Technical Assignment #3

Mechanical Systems Existing Conditions Evaluation Report

Hilton Hotel at BWI Airport
Linthicum Heights, MD

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Executive Summary

This report develops a detailed evaluation of the existing mechanical systems and equipment for the Hilton Hotel at BWI Airport. All the major components and equipment used in the system design are explained and examined. In order to accurately accomplish this, the design objectives and requirements for the project are identified first.

The design of a building is influenced by a variety of factors. In this case, for the BWI Hilton, some of these factors included the energy sources and rates of electricity and natural gas, mechanical equipment first costs, and the solar orientation of the building on the site plan.

Also included with this report are the design ventilation requirements from ASHRAE Standard 62.1-2004 for the air handling units and rooftop units. The design heating and cooling loads for the major equipment are calculated using Carrier's Hourly Analysis Program. HAP is used to estimate the annual energy consumption for the BWI Hilton, as well.

Schematic drawings are developed for the hot water and condenser water systems with the corresponding mechanical equipment. The major equipment schedules are listed with information taken from the design documents for the BWI Hilton.

To gain an understanding of how the mechanical systems of the BWI Hilton actually function, the sequences of operation for the air handling units, rooftop units, variable air volume system, hot water system, and condenser water system are studied. Finally, an evaluation of the existing mechanical systems is performed with a critique of the variable air volume air handling units on the two main floors of the hotel, the water source heat pumps in all the guest rooms, and the rooftop units serving the guest room tower and main floors.

Mechanical System Summary

The primary air-side components of the mechanical system on the ground and second floors use a VAV system with reheat hot water coils at the boxes in the public and service spaces.

One air handling unit and one rooftop unit on the north side roof of the ground floor provide conditioned air to many of the spaces on the ground level. Also located on the same roof is a make-up air unit to provide adequate ventilation to the kitchen. A long string of linear slot diffusers provide the required amounts of supply air to the spaces from above the large areas of windows in the pre-function area, meeting rooms, coffee bar, and restaurant. Since the sidewall supply registers in the lobby seating area dispense the necessary quantity of supply air, a parallel system of fin tube radiators help to balance the heat loss from the large sections of windows located along the exterior walls.

The second floor mechanical room houses several pieces of large mechanical equipment. One air handling unit (AHU) conditions air for the large double-story height meeting rooms, smaller meeting rooms, and the pre-function area on the ground floor. A second AHU services many of the employee services rooms and offices on the ground floor. Also in the same mechanical room is a pool dehumidifier unit that conditions for the swimming pool area. A rooftop unit on the ground level roof conditions air for several of the laundry and service spaces that are on the second floor. From the mechanical room on the northeast corner of the second floor, another AHU provides air to the offices, meeting rooms, and exercise room/health club.

On the third through eleventh floors, all the guest rooms are equipped with individual water source heat pumps, master thermostats, and control valves in each room. Through the process of value engineering, two air conditioning units located in the penthouse, which were originally scheduled to supply each guest room with 60 cfm of outside air, and all the related ductwork and fire dampers were eliminated.

The positive pressure in both stairwells is maintained by two stair pressurization fans that deliver 11,700 cfm to each stairway. The pressurization required in the corridors on the third through eleventh floors is maintained by three rooftop units located in the penthouse. These rooftop units also provide supply air to the housekeeping areas on all the guest room floors.

Exhaust registers in all of the guest room bathrooms are ducted to sub-ducts and then tapped into the exhaust stacks. There are a total of 17 main toilet exhaust riser stacks connected to toilet exhaust fans mounted on either the eleventh floor roof or the penthouse roof. This sub-duct method, which received a variance prior to design and construction, aims to prevent the spread of smoke to the other guest room floors without using smoke dampers in each of the ducts.

The primary water-side components of the mechanical system include the condenser water system and the hot water system. Due to initial budget constraints, the originally designed chilled water system was eliminated along with two water cooled chillers and two chilled water pumps. Two open-cell cooling towers are located on the north side of the building on grade with the ground floor level. These cooling towers provide condenser water to the air handling units and guest room water source heat pumps. Each heat pump is tapped off 1-1/2 inch supply and return piping, and it also has 1 inch drain piping. The condenser water is then looped back to the cooling towers through a reverse return system through 8 inch piping.

Three fossil-fuel boilers in the parking level mechanical room provide hot water for all the reheat coils in the VAV boxes, the freeze protection pumps for the air handling units, and the pool dehumidifier unit. Other pieces of equipment served by the hot water are the unit heaters, finned tube radiators, and hot air curtains located in the vestibules.

To achieve adequate ventilation of the automotive exhaust fumes in the parking level, two large outside air louvers located on the west side of the parking area draw 20,000 cfm. The mixed air is drawn out of the parking area through garage exhaust fans located on the east side of the building.

The large mechanical room located on the north side of the parking level contains much of the water-side equipment used in the hotel. This includes three boilers and their corresponding pumps, two condenser water pumps, one sedimentation separator filter, two plate and frame heat exchangers, two hot water pumps with variable frequency drives, two diaphragm expansion tanks, and some other pieces of equipment.

All sequences of controls for the entire building are performed by direct digital controls (DDC). This DDC system monitors all the sensors, and it is able to adjust all the set points and time delays for the equipment. The DDC system also provides start/stop, speed control, monitoring, and alarms for the variable frequency drives (VFD).

Design Objectives and Requirements

Project Information:

The Hilton Hotel at BWI Airport is a full-service hotel that is located less than two miles from the Baltimore-Washington International (BWI) Airport in Linthicum Heights, Maryland. The primary customers at the hotel will be both business and leisure travelers flying in and out of BWI Airport. There are two main floors and nine floors in the guest room tower above grade; below grade is a below-grade parking garage. The hotel is approximately 277,000 square feet, and has a variety of functions. Not only does it have 286 guest rooms, but it also includes several large and small meeting rooms, offices, restaurant, two bars, swimming pool, exercise room, and attached parking garage.

Basis of Design:

The main design objectives are to provide a quality, on-budget, and multi-functional hotel for the owner, Hilton Hotels. All three of these aspects form the foundation for many of the design decisions and requirements of the hotel. The Hilton franchise is very experienced at the design and construction process of their widespread hotels. All of their requirements are listed in a manual called the “Hilton Design and Construction Standards”. This manual is the basis for all the decisions that are made regarding the proper and required design of the hotel with its many spaces and functions.

The three design objectives have a direct effect on the mechanical systems in the hotel. The equipment, ductwork, and piping need to be well concealed from sight, and loud mechanical system sound levels should be avoided. The selected components need to be of decent quality, function as intended, and do not require constant repair. However, the cost of these mechanical systems is often the bottom line that helps to make many of the decisions in the design process.

Private Spaces:

The private spaces in the BWI Hilton consist of the nine floors in the guest room tower with a total of 280 guest rooms. The guest rooms will primarily be occupied at night when customers will be sleeping, and some during the morning and evening hours. It is intended that each guest room has a separate air conditioning unit with individual control over the space temperature. Noise issues are also a concern, which affects the type of system chosen. Possible guest room systems are described next.

Guest Room Air Conditioning Units:

The Hilton Design and Construction Standards list the possible air conditioning unit types for For example, the lower-end Hilton hotels mainly use of packaged terminal air conditioning (PTAC) units for all the guest rooms; the higher-end Hilton hotels require the use of a four-pipe fan coil unit (FCU) system with both chilled and hot water for the guest rooms. In this case, the BWI Hilton is allowed to have one of three different guest room units: two-pipe FCUs with resistance heating, water source heat pumps (WSHPs), or four-pipe FCUs.

The four-pipe FCU system is the highest quality system that is commonly being used in hotels, and the PTAC units are not even allowed to be used on the BWI Hilton project. This leaves either the two-pipe FCU system with resistance heating or the water source heat pumps. It was suggested by the mechanical contractor, Southland Industries, Inc., on the project to use the two-pipe FCU system. However, Hilton Hotels preferred the use of the WSHP system on this project.

Public Spaces:

The ground and second floors of the BWI Hilton are the primary public and service spaces in the hotel. The public spaces in the building have occupancies that are changing throughout the course of the day. This ever-changing fluctuation in these spaces lends itself well for use of a variable air volume (VAV) system in the public spaces.

The meeting rooms could be completely full with a convention or other gathering or completely empty when no one is using the spaces. The restaurant will mostly be used at concentrated times around breakfast, lunch, and dinner. The bar and coffee bar will primarily be used in the evening and night hours. The offices will be used most when many employees are working. During the day hours, mostly the room cleaning personnel are in the hotel, while the caterers are there more during the evening and dinner times. The lobby areas will be used almost constantly during both the day night hours as customers and employees are continually coming or leaving.

The other public spaces in the BWI Hilton include the swimming pool area and the exercise room. The swimming pool and exercise room will mostly be used in the morning and evening hours and possibly some during the day. However, the swimming pool has special temperature and humidity requirements that necessitate an air conditioning and dehumidification system separate from all the other public spaces.

Service Spaces:

The service spaces in the BWI Hilton are made up of the spaces that only employees typically use. These include the offices, boardroom, kitchen, employee cafeteria, employee locker rooms/toilets, and banquet storage spaces. The service spaces, like the public spaces, have changing occupancy conditions all through the day. A VAV system could also work well for these types of spaces. The kitchen also requires make-up air to replace the exhausted air through exhaust fans and fume hoods.

Other service spaces include mechanical and electrical equipment rooms, communication rooms, vending areas, as well as the laundry facilities. All of these spaces contain certain types of equipment that require ventilation to provide conditioning for the equipment-generated heat.

Energy Sources and Rates

The Hilton Hotel at BWI Airport is serviced by both electricity and natural gas energy sources. Since the hotel is still currently under construction, the energy rates are assumed based on information gathered from the respective energy provider websites.

The electric service in the Linthicum Heights area is provided by Baltimore Gas and Electric (BGE). The appropriate electric rates and tariffs were obtained from BGE's website (http://www.bge.com/) and with the assistance of a customer service representative. The rate schedule used for the BWI Hilton is the General Service Large (GL).

