	Shell & Tube	1,100
HX 5&6	Reheat	Shell & Tube	8,700

Table 6b Heat Exchanger Schedule

Heat Recovery Unit Schedule		
Unit Number	Air Quantity (CFM)	Water Flow Rate (GPM)
HRU -5	30,000	96
HRU -6	58,000	144
HRU -7	41,000	110
HRU -8	45,000	120
HRU -9	28,000	96
HRU -10	35,000	101
HRU -11	42,000	120
HRU -12	25,000	96
HRU -13	25,000	96
HRU -14	17,000	96

Table 6c Heat Recover Schedule

System Description

A complex system requires many drawing to convey every important detail for construction and operation. The patient tower alone has 7 mechanical schematic drawings. These drawings were simplified into three concise drawings for use in this report; redundancies in air handling units were grouped and only schematics for steam, chilled water, and heat recovery are shown. These schematics can be found in appendix A.

Chilled water is generated in the central utility plant. This chilled water is then distributed through the building and to the air handling cooling coils for AHUs. The AHUS are plumbed in parallel providing consistent pressure to each device. Each group of air handlers has a shut off valve, as well as each individual AHU. There are four AHUs and one MHU inside the building and eight AHUs on the roof. The used chilled water is recirculated to the central utility plant where it is reused within the system.

High pressure steam (150 PSIG) is supplied to the building by the central utility plant. This steam is then reduced in one of two two-stage pressure reducing valve stations to

15 PSIG. Each PVR station services both air handler preheat coils and hot water heat exchangers. The steam serving to the air handlers is sent through a control valve station for flow balancing and then to the air handler coil. The 15 PSIG steam for the hot water heat exchangers also is sent through a control valve system and then to the heat exchanger. The heat exchangers provide hot water to the building and to the terminal reheat boxes throughout the building. The used steam is then pumped back to the CUP via condensation pumps.

Energy recovery is used to preheat (in the winter) and precool (the summer) outside air for the eight roof top air handlers. A glycol solution is used in this closed loop system. Each heat recovery unit is connected in parallel, sent through an air separation chamber and then through recirculating pumps. The warm glycol solution is then distributed to the air handlers through a parallel plumbing system. The glycol is then completes the loop by returning to the heat recovery units to be reheated.

Lost Usable Space

Every mechanical component requires space within the building. The design for the University Medical Center minimizes this space to maximize useable space. To determine the lost usable space, the total floor area used by mechanical rooms and shafts was divided by the total floor area of the patient tower. The findings are summarized in table 7. The percent lost usable space is about 5.6%, a very reasonable number. The use of the mechanical shafts has been well planned and every mechanical space is used efficiently. The floor by floor break down is shown in Appendix B as “Lost Usable Space by Floor”.

Lost Usable Space Summary	
Total Floor Space	387,500
Total Lost Space	21,516
Percent Lost	5.55%

Table 7 Lost Usable Space

First Cost

Earlier in the report the annual operational cost of UMCP was given, but this is not the only cost associated with the mechanical system. The cost to purchase and install the equipment is significant in evaluating different systems possibilities and to calculate simple rate of return. A slight complication in calculating this number is that Turner Construction Corporation does not have costs separated for the patient tower alone. Therefore the total cost to purchase and install all of the mechanical and controls equipment within the hospital was accumulated. This total value was then divided by the total square footage of the entire building (including everything outside of the patient tower). It is shown that the cost per square foot for this particular mechanical system is about $124 per square foot. A reasonable considering the advanced mechanical system required to provide a high quality of air throughout the building. Table 8 reports the summary of this calculation. The table “Mechanical First Cost” in appendix B lists the total costs of the mechanical system by category as provided by Turner Construction.