The electric service rates are separated out into delivery service customer charge, demand charges, energy charges, and delivery service charge. The energy charges are divided into peak, intermediate, and off-peak periods. The information regarding these rates and hours can be found in Appendix A – Energy Rates.

The natural gas service is provided by Washington Gas, and the rates and tariffs were found on their website (http://www.washgas.com/). The natural gas rates were determined to be from rate schedule Number 2, which is for Firm Commercial and Industrial Sales service.

The natural gas rates are divided into the system charge and the distribution charge. The distribution charge is broken down based on the amount of gas (therms) used in one month. The information regarding the rates is located in Appendix A – Energy Rates.

Cost Factors

There are several cost factors that could have potentially influenced design decisions with the mechanical system for the Hilton Hotel at BWI Airport. These include first costs, operating and maintenance costs, life cycle costs, and rebates and incentives. Even though the system costs were very important, Hilton Hotels has predetermined design standards that it follows on all of its building projects. These items are described previously in the Design Objectives and Requirements section.

There were no available utility rebates or any offered energy incentives for the BWI Hilton project. Therefore, no special considerations or decisions were made for the mechanical system selection based on rebates or incentives.

After a discussion with the mechanical contractor on the project (Southland Industries, Inc.), it was determined that the only significant cost factor for the mechanical system and equipment selection was based on the first costs. The operation and maintenance costs were considered, but they were not as important as the first costs. There was no life cycle cost estimate obtained from the design engineer for the project, so it is not known whether it was taken into account in the mechanical system decision making process. Based on all these reasons, only the first costs of the mechanical systems were evaluated, and they are described next.

The total mechanical system first cost was found to be almost $6.5 million, after totaling the sheetmetal, pipe fitting, and plumbing costs for labor, materials, and fabrication, equipment costs, sub-contracted work costs, start/test labor costs, and general conditions costs. Once the total first cost was calculated, the price per square foot was determined. The cost per square foot was found to be $23.68/sf as shown below in Figure 1 – Mechanical System First Cost.

Mechanical System Cost per SF	
First Cost	$6,454,337
Total Building Area (sf)	272,567
Cost per SF	**$23.68/sf**

Figure 1 – Mechanical System First Cost

Site Factors

The Hilton Hotel at BWI Airport has one major site factor that influenced the design decisions for the building's mechanical systems. There are also a few items that played a role in the overall design of the hotel.

The only site factor that significantly affected the mechanical systems was the orientation of the BWI Hilton on the site. With the exterior walls of the building facing either in the north-south or east-west directions, the perimeter spaces have different heat loss and heat gain effects.

This is important with the large areas of windows in the main entrance lobby and restaurant. It was necessary to place hot water fin tube radiators (FTRs) around the lobby perimeter along the windows to make up for the window heat loss. More information on the FTRs is located in Figure 32 – Fin Tube Radiator Schedule in Appendix G – Major Equipment Schedules.

The solar loads on different sides of the building also affected all the guest rooms, which all have either north or south-facing windows. This influenced the required capacities of the water source heat pumps (WSHPs). All the spaces on the south-facing side of the nine-story guest room tower are equipped with a larger model WSHP than the ones on the north side. More information regarding the WSHPs is located in Figure 30 – Water Source Heat Pump Schedule in Appendix G – Major Equipment Schedules.

Being that the hotel is located less than two miles from the Baltimore-Washington International (BWI) Airport, a height restriction was placed on the structure of the building. Also, the Hilton Design and Construction Standards require a minimum of 150 guest rooms in the hotel, along with the inclusion of a variety of many other spaces in the building. Therefore, it is necessary that all of these required functions are adequately met within the constraints of the site plan area and below the building height restriction.

The site of the BWI Hilton is located outside of the Chesapeake Bay Critical Areas, so there are no special requirements for the site itself. The previous building on that lot was a structural steel fabrication and building support shop, and that should also have no effect on the new hotel.

Outdoor and Indoor Design Conditions

Outdoor Design Conditions:

The 2001 ASHRAE Fundamentals Handbook provides weather data in Chapter 27 – Climatic Design Information for cities in the United States, Canada, and other countries around the world. The information for the Hilton Hotel at BWI Airport was gathered from the values for the most extreme conditions given for Maryland – Baltimore, BWI Airport. Some of the weather data listed includes heating and cooling design temperatures and other design conditions.

The information used for the BWI Hilton is listed in Figure 6 – Heating and Wind Design Conditions and Figure 7 – Cooling and Dehumidification Design Conditions, which is found in Appendix B – Outdoor Design Conditions.

Carrier's Hourly Analysis Program (HAP) was used to simulate and model the BWI Hilton's energy usage. In order to accurately do this, proper weather conditions were selected for the hotel's site. Baltimore, Maryland was selected for both the Design City and the Simulation City. HAP automatically inputs the correct weather design data, which was also taken from the 2001 ASHRAE Fundamentals Handbook.

The HAP weather conditions and data used in the simulation process can be found in Appendix B – Outdoor Design Conditions.

Indoor Design Conditions:

The indoor design conditions for the Hilton Hotel at BWI Airport are defined in the Sequences of Operations. They specify certain design conditions for all the spaces with variable air volume (VAV) boxes that condition the supply air to the rooms in each VAV box zone. These spaces include the large and small meeting rooms, boardroom, pre-function area, offices, restaurant, bars, and many of the employee service spaces.

However, no cooling and heating setpoints were specified for the guest rooms or any of the other spaces on the nine floors of the guest room tower. Therefore, it was assumed that these same prescribed design conditions for the VAV zones above should be applied to all the rest of the spaces in the hotel.

The Sequences of Operations only define the dry bulb temperature setpoint for cooling and heating. A standard assumption was made that the relative humidity conditions for the summer and winter are both 50%.

The typical range for the space thermostat settings are based on the sensitivity of the room temperature sensors, which is typically about 1.0-1.5^{o}F.

These specified indoor design conditions for the BWI Hilton are shown below in Figure 2 – Indoor Design Conditions.

Indoor Design Conditions		
	Summer	Winter
Dry Bulb Temperature	74^{o}F	70^{o}F
Relative Humidity	50%	50%

Figure 2 – Indoor Design Conditions

Design Ventilation Requirements

ASHRAE Standard 62.1-2004 is used to determine minimum ventilation rates for the Hilton Hotel at BWI Airport. The supply air to the building is conditioned by four air handling units (AHUs), which range in size from 7500 cfm to 25,000 cfm. The minimum amount of outside air to the four AHUs varies between 2000 cfm and 16,000 cfm. In addition to the four AHUs, the hotel is also served by six rooftop units (RTUs). The RTUs range in size between 2500 and 11,100 cfm.

After calculating the required amount of outside air for each AHU and RTU, the compliance of each unit was determined. These design AHU and RTU ventilation summaries are listed in Appendix C – Design Ventilation Requirements.

Comparing the calculated outdoor airflow rates from ASHRAE Standard 62.1-2004 with those in the design documents, it can be seen that three of the AHUs do not comply with the ventilation standard. The primary reason for the non-compliance of three of the four AHUs is based on the assumption made for the space occupancies. The design occupancies for all the rooms of the hotel were unknown, since that information was not provided from the designers. Therefore, the default occupancies (number of people per 1000 square feet) from ASHRAE Standard 62.1-2004 were assumed to be the actual occupancies of all the spaces. However, most of these assumed occupancies were too high, and the required ventilation rates were also calculated to be too high.

These assumed design occupancies and ventilation rates per person and per square foot for the AHUs and RTUs are listed in Figures 12 and 13 in Appendix C – Design Ventilation Requirements.

Design Heating and Cooling Loads

The design heating and cooling loads for the Hilton Hotel at BWI Airport were compiled from the project's equipment schedules. The selected equipment includes all air handling units (AHUs), rooftop units (RTUs), make-up air handling unit (MAU), pool dehumidifier unit (DHU), water source heat pumps (WSHPs), and fin tube radiators (FTRs). This equipment and their corresponding load capacities are shown in Figure 14 – Equipment Design Loads from Design Documents.

Approximate design loads were estimated by using HAP for the AHUs and RTUs for the BWI Hilton. These estimated design loads are included in Figure 15 – Estimated Design Loads from HAP.

However, there is some variation in the cooling loads for the AHUs and RTUs between the design documents and the HAP output. This could be due to several different factors, one of which deals with the assumed design occupancies for all of the spaces in the hotel. As described previously in the Design Ventilation Requirements section, the assumed default occupancies from ASHRAE Standard 62.1-2004 are greater than the actual room occupancies. This over-estimation is a likely cause for the differences of the heating and cooling loads of the BWI Hilton.

All the designer and HAP estimated design loads are located in Appendix D – Design Heating and Cooling Loads.

Annual Energy Use

The annual energy use estimate was not available from the designers on the Hilton Hotel at BWI Airport project. The building design engineer was contacted about a hotel energy analysis. However, if an energy analysis was performed during the design stage, it was never released, and there was no chance of obtaining any information from the design engineer. It is unclear whether or not an energy analysis was ever done for the BWI Hilton. Also, no meter data or utility bills were available since construction is currently in progress at the new hotel.

To determine an approximate annual energy use for the hotel, Carrier's Hourly Analysis Program (HAP) was used. As can be seen below in Figure 3 – Energy Totals, the electric usage is much more significant than the natural gas usage in the building. This can be accounted for in that nearly all the lighting and electric equipment loads were entered as known values. However, only a fraction of the natural gas loads were simulated in HAP. This is because not all of the mechanical equipment using natural gas was able to be accurately modeled in the systems (most notably, the 286 water-source heat pumps in all of the guest rooms).

Energy Totals	
Electric (kWh)	1,486,663
Natural Gas (Therm)	7,312

Figure 3 – Energy Totals

For more information regarding the annual energy consumption and the annual energy costs, please refer to the tables in Appendix E – Annual Energy Use.

Schematic Drawings of Existing Mechanical Systems

Overview:

There are several mechanical systems used in the design and construction of the Hilton Hotel at BWI Airport. The main hydronic systems in the building are the hot water piping and the condenser water piping. All the flow rates, pipe sizes, equipment sizes, and water temperatures are included where they are known.

These piping schematics and the necessary equipment and components are depicted in Appendix F – Schematic Drawings. The corresponding keys for both of the diagrams are also included.

Hot Water Schematic:

The Hot Water Flow Diagram shows the hot water supply and return piping system. Some of the major equipment in the schematic includes the boilers, boiler pumps, hot water pumps, hot water generators, heat exchanger, boiler tank, and expansion tank. All of the known values for the various pipe sizes, flow rates, and flow directions for the piping are also shown on the schematic drawing. The Hot Water Flow Diagram is shown in Figure 19, and the Hot Water Flow Diagram Key is listed in Figure 20.

Condenser Water Schematic:

The Condenser Water Flow Diagram shows the condenser water supply and return piping system to and from the cooling towers with the cooling tower condenser water supply and return piping, as well. Some of the major equipment in the schematic includes the cooling towers, condenser water pumps, heat pump loop pumps, heat exchangers, expansion tank, air separator, and sedimentation separator. All the various pipe sizes, flow rates, and flow directions for the piping are also shown on the schematic drawing. The Condenser Water Flow Diagram is shown in Figure 21, and the Condenser Water Flow Diagram Key is listed in Figure 22.

Major Equipment Summary

There is a variety of mechanical equipment used in the Hilton Hotel at BWI Airport. Of all the different types of equipment in the building, only eleven were selected as being “major” components of the mechanical system. Each of these major equipment types are described below. For all the required data from the equipment schedules from the design documents, refer to Appendix G – Major Equipment Schedules.

Air Handling Units:

Four variable air volume (VAV) air handling units (AHUs) serve the majority of the spaces on the two main floors of the BWI Hilton. They primarily provide conditioned air to the meeting rooms, lobbies, offices, support areas, bars, and the restaurant. All AHUs are equipped with economizer cycles, as well as 25-100% variable frequency drives.

For operating conditions and additional information on the AHUs, refer to Figure 23 – Air Handling Unit Schedule.

Rooftop Units:

The six rooftop units (RTUs) serve all nine floors of the guest room tower, as well as part of the two main floors of the BWI Hilton. The pressurization required in the corridors on the third through eleventh floors is maintained by three RTUs located in the penthouse. These rooftop units also provide supply air to the housekeeping areas on all the guest room floors. The RTU on the ground level roof conditions air for several of the laundry and service spaces that are on the second floor.

Four of the RTUs provide 100% outdoor air, and one RTU has a minimum of 97% outdoor air. The other RTU supplies air to the elevator machine room in the penthouse on top of the guest room tower, and it uses all return air with no minimum amount of outdoor air.

For operating conditions and additional information on the RTUs, refer to the schedule in Figure 24 – Rooftop Air Handling Unit Schedule.

Make-Up Air Handling Unit:

The make-up air handling unit (MAU) provides additional conditioned air to the large commercial kitchen that serves the restaurant on the ground floor of the BWI Hilton. This make-up air is needed to replace the exhausted air through all the kitchen fume hoods.

For operating conditions and additional information on the MAU, refer to Figure 25 – Make-Up Air Handling Unit Schedule.

Pool Dehumidification Unit:

The pool dehumidification unit (DHU), which is located in one of the second floor mechanical rooms, supplies and returns conditioned air to and from the swimming pool area. The DHU is used because it has different air and humidity conditions and controls than all the AHUs and RTUs.

For operating conditions and additional information on the DHU, refer to Figure 26 – Pool Dehumidifier Unit Schedule.

Cooling Towers:

The cooling towers, which consist of two open-cell units, are located on-grade on the north side of the BWI Hilton outside of the kitchen and restaurant. The cooling towers provide condenser water for the four AHUs and the water source heat pumps in all the guest rooms of the hotel.

For operating conditions and additional information on the cooling towers, refer to Figure 27 – Cooling Tower Schedule.

Boilers:

Three natural gas-fired fossil-fuel boilers provide hot water to all eleven floors of the hotel. The three boilers are located in the main mechanical equipment room on the parking garage level.

For operating conditions and additional information on the boilers, refer to Figure 28 – Boiler Schedule.

Heat Exchangers:

Two plate and frame heat exchangers are located in the main mechanical equipment room on the parking garage level. The one heat exchanger provides cooling for the condenser water loop from the cooling towers. The other heat exchanger provides heating for the hot water loop from the boilers.

For operating conditions and additional information on the heat exchangers, refer to Figure 29 – Heat Exchanger Schedule.

Water Source Heat Pumps:

All the guest rooms on floors three through eleven of the guest room tower and other special rooms on the eleventh floor have individual water source heat pumps (WSHPs). Each of the 286 WSHPs are provided with individual thermostats for independent operation and temperature control in each room.

For operating conditions and additional information on the WSHPs, refer to Figure 30 – Water Source Heat Pump Schedule.

Variable Air Volume Boxes:

The conditioned air from each of the four AHUs is ducted to variable air volume (VAV) boxes that are located in the ceiling plenum spaces on the ground and second floors of the BWI Hilton. Each of the eight different sizes of VAV boxes has a selected range of cfm. There are also different gpm amounts for the hot water reheat coils to each of the VAV boxes.

For operating conditions and additional information on the VAV boxes, refer to Figure 31 – VAV Box Schedule.

Fin Tube Radiators:

The large windows in the main entrance lobby are the main source of heat loss for the space. To counter these cooling effects, hot water fin tube radiators are placed along the windows around the perimeter of the lobby seating area and the coffee bar.

For operating conditions and additional information on the FTRs, refer to Figure 32 – Fin Tube Radiator Schedule.

Pumps:

There are several different types of pumps in the BWI Hilton. The majority of the pumps are located in the main mechanical equipment room on the parking garage level of the building. Boiler pumps serve each of the three fossil-fuel boilers. Two condenser water pumps serve the cooling tower open loop, and two more pumps serve the heat pump loop. Three other pumps serve the hot water system; two for the primary hot water, and one for the radiant hot water. All four of the AHUs have one freeze protection pump.

For operating conditions and additional information on the pumps, refer to Figure 33 – Pump Schedule.

Conceptual Description of System Operation

System Overview:

The Hilton Hotel at BWI Airport consists of both air-side and water-side mechanical systems and equipment. The air-side is comprised of air handling units (AHUs), rooftop units (RTUs), a make-up air unit (MAU), a pool dehumidifier unit (DHU), and the variable air volume (VAV) boxes.

The water-side operation includes both a hot water system and a condenser water system. The hot water components are the boilers, their respective pumps, a heat exchanger, a boiler tank, and an expansion tank. The condenser water system components are the cooling towers, their respective pumps, heat exchangers, an expansion tank, an air separator, and a sedimentation separator.

For a brief overview of the mechanical system and locations of the major equipment, refer to the Mechanical System Summary section.

The Sequences of Operations provide a detailed summary of all the direct digital controls (DDCs) used in the mechanical systems of the BWI Hilton. It was referenced numerous times for the system operations.

Schedule of Operation:

The BWI Hilton essentially has an operating schedule of 24 hours a day, 7 days a week, and 365 days a year. This is due to the high variability of occupants, both employees and customers, that are in the building throughout the day and night. The public spaces are mainly used during the day, while the private spaces are mostly used at night. The service spaces could be used all day, since there will always be employees in the building working at the front desk. For more information about the public, private, and service spaces of the hotel, refer to the Design Objectives and Requirements section.

All the control sequences for the mechanical systems in the entire building are performed by the DDCs. This DDC system monitors all the sensors, and it is able to adjust all the set points and time delays for the equipment. The DDC system also provides start/stop, speed control, monitoring, and alarms for the variable frequency drives (VFDs).

For more information and design conditions about these systems, refer to the Major Equipment Summary section, as well as Appendix G – Major Equipment Schedules for the equipment schedules.

Air Handling Unit Operation:

Description:

The four air handling units (AHUs) serve the majority of the public and private spaces in the BWI Hilton. Two of the AHUs supply air at 51^{o}F and the other two supply air at 50 ^{o}F. All four are equipped with 25-100% variable frequency drives (VFDs) to modulate the flow rate of supply air. Only AHU-2, which serves the restaurant, bar, coffee bar, and the main entrance lobby, has an axial return fan with VFD control. The four AHUs all are provided with economizer cycles on the outdoor air dampers to adjust between the minimum outdoor airflow ventilation rates and 100% outdoor air. The condenser water serves the AHUs in the cooling coil section, and hot water is supplied to the heating coil. Freeze protection pumps are also used to prevent the solidifying of any fluids in the AHU coils.

The four AHUs all provide conditioned air to the ground and second floors as a part of a variable air volume (VAV) system with reheat hot water coils at the VAV boxes in the public and service spaces. With the supply air from the AHU at 50-51^{o}F, the temperature at the box will be about 55^{o}F. At the VAV box, the amount of ventilation air to each room is determined and reheated, if necessary. There is no local recirculation or mixing of supply air in any of the spaces in the hotel. All the return air is ducted back to the respective AHU.

This is based on the thermostat controls provided in each of the VAV box zones. The larger rooms on the meeting rooms all have their own VAV zone, but many of the smaller offices and other private spaces do not have individual room controls. A single thermostat control for that particular VAV zone is used to select all those room set-point temperatures.

The meeting rooms primarily function as either occupied or unoccupied spaces. All the other public and private spaces operate at part-load conditions for the majority of the time.

Operation:

The DDC controller will have no direct control of the four AHUs, supply fans, and return fans. This is because the four AHUs are to be controlled via the factory installed controller. The AHU used as the basis of design for the VAV AHUs is manufactured by McQuay. The McQuay equipment submittal contains all the details on the sequence of operation, but it was not available as a reference for this assignment.