Mechanical First Cost Summary	
Total Cost	$79,032,000
Total Square Footage	639,000 SF
Cost per Square Foot	$123.68

Table 8 Mechanical First Cost Summary

LEED Analysis

The University Medical Center of Princeton is design with the initiatives of LEED. Princeton Healthcare Services, however, does not list the building as being rated, but that does not mean the building does not qualify. After a simple analysis of the mechanical system, UMCP has 20 points, enough points to be certified. There are at least 5 other points that could easily be attainable if not already done so. Table 9 shows a list of the various requirements and credits that have been achieved by the current design. Through the analysis, it was found that E&E prereq 2 has not been reached. In Technical Report One it was found that UMCP did not meet ASHRAE 90.1 standards as required for this LEED prerequisite.

To better incorporate the new hospital into the community various alternative transportations are available. The New Jersey transit is currently working on creating new bus links that will have a new stop at the hospital. Also UMCP has made arrangements to transport all senior citizens to the hospital via bus and van. The hospital also promotes the use of bicycles by providing bicycle racks and paths into the hospital and around the 171 acre health campus.

In an effort to conserve energy and help protect the environment, UMCP is implementing various energy generation and conservation elements. The UMCP website specifies that there will be photovoltaic panels placed in the northeast parking lot that will generate 225kW. There are eight heat recovery units to supplement the 100% outside air units to reduce preheating and cooling costs. A chilled water thermal storage system is listed as being included as part of the energy reduction initiative. This is not show in the current Turner Construction drawings, it is likely that this system will be located within the central utility plant. The website for the UMCP reports that all of these systems will reduce the energy consumption by approximately 25% compared to current design and construction methods. This energy savings translates to five points for the Energy and Atmosphere Credit 1 and at least one point for credit 2.

The indoor air quality within the medical center is a concern for patient health. The requirements set forth by the Princeton Healthcare Services provide ventilation air rates well above those dictated in ASHRAE standard 60.2. These ventilation rates can be seen in Technical Report One. The hospital is also using low-emitting materials to assist in patient health, which meets the requirements for LEED credits 4.1-4 under Indoor Environmental Quality.

The five other points are assumed to be met through various means. The Princeton Healthcare Services has specified that a rain water collection system be installed. The goal of this system is to collect 250 gallons of water per week. The use of water saving fixtures within the hospital is also been required. Other points could be possible through the use of local materials, orientation of the building to the site, and the use of indigenous landscape materials.

LEED Point Analysis			
Category	Prereq/Credit	Description	Point
Sustainable Sites			
	Prereq 1	Construction Activity Pollution Prevention	1
	Credit 1	Site Selection	1
	Credit 4.1	Alternative Transportation	1
	Credit 4.2	Alternative Transportation	1
	Credit 5.2	Site Development	1
Energy & Atmosphere			
	Prereq 1	Fundamentals Commissioning of Building Energy Systems	
	Prereq 3	Fundamental Refrigeration Management	1
	Credit 1	Optimize Energy Performance	5
	Credit 2	On-Site Renewable Energy	2
	Credit 4	Enhanced Refrigerant Management	1
	Credit 6	Green Power	1
Indoor Environmental Quality			
	Prereq 1	Minimum IAQ Performance	
	Prereq 2	Environmental Tobacco Smoke Control	
	Credit 2	Increased Ventilation	1
	Credit 3.1	Construction IAQ Management Plan	1
	Credit 3.2	Construction IAQ Management Plan	1
	Credit 4.1	Low-Emitting Materials	1
	Credit 4.2	Low-Emitting Materials	1
	Credit 4.3	Low-Emitting Materials	1
	Credit 4.4	Low-Emitting Materials	1
	Credit 5	Indoor Chemical & Pollutant Source Control	1
	Credit 6.2	Controllability of System	1
	Credit 7.1	Thermal Comfort	1
	Credit 8.1	Daylight & Views	1
Other Possible Points outside of Mechanical System			5
		Total Possible Points	**31**

Table 9 Summary of achieved LEED credits and prerequisites by current design and specifications

Overall Evaluation

The current mechanical system design for the medical center is very sophisticated and well thought out. The use of a central utility plant places the efficiency of this system well above those of systems for similar sized buildings. Although the details of the specific equipment within the CUP are not known at this time, it can be assumed based on the requirements of the owner with other aspects the building, that no expense was spared in the goals of creating a highly efficient system. Heat recovery units used to preheat and precool the outside air; and the use of photovoltaics will help reduce energy consumption, as well as operating costs.