Rooftop Unit Operation:

Description:

The six rooftop units (RTUs) are located on the second floor roof or the penthouse roof of the guest room tower. One of the primary purpose for the RTUs is to provide ventilation air to several of the public spaces on the first two floors of the hotel. The major purpose of three of the RTUs is for pressurization of all the corridors of the guest room tower. These functions and the outdoor air percentages of the RTUs have been described before.

The supply air temperatures range between 52 and 62^{o}F for each of the six RTUs. Except for the one in the elevator machine room, the scroll compressors of the air-cooled condensing unit are located on the exterior of the RTUs. All six of the RTUs are also provided with indirect gas-fired heaters with combustion blowers.

The RTU that provides ventilation air to the second floor laundry room areas supplies conditioned air to the spaces as it is called for based on the thermostat settings. The RTU that serves the kitchen area provides ventilation air for the employees working, as well as cooler air to offset the heat gains from the all the kitchen equipment.

The three RTUs that provide corridor pressurization also ventilate the communications rooms, housekeeping, and vending areas on all nine floors of the guest room tower. These air-cooled condensing units allow for the corridors to provide humidity control and meet exhaust and ventilation requirements in the guest room tower.

This positive pressure serves several purposes. First, it keeps the direction of moisture flow through the exterior walls towards the outside. Second, it prevents infiltration into the building by maintaining slight exfiltration. Finally, it provides odor mitigation for all the guest rooms. This is done by forcing the air in the corridors to flow into the guest rooms via the door undercuts using the positive pressure of the corridors and the negative pressure from each of the guest room toilet exhaust fans. In this way, odors from guest rooms cannot be transferred into the corridor and into other guest rooms.

Operation:

The DDC controller will have no direct control of the six RTUs, supply fans, and return fans. This is because the four AHUs are to be controlled via the factory installed controller. The AHU used as the basis of design for the VAV AHUs is manufactured by Aaon. The Aaon equipment submittal contains all the details on the sequence of operation, but it was not available as a reference for this assignment.

Variable Air Volume System Operation:

Description:

The variable air volume (VAV) boxes are connected in-line with ductwork for the supply air provided by the four AHUs, which were described previously. All of the VAV boxes have hot water reheat in the BWI Hilton project. Some of the spaces are provided with a VAV box for just that room. These spaces have individual temperature controls. Some of the other VAV boxes condition air for more than one space. These zones only have one temperature control, so all the spaces in those zones are conditioned to the same setpoint from the one thermostat.

Operation:

The VAV boxes are designed to maintain temperature at a cooling setpoint of 74 ^{o}F and at 70 ^{o}F for the heating setpoint. However, some of the spaces (namely the large meeting rooms) have occupancy sensors to detect motion with the room. When motion is detected and after a 15 minute time delay, the corresponding VAV box will run at its occupied cfm and temperature setpoints.

Several different modes of maintaining space setpoint temperatures can be accomplished by the system. The selected mode is based on whether the zone is occupied or unoccupied. The other criteria deal with the zone temperature as it is either above the cooling setpoint, below the cooling setpoint, or less than the heating setpoint. The primary means of maintaining space setpoint temperatures is done through the modulation of the zone damper between its minimum and maximum settings.

The DDC controller also measures the zone temperatures and modulates the reheating coil valve open to maintain its heating setpoint.

Hot Water System Operation:

Description:

The three boilers and natural gas burners generate water at 180 ^{o}F for the hot water system at the BWI Hilton. All three boilers have identical output capacities and firing rates, and they are arranged in a parallel piping configuration. The parallel piping is done to supply each boiler with the same inlet water temperature. In this way, it is also possible to achieve independent flow through each boiler and boiler pump. Also, a check valve for each boiler is needed to prevent backflow a boiler is inactive.

The boiler pumps directly pump the return water into the boiler. On the other side, two parallel hot water pumps with VFDs draw the hot water out of the boiler tank. This is known as a primary secondary pumping arrangement with a tank used as the bridge. This configuration is clearly illustrated in the Hot Water Flow Diagram in Figure 19.

These three boilers and natural gas burners provide hot water for several different pieces of hydronic equipment. The boiler pumps maintain constant pressure in the water entering the boilers to ensure proper operation. The hot water pumps circulate the hot water to the pool dehumidifier unit, hot air curtains, unit heaters, and the reheat coils in the VAV boxes. A separate radiant hot water pump circulates the hot water to the fin tube radiators in the main entrance lobby. As mentioned before, the AHUs also receive hot water for the heating coil and as freeze protection from the hot water pumps.

For a drawing of this system, refer to the schematic diagram of the hot water system in Figure 19 – Hot Water Flow Diagram in Appendix F – Schematic Drawings.

Operation:

The hot water pumps are enabled when a certain number of VAV box hot water reheat coils require heating, the outside air temperature is less than 60^{o}F, or the water source heat pump (WSHP) loop is in heating mode. The pumps will run as freeze protection when the outside air temperature is less than 38^{o}F.

The two hot water pumps run in a lead/lag manner. This means that the lead pump runs first, unless it fails. Then the lag pump runs and the lead pump stops running. If the hot water differential pressure decreases, the lag pump runs along with the lead pump to maintain the hot water differential pressure setpoint.

This hot water differential pressure is measured by the DDC controller, and it modulates the hot water pump VFDs to maintain the hot water differential pressure setpoint. This setpoint is 15 psi, and the minimum speed of the VFDs does not drop below 20%.

To maintain the setpoint, the controller modulates the lead VFD. But if the lead VFD is more than 90%, the lag VFD runs and ramps up to meet the lead VFD speed. The two VFDs run together to maintain the setpoint.

The FTR radiant hot water pump cycles on when the outside air temperature falls below 55^{o}F. After the outside air temperature rises above 60^{o}F, the radiant hot water pump cycles off.

Condenser Water Operation:

Description:

Two open-cell cooling towers provide cooling tower condenser water to the four AHUs and the 286 guest room water source heat pumps (WSHPs). Each vertical WSHP unit is tapped off the condenser water supply piping header at the top level. Each one is then connected to the WSHPs above and below it in the riser. This works very well with each WSHP having the riser piping pre-connected. The WSHP condenser water return is then looped back through reverse return piping to balance the risers and the system.

The condenser water runs through a plate and frame counterflow heat exchanger with the cooling tower condenser water. This heat exchanger keeps the cooling tower condenser water separated from the water run through the entire condenser water loop. This is important because the cooling tower condenser water is open to the atmosphere as it runs down through the fill and into the basin. Since the cooling tower loop is open to the atmosphere, it is possible for the water to become contaminated or dirty. This could potentially damage all the other condenser water equipment, including the 286 guest room WSHPs, which would cause a lot of operation problems and maintenance costs for the hotel.

All of the guest rooms are provided with individual WSHPs, master thermostats, and control valves to allow for maximum control of the system in each room. This method enables the occupants to control their own space temperature, and feedback shows that there is minimal dissatisfaction with the system.

For a drawing of this system, refer to the schematic diagram of the condenser water system in Figure 21 – Condenser Water Flow Diagram in Appendix F – Schematic Drawings.

Cooling Tower Operation:

The cooling tower runs when the WSHP loop is in cooling mode and the outside air temperature is above 60^{o}F. If the outside air temperature falls below 40^{o}F, the electric basin heaters and the electric heat tracing for the outdoor piping are turned on.

The DDC controller measures the cooling condenser water supply basin temperature and modulates the bypass valve and fan VFD at the same time to maintain setpoints. The controller modulates the bypass valve to maintain a setpoint of 84 ^{o}F and the fan VFD to maintain a setpoint of 85 ^{o}F.

If the condenser water supply temperature continues to rise, the second cooling tower runs to maintain setpoints. To maintain the setpoint, the controller modulates the lead VFD. But if the lead VFD is more than 90%, the lag tower fan VFD runs and ramps up to meet the lead VFD speed. The two VFDs run together to maintain the setpoint.

If the condenser water supply temperature continues to fall, the VFD cycles off as described next. If the VFD speeds drop below 60%, then the lag VFD stops running, and the lead VFD continues to run to maintain setpoint.

The condenser water pumps operate in a lead/standby manner. The lead pump runs first, and the other pump is on standby. If the lead pump fails, then the standby pump funs and the lead pump stops running.

Water Source Heat Pump Operation:

The WSHP loop runs continuously while any zone is occupied or a certain number of unoccupied zones require heating or cooling.

The two WHSP loop pumps run in a lead/lag manner. This means that the lead pump runs first, unless it fails. Then the lag pump runs and the lead pump stops running. If the loop water differential pressure decreases, the lag pump runs along with the lead pump to maintain the loop water differential pressure setpoint.

The WSHP loop water differential pressure is measured by the DDC controller, and it modulates the loop water pump VFDs to maintain the loop water differential pressure setpoint. This setpoint is 15 psi, and the minimum speed of the VFDs does not drop below 20%.

If the loop water differential pressure continues to decrease, the controller modulates the lead VFD to maintain the setpoint. But if the lead VFD is more than 90%, the lag VFD runs and ramps up to meet the lead VFD speed. The two VFDs run together to maintain the setpoint.

If the WSHP loop water differential pressure rises, the VFD cycles off as described next. If the VFD speeds modulate below 60%, then the lag VFD stops running, and the lead VFD continues to run to maintain setpoint.

Operating History of Mechanical Systems

Since the Hilton Hotel at BWI Airport is still currently under construction, no information is available regarding the building's mechanical system operating history. Therefore, no costs, energy consumption, emissions, or any other data can be listed for the hotel.

Critique of Mechanical Systems

Overview:

The mechanical system design for the Hilton Hotel at BWI Airport could be characterized as being satisfactory. The chosen systems, namely the VAV AHU system and the condenser water system seem to be an adequate and plausible design, as was previously described. However, there are many aspects of the mechanical system design that really need to be reevaluated, revised, and redesigned. Also, it seems like many of the decisions were made in order to just create a working design for the building. Much more could be done to truly optimize the system and equipment selections.

Guest Room Air Conditioning Units:

Current Design:

One of the biggest areas of possible improvement in the BWI Hilton project deals with the selection of 286 water source heat pumps (WSHPs) as the air conditioning equipment used in the guest room tower.

However, the current WSHP design has a few good qualities. The first benefit is that the vertical units come manufactured with the supply and return piping. It is only necessary to interconnect the units on adjacent floors in vertical risers, and this eliminates the need to run riser piping all around the hotel.

Another aspect of the design that works well is the reverse return system from all of the WSHPs. With the header at the top level, there is one express riser that brings the return water back down the guest room tower. This reverse return design balances out all the risers and less balancing needs to be done at a later time.

The final benefit of the WSHP system is that it is hard to beat for response to the guests. It is possible to have heating or cooling whenever it is desired, and it can put energy back into the loop for other WSHPs to use. This averages out if one WSHP is in cooling and another is in heating.

Despite of these benefits, the hotel business typically views a WSHP system for the guest rooms to be a fairly low-end kind of system that requires frequent maintenance in the guest rooms when the compressors fail in the units. Maintenance costs could become expensive, and there is the possibility of disturbing the hotel guests in their rooms.

The WSHP system is considered to be just one step above the bottom in guest room air conditioning systems. The worst type is a packaged terminal air conditioning (PTAC) unit. PTACs are extremely noisy, and are typically only used in lower-grade hotels. PTACs are only used in hotels where guest room rates verses client base will accept the noise of the PTAC units.

Design Alternatives:

The next system up from a vertical stack WSHP system is the vertical fan coil unit (FCU). The FCU system is a huge improvement over the WSHP because there is no compressor located in every guest room. This can also be a big improvement in energy usage due to the fact that the fan coils are served by a chiller plant. The WSHP heat pump has a high kW/ton ratio, which is approximately 1.4, but is touted as an energy saving system. This is because there are times when some WSHPs are in cooling mode and others are in heating mode. The energy can be exchanged in the system, but this is a rare condition and the high majority of the time the WSHP system is not very energy efficient.

A two-pipe FCU system with electric reheat could act similarly to a four-pipe system, and work as well as the WSHPs for comfort conditions. This is better than the high-end design of a four-pipe FCU design that circulates hot and cold water whether guests use it or not. However, the higher-end hotels often use this four-pipe FCU design because the room rates warrant comfort and low noise.

Value Engineering Decisions:

The original design of the BWI Hilton called for a four-pipe system with a chilled water loop and hot water heating, which was used for the meeting rooms and office spaces. However, this system was too expensive, and the owner could not bring the project in on budget. By using the self-contained AHUs, it eliminated the chiller plant and the chilled water piping loop. Also, a major section of hot water piping was eliminated from the VAV AHUs that was running parallel to the condenser water loop for the tower.

This was all due to initial budget constraints, and the originally-designed chilled water system was eliminated along with two water-cooled chillers and two chilled water pumps. Through the process of value engineering, two air conditioning units located in the penthouse, which were originally scheduled to supply each guest room with 60 cfm of outside air, and all the related ductwork and fire dampers were also eliminated.

Guest Room Ventilation:

During the value engineering process for the Hilton Hotel at BWI Airport, it was mentioned previously that the two air conditioning units in the penthouse were eliminated. These provided 60 cfm of ventilation air to each of the 280 guest rooms in the guest room tower. After eliminating the primary source of fresh air, a variance was granted for the BWI Hilton project to use an alternative method of ventilation. This method takes the supply air that the RTUs use to provide pressurization to the guest room tower corridors and has it drawn into each of the guest rooms through the undercut in the doors. The corridor air is drawn into the guest rooms either through the mechanical exhaust fan in the bathrooms or the use of operable windows.

It seems as if a better concept could be used to provide adequate amounts of ventilation to all of the guest rooms.

VAV AHU System:

As mentioned previously, the design of the VAV system with the four AHUs to all the public spaces on the two main ground floors is a feasible solution. However, there are many other alternative mechanical systems that could improve thermal comfort, be more energy efficient, or even be a more economical solution. Oftentimes, designers fail to spend enough time in the conceptual stage of design, and they simply choose the most familiar or popular design without adequately comparing all of their options.

Again, a better concept and solution could be devised to properly condition all the spaces of the BWI Hilton.

Appendix A – Energy Rates

Electric Rates from Baltimore Gas and Electric:

GENERAL SERVICE LARGE -- ELECTRIC SCHEDULE GL		
Delivery Service Customer Charge:	$110	per month
Demand Charges:	Summer	Non-Summer
Generation Market-Priced Service:	(per kW)	(per kW)
Type II	-	-
Transmission Charge for Market-Priced Service:		
Type II	$1.05	$1.05
Delivery Service	$2.67	$2.67
Energy Charges:		
Generation Market-Priced Service (¢/kWh): (Excludes Rider 8 – Energy Cost Adjustment)	Summer	Non-Summer
Type II		
Peak	9.319	5.534
Intermediate	8.802	5.406
Off-Peak	8.464	5.118
Delivery Service Charge:	1.239	¢/kWh
Hours:	Summer	Non-Summer
Peak	10 am - 8 pm	7 am - 11 am 5 pm - 9 pm
Off-Peak	11 pm - 7 am	9 pm - 7 am
Intermediate	7 am - 10 am 8 pm - 11 pm	11 am - 5 pm

Figure 4 – Electric Rates from Baltimore Gas and Electric

Natural Gas Rates from Washington Gas:

Natural Gas Utility Rates		
System Charge		
	$36.25	per customer
Distribution Charge		
First 300 therms:	$0.3158	per therm
Next 6700 therms:	$0.2152	per therm
Over 7000 therms:	$0.1573	per therm

Figure 5 – Natural Gas Rates from Washington Gas

Appendix B – Outdoor Design Conditions

2001 ASHRAE Fundamentals Handbook:

Station	Latitude	Longitude	Elevation (ft)	Std. Pressure (psia)	Dates
Maryland - Baltimore, BWI Airport	39.18	76.67	154	14.614	6193

Heating Dry Bulb	Extreme Wind Speed (mph)	Coldest Month		MWS/PWD to DB				Extreme Annual Daily			
		1.0%		99.6%		0.4%		Mean DB		Std Dev DB	
99.6%	1.0%	WS	MDB	MWS	PWD	MWS	PWD	Max	Min	Max	Min
11	24	25	31	10	290	11	280	97	4.0	2.9	5.8

Figure 6 – Heating and Wind Design Conditions

Cooling DB/MWB		Evaporation WB/MDB		Dehumidification DP/MDB and HR			Range of DB
0.4%		0.4%		0.4%			
DB	MWB	WB	MDB	DP	HR	MDB	
93	75	78	88	75	132	83	18.8

Figure 7 – Cooling and Dehumidification Design Conditions

Carrier's Hourly Analysis Program (HAP) Weather Properties:

Carrier's HAP Weather Properties				
Design Parameters				
Region	U.S.A.		Atmospheric Clearness Number	1.0
Location	Maryland			
City	Baltimore		Average Ground Reflectance	0.2
Latitude	39.2 deg			
Longitude	76.7 deg		Soil Conductivity	0.8 Btu/hr/ft/F
Elevation	154.0 ft		Design Cooling Calculation Months	January to December
Summer Design DB	93.0 ^oF			
Summer Coincident WB	75.0 ^oF		Time Zone (GMT +/-)	5.0 hours
Summer Daily Range	18.8 ^oF		Daylight Savings Time	Yes
Winter Design DB	11.0 ^oF		DST Begins	April 3
Winter Coincident WB	8.6 ^oF		DST Ends	October 30
*From 2001 ASHRAE Fundamentals Handbook				

Figure 8 – HAP Weather Design Parameters

Design Temperatures				
Monthly Max/Min				
	Dry Bulb (^oF)		Web Bulb (^oF)	
Month	Max	Min	Max	Min
January	54.8	36.0	49.4	35.5
February	57.2	38.4	53.8	37.9
March	67.0	48.2	61.6	47.7
April	75.8	57.0	65.4	56.9
May	84.6	65.8	70.4	64.9
June	90.0	71.2	72.9	67.6
July	93.0	74.2	74.8	69.8
August	93.0	74.2	74.8	69.8
September	88.6	69.8	72.4	67.1
October	79.4	60.6	68.0	60.5
November	71.0	52.2	62.8	51.7
December	59.8	41.0	54.4	40.5

Figure 9 – HAP Monthly Design Temperatures

Appendix C – Design Ventilation Requirements

AHU Ventilation Summary:

Unit	Zone Max. Zp	System Ventilation Efficiency, E_v	Uncorrected Outdoor Air Intake V_{ou} (cfm)	Total Outdoor Airflow ΣV_{oz} (cfm)	Design Outdoor Air Intake Flow V_{ot} (cfm)	Unit Min. Outdoor Air (cfm)	Unit Total Supply Air (cfm)
AHU-1	0.37	0.70	6395	6395	9136	16,000	25,000
AHU-2	1.00	0.59	9365	9365	15,873	11,500	23,000
AHU-3	0.80	0.56	2957	2957	5280	4300	8600
AHU-4	0.80	0.60	2087	2087	3478	2000	7500

Figure 10 – AHU Ventilation Summary

RTU Ventilation Summary:

Unit	Zone Max. Zp	System Ventilation Efficiency, E_v	Uncorrected Outdoor Air Intake V_{ou} (cfm)	Total Outdoor Airflow ΣV_{oz} (cfm)	Design Outdoor Air Intake Flow V_{ot} (cfm)	Unit Min. Outdoor Air (cfm)	Unit Total Supply Air (cfm)
RTU-1	0.37	0.90	288	821	913	4400	4400
RTU-2	0.51	0.60	678	2987	4978	11,100	11,100
RTU-3	0.31	0.80	324	830	1038	4520	4520
RTU-7	0.40	0.70	1276	1276	1823	3500	3500
RTU-8	0.26	0.80	711	711	889	3400	3500
RTU-11	0.03	1.00	71	71	71	--	2500