The constant use of the hospital creates a flatter energy consumption profile. Unlike many other large buildings within the United State, hospitals operate 24/7. Although the use does decrease during the night hours, there are still patients, doctors, nurses, and janitors using electricity and generating cooling loads. This flatter load profile allows the system to operate closer to full load more often, thus increasing efficiency.

The motto used by the University Medical Center is “Design for Healing”. To better assist in the healing process, each patient has a single room with individual climate and lighting control. Also, every patient, exam, imaging and operating space is supplied with 100% outside air. All ventilation air is filtered with HEPA filters and sterilized with UV light. It is clear that the design of this mechanical system is aimed to create a very healthy environment.

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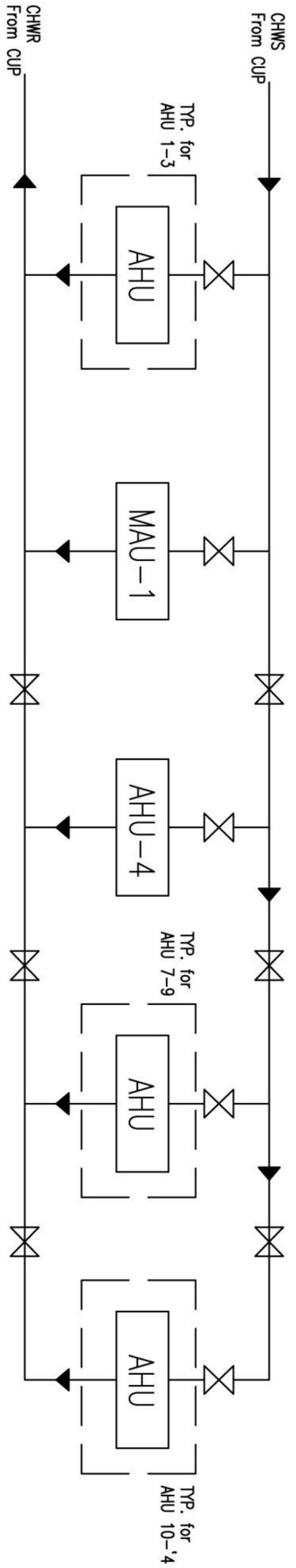
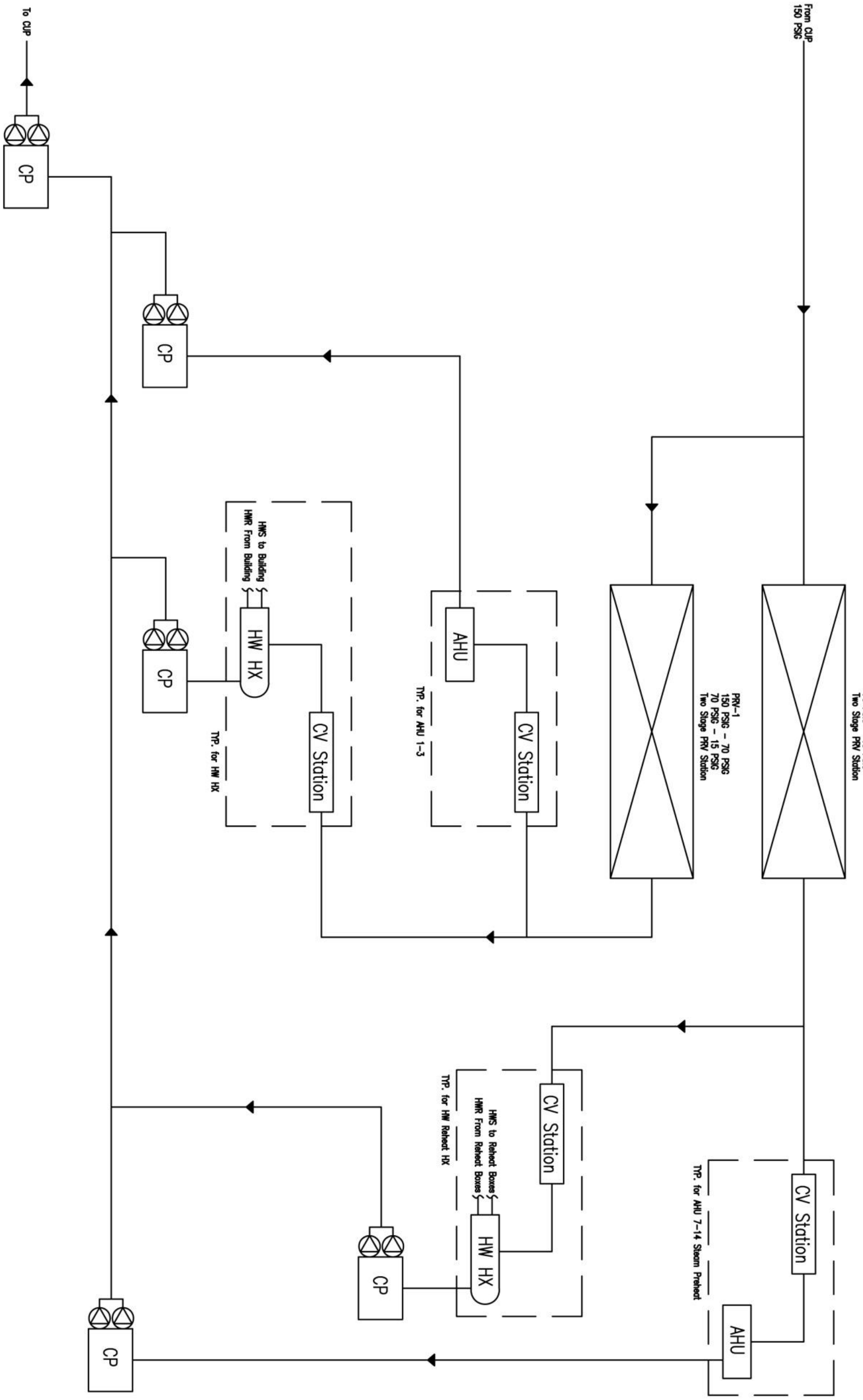
Appendix A