Figure 11 – RTU Ventilation Summary

AHU Space Ventilation Criteria:

Space / Function	People Outdoor Air Rate Rp (cfm/person)	Area Outdoor Air Rate Ra (cfm/sf)	Default Occ. Density (#/1000 sf)
Conference/Meeting Room	5	0.06	50
Lobby/Pre-function Area	7.5	0.06	120
Restaurant Dining Rooms	7.5	0.18	70
Toilet Room	0	0.2	0
Electrical Room	0	0.5	0
Bar	7.5	0.18	100
Telephone/Data Entry	5	0.06	60
Office Space	5	0.06	5
Corridor	0	0.06	0
Storage Room	0	0.12	0
Elevator Lobby	0	0.5	0
Mechanical Room	0	0.3	0
Health Club/Aerobics Room	20	0.06	40
Cafeteria	7.5	0.18	100

Figure 12 – AHU Space Ventilation Criteria

RTU Space Ventilation Criteria:

Space / Function	People Outdoor Air Rate R_p (cfm/person)	Area Outdoor Air Rate R_a (cfm/sf)	Default Occ. Density (#/1000 sf)
Corridor	0	0.06	0
Communications Room	0	0.5	0
Housekeeping Area	7.5	0.06	20
Vending Area	0	0.5	0
Elevator Lobby	0	0.5	0
Bedroom/Living Room	5	0.06	10
Kitchen	15	0.06	20
Storage Room	0	0.12	0
Office Space	5	0.06	5
Laundry Area	7.5	0.06	20
Service Elevator Lobby	0	0.5	0
Elevator Machine Room	0	0.5	0

Figure 13 – RTU Space Ventilation Criteria

Appendix D – Design Heating and Cooling Loads

Equipment Design Heating and Cooling Loads:

Equipment Design Loads			
System	**Heating Capacity (MBH)**	**Sensible Cooling Capacity (MBH)**	**Total Cooling Capacity (MBH)**
AHU-1	1140	918	1754
AHU-2	621	904	1510
AHU-3	232	316	576
AHU-4	162	226	364
RTU-1	540	157	313
RTU-2	780	430	833
RTU-3	540	176	341
RTU-7	390	108	201
RTU-8	390	108	201
RTU-11	180	74	115
MAU-1	600	--	--
DHU-1	902	--	--
WSHP-1	1.74	1.15	1.58
WSHP-2	2.62	1.96	2.53
FTR-1	19.58	--	--
FTR-2	13.55	--	--

Figure 14 – Equipment Design Loads from Design Documents

Estimated Design Heating and Cooling Loads from HAP:

Estimated Design Loads				
System	**Design Load (MBH)**	**Load (ton)**	**Design Load (sf/ton)**	**Cooling (sf/ton)**
AHU-1	1754	146.2	89.6	135.9
AHU-2	1510	125.8	135.2	162.2
AHU-3	576	48.0	174.3	261.6
AHU-4	364	30.3	353.9	759.4
RTU-1	313	26.1	281.3	802.6
RTU-2	833	69.4	171.1	494.3
RTU-3	341	28.4	285.9	819.8
RTU-7	201	16.8	235.2	492.5
RTU-8	201	16.8	230.4	583.6
RTU-11	115	9.6	14.8	865.2

Figure 15 – Estimated Design Loads from HAP

Appendix E – Annual Energy Use

Annual Energy Consumption:

Annual Energy Consumption	
Component	**Energy Use**
HVAC Components	
Electric (kWh)	371,064
Natural Gas (Therm)	7,312
Non-HVAC Components	
Electric (kWh)	1,115,599
Natural Gas (Therm)	0
Totals	
Electric (kWh)	1,486,663
Natural Gas (Therm)	7,312

Figure 16 – Annual Energy Consumption

Annual Energy Consumption by Energy Source				
Component	**Site Energy (kBTU)**	**Site Energy (kBTU/ft²)**	**Source Energy (kBTU)**	**Source Energy (kBTU/ft²)**
HVAC Components				
Electric	1,266,071	14.985	4,521,682	53.516
Natural Gas	731,210	8.654	731,210	8.654
HVAC Sub-Total	**1,997,281**	**23.639**	**5,252,892**	**62.17**
Non-HVAC Components				
Electric	3,806,424	45.051	13,594,373	160.895
Natural Gas	0	0	0	0
Non-HVAC Sub-Total	**3,806,424**	**45.051**	**13,594,373**	**160.895**
Grand Total	**5,803,705**	**68.689**	**18,847,265**	**223.066**

Figure 17 – Annual Energy Consumption by Energy Source

Annual Energy Costs:

Annual Energy Costs			
Component	**Annual Cost ($/yr)**	**Square Foot Cost ($/ft²)**	**Percent of Total (%)**
Electric	25,642	0.304	24.7
Natural Gas	2,213	0.026	2.1
HVAC Sub-Total	**27,855**	**0.33**	**26.8**
Non-HVAC Components			
Electric	75,905	0.898	73.2
Natural Gas	0	0	0
Non-HVAC Sub-Total	**75,905**	**0.898**	**73.2**
Grand Total	**103,760**	**1.228**	**100**

Figure 18 – Annual Energy Costs

Appendix F – Schematic Drawings

Hot Water Flow Diagram:

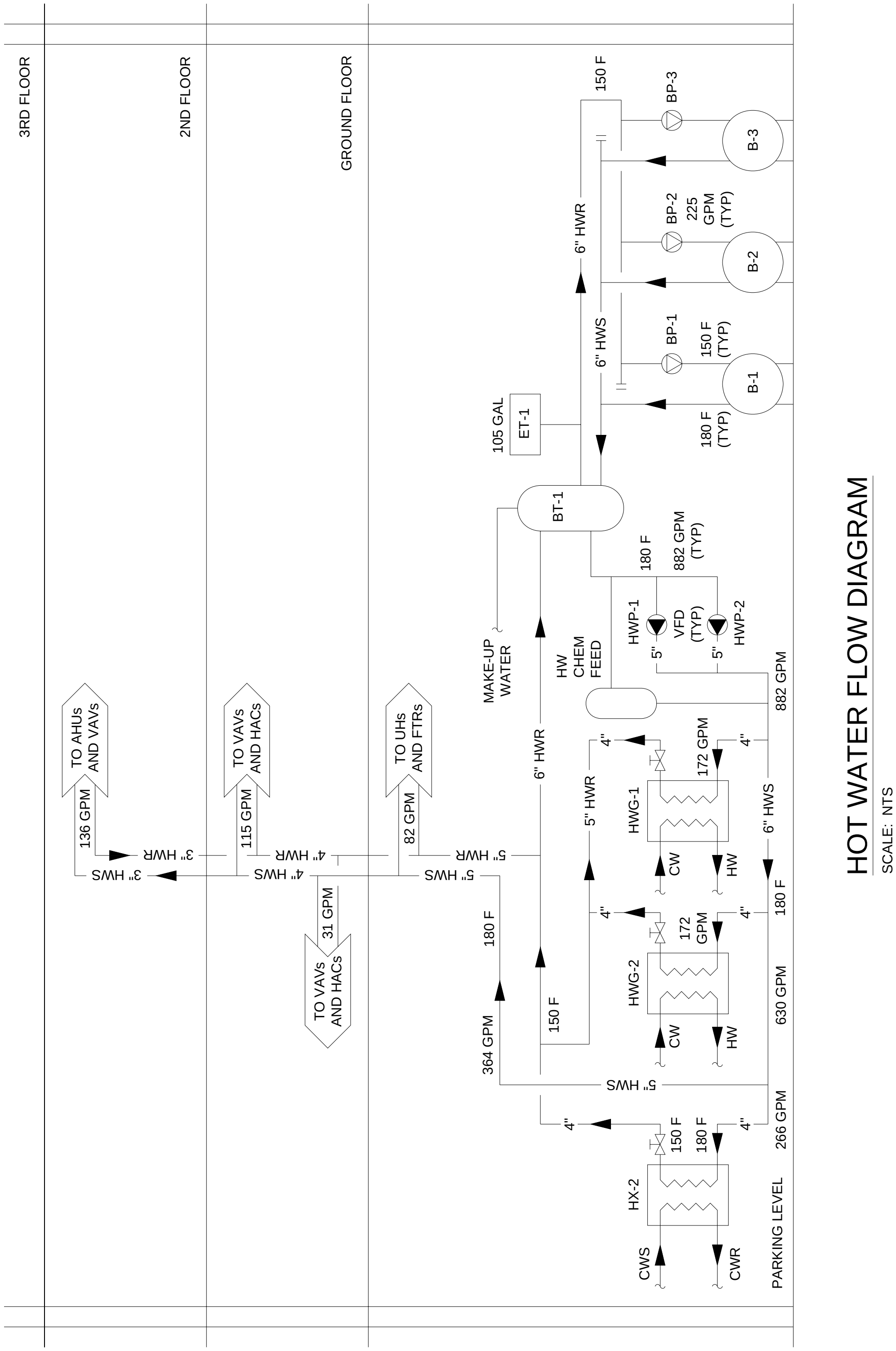

Figure 19 – Hot Water Flow Diagram

Hot Water Flow Diagram Key:

Hot Water Flow Diagram Key	
AHU	Air Handling Unit
B	Boiler
BP	Boiler Pump
BT	Boiler Tank
CW	Domestic Cold Water
CWR	Condenser Water Return
CWS	Condenser Water Supply
ET	Expansion Tank
FTR	Fin Tube Radiator
GPM	Gallons per Minute
HAC	Heated Air Curtain
HW	Domestic Hot Water
HWG	Hot Water Generator
HWR	Hot Water Return
HWS	Hot Water Supply
HX	Heat Exchanger
UH	Unit Heater
VAV	Variable Air Volume
VFD	Variable Frequency Drive

Figure 20 – Hot Water Flow Diagram Key

Condenser Water Flow Diagram:

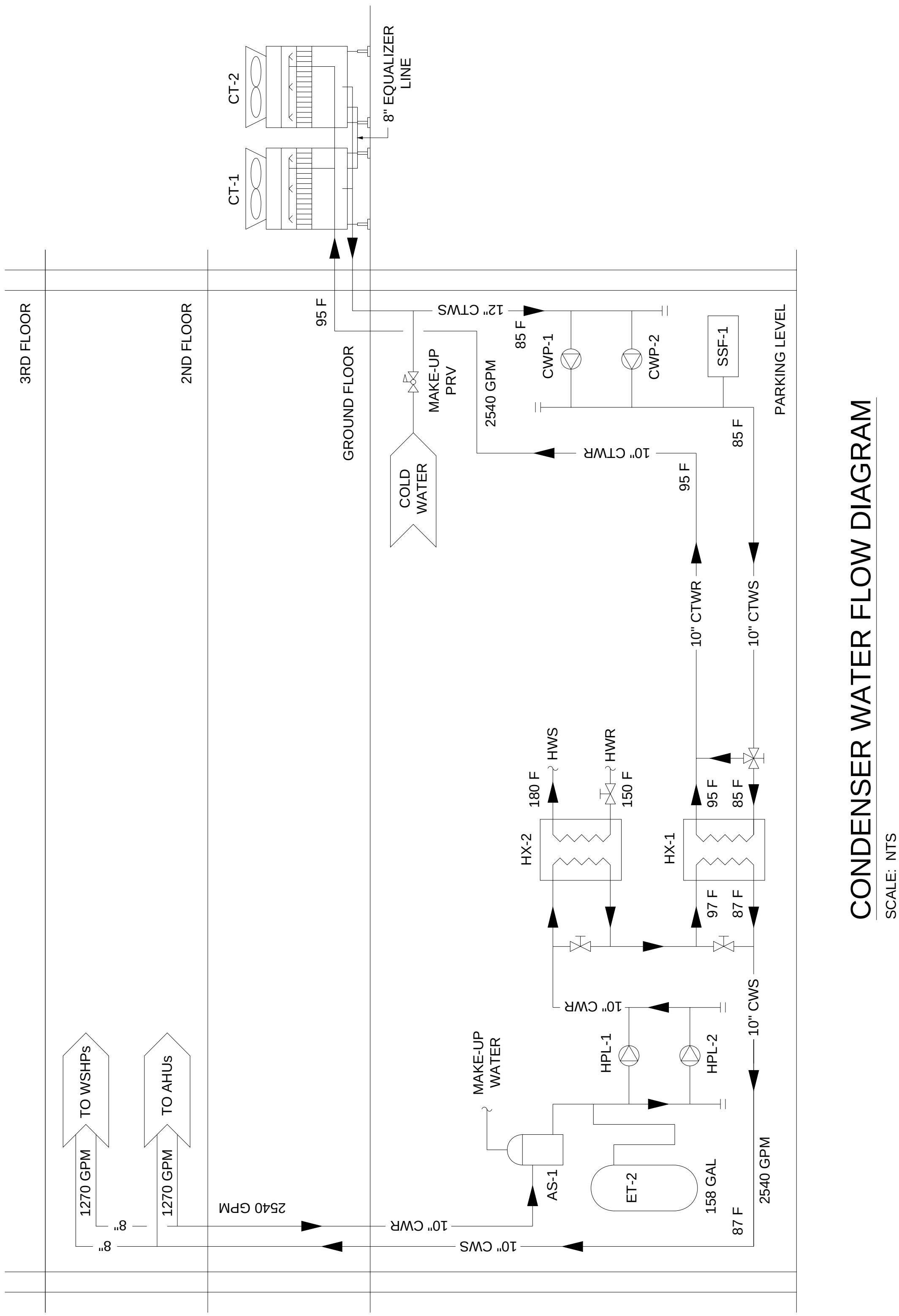

Figure 21 – Condenser Water Flow Diagram

Condenser Water Flow Diagram Key:

Condenser Water Flow Diagram Key	
AHU	Air Handling Unit
AS	Air Separator
CT	Cooling Tower
CTWR	Cooling Tower Water Return
CTWS	Cooling Tower Water Supply
CWP	Condenser Water Pump
CWR	Condenser Water Return
CWS	Condenser Water Supply
ET	Expansion Tank
GPM	Gallons per Minute
HPL	Heat Pump Loop
HW	Hot Water
HWR	Hot Water Return
HWS	Hot Water Supply
HX	Heat Exchanger
PRV	Pressure Reducing Valve
SSF	Sedimentation Separator
WSHP	Water Source Heat Pump

Figure 22 – Condenser Water Flow Diagram Key

Appendix G – Major Equipment Schedules

Air Handling Unit Schedule:

Air Handling Unit Schedule													
Unit No.	Service	Location	Total cfm	Min. OA cfm	Supply Fan Data								
					Capacity Control		SP (in wg)		Wheel		Max.	Motor
					Range	Type	Ext.	Total (dirty)	Dia. (in)	Type	bhp	hp
AHU-1	Meeting Rooms	2nd Floor - MER	25,000	16,000	25-100%	VFD	3.25	5.4	17	AF	31	40
AHU-2	Restaurant	2nd Floor - Roof	23,000	11,500	25-100%	VFD	3.25	4.1	--	AF	40	40
AHU-3	Administration	2nd Floor - MER	8600	4300	25-100%	VFD	3.25	4.4	20	FC	8	10
AHU-4	Storage/Office	2nd Floor - MER	7500	2000	25-100%	VFD	3.25	4.8	18	FC	11	15

Air Handling Unit Schedule (continued)								
Unit No.	Return Fan Data							
	Capacity Control		Ext. SP (in wg)	Wheel		cfm	Max. bhp	Motor hp
	Range	Type		Dia. (in)	Type			
AHU-1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
AHU-2	25-100%	VFD	1	--	Axial	11,500	10	10
AHU-3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
AHU-4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Air Handling Unit Schedule (continued)												
Unit No.	Cooling Coil											
	Total MBH	Sens. MBH	Face Velocity (fpm)	Air Data					Condenser Water Data			
				EAT (°F)		LAT (°F)		Max. PD (in wg)	gpm	EWT (°F)	LWT (°F)	Max. PD (ft)
				DB	WB	DB	WB					
AHU-1	1754	918	450	85.5	72.8	51	51	1	441	85	95	20
AHU-2	1510	904	320	84	71.2	50	50	1	398	85	95	20
AHU-3	576	316	455	84	71.2	50	50	1	141	85	95	20
AHU-4	364	226	425	80	67	51	51	1	72.8	85	95	20

Air Handling Unit Schedule (continued)												
Unit No.	Heating Coil									Electrical		
	Total MBH	Face Velocity (fpm)	Air Data			Hot Water Data						
			EAT (°F)	LAT (°F)	Max. PD (in wg)	gpm	EWT (°F)	LWT (°F)	Max. PD (ft)	Volts	Phase	Hz
AHU-1	1140	520	35	76.7	0.25	45	180	129.3	20	460	3	60
AHU-2	621	320	35	60	0.25	41.4	180	150	20	460	3	60
AHU-3	232	430	35	77.5	0.25	16	180	129.3	2	460	3	60
AHU-4	162	500	40	75.2	0.25	10.8	180	126.6	20	460	3	60

Figure 23 – Air Handling Unit Schedule

Rooftop Air Handling Unit Schedule:

Rooftop Air Handling Unit Schedule													
Unit No.	Service	Location	Min. OA Conditions			Bldg. RA Conditions		Supply Fan					
			cfm	DB (°F)	WB (°F)	DB (°F)	WB (°F)	Total cfm	SP (in wg) Total (dirty)	SP (in wg) Ext.	Max. bhp	Motor hp
RTU-1	Guest/Corridor	Penthouse/Roof	4400	91	77	--	--	4400	2.8	2	2@1.94	2@3
RTU-2	Housekeeping	Penthouse/Roof	11,100	91	77	--	--	11,100	2.8	2	12.98	15
RTU-3	Guest/Corridor	Penthouse/Roof	4520	91	77	--	--	4520	2.8	2	2@1.98	3
RTU-7	Kitchen	2nd Floor Roof	3500	91	77	--	--	3500	3	1.5	1.9	3
RTU-8	Laundry	2nd Floor Roof	3400	91	77	--	--	3500	3	1.5	1.9	3
RTU-11	Elev. Mach. Rm.	Penthouse/Roof	--	--	--	80	67	2500	2	1.5	1.47	3

Rooftop Air Handling Unit Schedule (continued)												
Unit No.	Unit Cooling Capacity					Air-Cooled Condensing Unit						
	Total MBH	Min. Sens. MBH	Max. Face Velocity (fpm)	Unit LAT DB (°F)	Unit LAT WB (°F)	Compressor(s) Type	Compressor(s) No.	Compressor(s) Nom. RLA Ea.	Compressor(s) Steps of Unload	DB Temp. (°F)	Condenser Fan(s) No.	Condenser Fan(s) HP Ea.
RTU-1	313	157	138	57	56	Scroll	4	9	--	--	4	3/4
RTU-2	833	430	254	54	54	Scroll	4	23.7	--	--	6	3/4
RTU-3	341	176	142	58	55	Scroll	4	9	--	--	4	3/4
RTU-7	201	108	180	62	60	Scroll	2	11	2	95	2	3/4
RTU-8	201	108	180	62	60	Scroll	2	11	2	95	2	3/4
RTU-11	115	74	215	52	51	Scroll	2	9	2	95	1	3/4

Rooftop Air Handling Unit Schedule (continued)												
Unit No.	Indirect Gas-Fired Heater Data								Electrical Service			
	Input MBH	Output MBH	Air Side EAT (°F)	Air Side LAT (°F)	Air Side Max. PD (in wg)	Gas Press. (in wg)	Combustion Blower Motor No.	Combustion Blower Motor hp Ea.	Volts	MCA	Phase	Hz
RTU-1	540	438	10	101	--	--	2	1/4	460	57	3	60
RTU-2	780	632	10	62	--	--	2	1/4	460	136	3	60
RTU-3	540	438	10	62	--	--	2	1/4	460	57	3	60
RTU-7	390	315.9	13	75	1.5	8	1	1/4	480	34	3	60
RTU-8	390	315.9	13	77	1.5	8	1	1/4	480	34	3	60
RTU-11	180	146	45	80	1.5	8	1	0.09	480	27	3	60