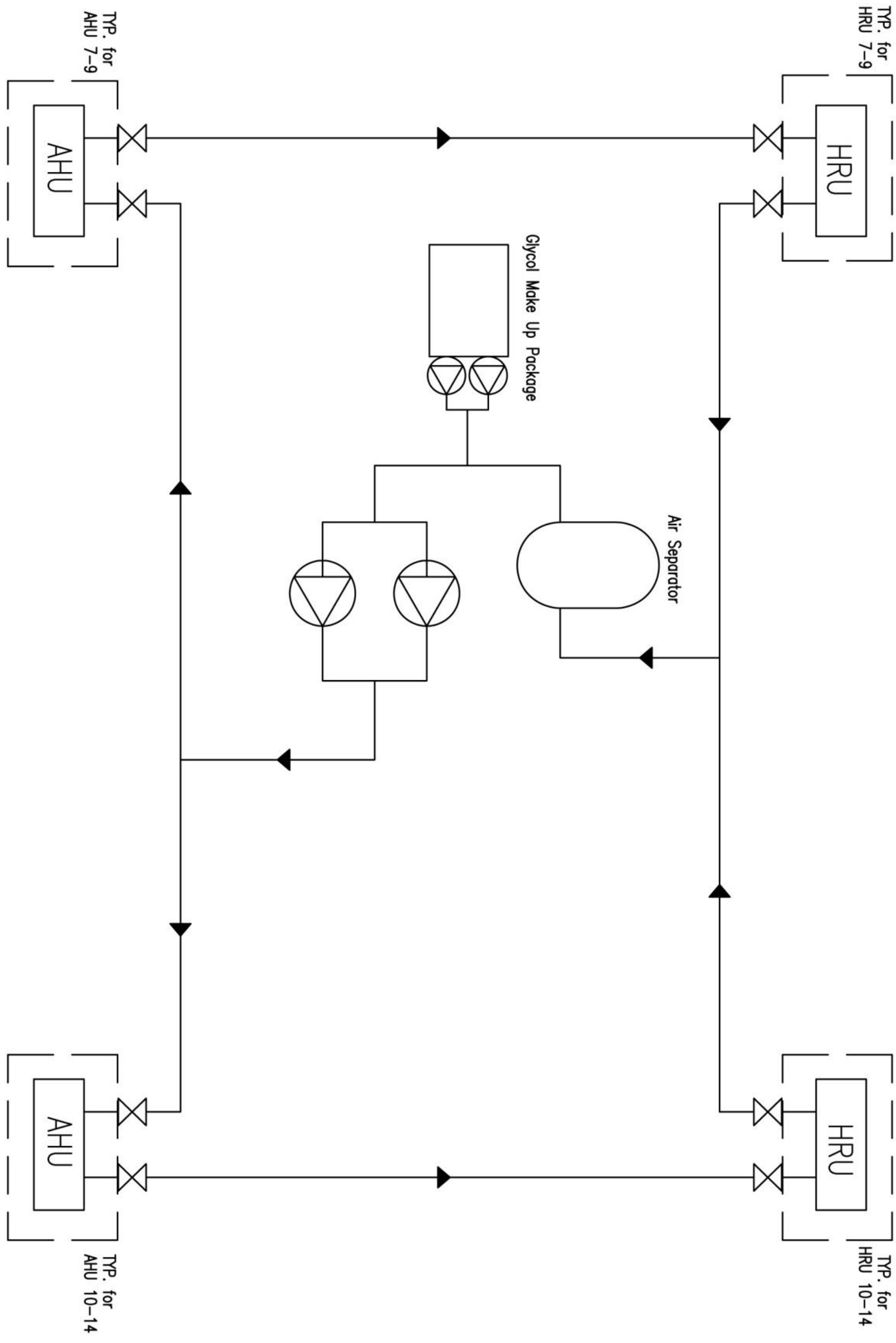


Simplified Chilled Water Flow Schematic

Simplified Steam Distribution Schematic



Simplified Energy Recovery Schematic



Appendix B

Lost Usable Space by Floor		
Floor	Area	Lost Area
0	60,700	14,500
1	60,700	848
2	60,700	788
3	51,350	1,345
4	51,350	1,345
5	51,350	1,345
6	51,350	1,345

Energy Consumption Summary			
Equipment	Fuel	Consumption	units
Boiler	Nat. Gas	23	1000 ft3/hr
Chiller	Electricity	743	kWh
Fan/motor	Electricity	1569	kWh
Lighting and Misc.	Electricity	552	kWh

Mechanical First Cost	
Category	Cost
Core & Shell Plumbing	$7,080,000
Fitout Plumbing	$16,600,000
Sprinkler System	$4,350,000
Ductwork	$18,000,000
HVAC Piping Core & Shell	$14,160,000
HVAC Piping Fitout	$4,790,000
Air & Water Balancing	$600,000
Temp and Fire Alarm Controls	$7,440,000
AHU	$4,780,000
HRU	$1,232,000