Figure 24 – Rooftop Air Handling Unit Schedule

Make-Up Air Handling Unit Schedule:

Make-Up Air Handling Unit Schedule															
Unit No.	Service	Location	Supply Fan					Indirect Gas-Fired Heater Data					Electrical Service		
			Total cfm	SP (in wg) Total (dirty)	SP (in wg) Ext.	rpm	Motor hp	Input MBH	Output MBH	Air Side EAT (^oF)	Air Side LAT (^oF)	Gas Press. (in wg)	Volts	Phase	Hz
MAU-1	Kitchen	Roof	8500	1.2	0.75	1725	7.5	600	435	13	60	8	480	3	60

Figure 25 – Make-Up Air Handling Unit Schedule

Pool Dehumidifier Schedule:

Pool Dehumidifier Schedule									
Unit No.	Service	Location	Inlet Temp. (^oF)	Air RH	Water Temp. (^oF)	Moisture Removal Cap. (lb/hr)	Evaporator Capacity (MBH)	Reheat Capacity (MBH)
DHU-1	Pool	2nd Floor - MER	82	60	80	70	194	231

Pool Dehumidifier Schedule (continued)																
Unit No.	Evaporator Fan				Return Fan			Auxiliary Heat				Auxiliary Heat			
	SA cfm	OA cfm	ESP (in wg)	hp	SA cfm	ESP (in wg)	hp	Cap. MBH	EWT (^oF)	LWT (^oF)	Max. PD (in wg)	Cap. MBH	EWT (^oF)	LWT (^oF)	Max. PD (in wg)
DHU-1	3400	800	1.5	5	3200	0.5	3	461	180	150	15	231	85	95	25

Pool Dehumidifier Schedule (continued)									
Unit No.	Pool Water Condenser			Compressor			Electrical Service		
	Cap. MBH	Flow gpm	Max. PD (ft)	Qty.	FLA (Ea.)	LRA (Ea.)	Volts	Phase	Hz
DHU-1	210	30	25	1	59	425	480	3	60

Figure 26 – Pool Dehumidifier Schedule

Cooling Tower Schedule:

Open-Cell Cooling Tower Schedule									
Unit No.	Service	Location	Type	No. of Cells	Nominal Tons/ Cell	Summer Data			
						gpm/ Cell	EAT (°F)	LAT (°F)	EAT WB (°F)
CT-1,2	HX-1	Grade	Cross Flow Induced Draft	2	424	1270	95	85	79

Open-Cell Cooling Tower Schedule (continued)										
Unit No.	Fan Data (per Cell)				Basin Heater		Electrical			Operating Weight (lbs)
	cfm	Motor		Drive Type	No.	kW Ea.	Volts	Phase	Hz	
		Speeds	HP							
CT-1,2	247,100	VFD	2(30)	Belt	2	8	480	3	60	35,760

Figure 27 – Cooling Tower Schedule

Boiler Schedule:

Fossil-Fuel Boiler Schedule										
Unit No.	Location	Output Capacity (Net IBR)		Firing Rate	Oper. Press. (psig)	Water			Fan Motor hp	FLA
		MBH	hp	Gas (cfh)		EWT (°F)	LWT (°F)	gpm		
B-1	Parking Level - MER	3350	100	4035	150	180	180	225	7.5	10
B-2	Parking Level - MER	3350	100	4035	150	180	180	225	7.5	10
B-3	Parking Level - MER	3350	100	4035	150	180	180	225	7.5	10

Figure 28 – Boiler Schedule

Heat Exchanger Schedule:

Plate and Frame Heat Exchanger Schedule											
Unit No.	Location	Capacity MBH	Hot Side				Cold Side				Fouling Factor (Ea. Side)
			EWT (^oF)	LWT (^oF)	Flow gpm	Max. PD (ft water)	EWT (^oF)	LWT (^oF)	Flow gpm	Max. PD (ft water)	
HX-1	Parking Level - MER	7000	97	87	1400	25	85	95	1400	25	0.0005
HX-2	Parking Level - MER	4000	180	150	266	10	48	55	1142	25	0.0005

Figure 29 – Heat Exchanger Schedule

Water Source Heat Pump Schedule:

Water Source Heat Pump Schedule												
Unit No.	Location	Cooling Capacities							Heating Capacity			
		EWT (^oF)	LWT (^oF)	EAT (^oF)		Total MBH	Sens. MBH	Rejected MBH	EWT (^oF)	LWT (^oF)	Total MBH	EAT DB (^oF)
				DB	WB							
WSHP-1	Guest rooms	87	97	80.6	86.2	11	8	14	55	49.2	12.1	68
WSHP-2	Guest rooms	87	97	80.6	86.2	17.6	13.6	23	55	48.8	18.2	68

Water Source Heat Pump Schedule (continued)										
Unit No.	Water Side		Air Side		Electrical Characteristics					
	gpm	PD (ft water)	cfm	ESP (in water)	Fan			Compressor		
					HP	FLA	Volts	RLA	Volts	Phase
WSHP-1	3.1	10	470	0.1	0.1	0.6	227	4.3	277	1
WSHP-2	4.5	10	730	0.1	0.2	1	227	6.3	277	1

Figure 30 – Water Source Heat Pump Schedule

VAV Box Schedule:

VAV Box Schedule											
Unit No.	Type	Selection Range (cfm)	Inlet Size Dia. (in)	Discharge Size WxH (in)	Max. SP Drop (in wg)	NC Rating @ 1 in SP		Reheat Coil (Hot Water)			
						Discharge	Radiated	EWT (^oF)	LWT (^oF)	EAT (^oF)	gpm
VV-1	Single Duct Press. Ind.	0-390	6	12x8	0.2	23	27	180	150	55	Varies
VV-2	Single Duct Press. Ind.	391-500	7	12x10	0.2	20	23	180	150	55	Varies
VV-3	Single Duct Press. Ind.	501-650	8	12x10	0.2	20	25	180	150	55	Varies
VV-4	Single Duct Press. Ind.	651-825	9	14x12	0.2	20	27	180	150	55	Varies
VV-5	Single Duct Press. Ind.	826-1000	10	14x12	0.2	20	31	180	150	55	Varies
VV-6	Single Duct Press. Ind.	1001-1500	12	16x15	0.2	20	29	180	150	55	Varies
VV-7	Single Duct Press. Ind.	1501-2000	14	20x17	0.2	35	43	180	150	55	Varies
VV-8	Single Duct Press. Ind.	2000-3000	16	24x18	0.2	35	43	180	150	55	Varies

Figure 31 – VAV Box Schedule

Fin Tube Radiator Schedule:

Hot Water Radiation Schedule							
Unit No.	Water Temp. (^oF)		Btuh per ft	Length (ft)	Total MBH	Flow Rate (gpm)	Head Loss (ft/100)
	EWT (^oF)	LWT (^oF)					
FTR-1	180	150	753	26	19.6	1.3	3
FTR-2	180	150	753	18	13.6	0.9	3

Figure 32 – Fin Tube Radiator Schedule

Pump Schedule:

Pump Schedule					
Unit No.	Service	Location	Casing Type	Fluid	
				Type	Temp. (^oF)
BP-1	Boiler B-1	Parking Level - MER	In-Line	Water	180
BP-2	Boiler B-2	Parking Level - MER	In-Line	Water	180
BP-3	Boiler B-3	Parking Level - MER	In-Line	Water	180
CWP-1	Cooling Tower Open Loop	Parking Level - MER	End Suction	Water	97
CWP-2	Cooling Tower Open Loop	Parking Level - MER	End Suction	Water	97
HPL-1	Heat Pump Loop	Parking Level - MER	End Suction	Water	95
HPL-2	Heat Pump Loop	Parking Level - MER	End Suction	Water	95
HWP-1	Primary Hot Water Pump	Parking Level - MER	End Suction	Water	180
HWP-2	Primary Hot Water Pump	Parking Level - MER	End Suction	Water	180
HWP-5	Radiant Hot Water Pump	Garage	In-Line	Water	180
FRP-1	Freeze Protection Pump	AHU-1	In-Line	Water	180
FRP-2	Freeze Protection Pump	AHU-2	In-Line	Water	180
FRP-3	Freeze Protection Pump	AHU-3	In-Line	Water	180
FRP-4	Freeze Protection Pump	AHU-4	In-Line	Water	180

Pump Schedule (continued)										
Unit No.	gpm	NPSHR (ft)	Head (ft)	Impeller Size (in)	Working Press. (psi)	Pump rpm	Motor hp	Electrical		
								Volts	Phase	Hz
BP-1	225	--	12	6.875	150	1150	1	480	3	60
BP-2	225	--	12	6.875	150	1150	1	480	3	60
BP-3	225	--	12	6.875	150	1150	1	480	3	60
CWP-1	1270	12	85	10	175	1770	40	480	3	60
CWP-2	1270	12	85	10	175	1770	40	480	3	60
HPL-1	1270	--	135	11.75	175	1770	75	480	3	60
HPL-2	1270	--	135	11.75	175	1770	75	480	3	60
HWP-1	470	--	60	8.375	175	1750	15	480	3	60
HWP-2	470	--	60	8.375	175	1750	15	480	3	60
HWP-5	7.5	--	20	4.875	175	1725	0.33	480	3	60
FRP-1	47	--	35	5.875	175	1750	1.5	480	3	60
FRP-2	45	--	35	5.875	175	1750	1.5	480	3	60
FRP-3	15	--	35	5.875	175	1750	0.75	480	3	60
FRP-4	11	--	35	5.875	175	1750	0.75	480	3	60

Figure 33 – Pump Schedule

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