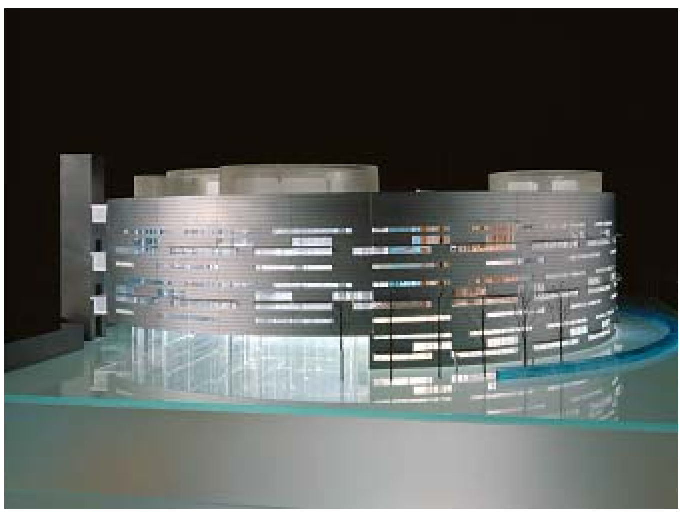
Technical Assignment 3

Building Mechanical & Energy Systems Option

Mechanical System
Existing Conditions Evaluation



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Buffalo, New York

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Mechanical Option

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Executive Summary

The Hauptman-Woodward Medical Research Institute is a 3 story, 73,000 square foot building which provides a full service biomedical research lab as well as supporting office and classroom spaces to the Buffalo-Niagara Medical Campus in Buffalo, New York. This report develops a detailed evaluation of the existing mechanical systems and equipment for the Hauptman-Woodward Medical Research Institute. Major equipment and system components are discussed in detail in preparation for the upcoming senior thesis proposal.

Design objectives and requirements are discussed to gain a better understanding of what dictated the mechanical system design. At the Hauptman-Woodward Medical Research Institute, there were many factors which influenced building design. Energy sources and rates, mechanical equipment first costs, and maintenance costs were all considered in the design.

In addition to design objectives, the design ventilation requirements from the ASHRAE Standard 62.1-2004 study are included for all air handling systems. Design heating and cooling loads for major equipment were calculated using Trane TRACE-700 and compared with actual design loads from construction documents. Energy consumption was also estimated with Trane TRACE as well, based upon utility data from the city of Buffalo.

Schematic drawings were developed for all major systems at the Hauptman-Woodward Medical Research Institute, including air handling units, heating and cooling loops, heat recovery systems and the atrium smoke exhaust system. In addition, schedules pertaining to major equipment were condensed in this report, taken from design documents by Cannon Design.

Once all of the design information was organized and compiled, the sequences of operation for all major systems were analyzed, including air handling units, terminal reheat boxes, atrium smoke exhaust system, laboratory heat recovery system and all hydronic piping systems. Based upon this information, an evaluation of the existing mechanical system was completed with a critique of major components and possible areas of study for the senior thesis project.

Design Objectives and Requirements

Project Information:

The Hauptman-Woodward Medical Research Institute is a 3 story, 73,000 square foot building which provides a full service biomedical research lab as well as supporting office and classroom spaces to the Buffalo-Niagara Medical Campus in Buffalo, New York. Not only does it serve as a center for research and development, the large atrium and classroom spaces make the Hauptman-Woodward Institute a prime gathering place for seminars and gatherings, as shown here in Figure I.

Figure I: Atrium at the Hauptman-Woodward Medical Research Institute

The Ellicott street entrance leads visitors to the grand atrium, where they can observe the scientific working environment as well as easily navigate to all areas of the facility. On the first floor, executive offices and the Board Room are found to the south. To the north is the main lecture/assembly hall, followed by several specialized laboratories, storage rooms and shipping and receiving for the facility.

Housed in the second floor atrium are the employee's lunchroom and kitchen, plus a large central area furnished with chairs and other seating for informal meetings. To the south are offices for scientists and study tables for students. To the north are the Crystal Growth Lab, a number of individual labs and central shared equipment and research support rooms.

The third floor atrium houses research library at HWI. To the north are additional cold rooms, laboratories, and shared research and support facilities. To the south are more offices for research scientists and technicians as well as additional areas for student research.

Basis of Design:

The main design objective at the Hauptman-Woodward Medical Research Institute is to provide a safe, accommodating atmosphere for improving human health through molecular studies of the causes and potential cures of many diseases. In contrast to clinical research, the focus of Hauptman-Woodward's basic research is to determine the structures of individual substances such as proteins that play a role in the development of specific diseases. In order to achieve this task, the Institute required a biomolecular research lab that would minimize outside contamination, in addition to office, library and classroom space that would support the program faculty, staff and students who frequent the facility on a daily basis. In addition to these strict requirements, the not-for-profit organization wanted to make an architectural design statement in the heart of downtown Buffalo, while at the same time reducing total building cost so that the focus of their efforts could be on research. One of the typical laboratory spaces within the finished building are shown in Figure II, below. As you can see, the laboratory overlooks the glass atrium, giving visitors a prime view of what's happening at the Institute.

Figure II: Typical Laboratory Space at HWI

Energy Sources and Rates

The Hauptman-Woodward Medical Research Institute utilizes two energy sources for operation of its building mechanical systems. These sources include electric power (kWh) and natural gas (therm), and are provided directly to the site. Since monthly utility data was not available from the owner, rates were determined based on site and city data for Buffalo, New York, and estimated with Trane TRACE-700.

Electricity and Natural Gas were the two most practical energy sources based on site conditions. Due to the specialized nature of the Buffalo Niagara Medical Campus, it would not be practical to have a centralized plant. Therefore, the Hauptman-Woodward Medical Research Institute is self-contained with chiller and boiler plants located within the 4th floor mechanical penthouse. These localized systems provide all the heating and cooling necessary for the building to operate as it was intended.

Electric Service at the Hauptman-Woodward Medical Research Institute is provided by National Grid, a primary electric service provider throughout Western New York. The electric rate is broken down into specific charges, as shown in Figure III.

	Charge
Basic Service Charge	$51.60
Delivery Charge for Demand (per kW)	$9.48
Delivery Charge (per kWh)	2.032¢
Delivery Charge Adjustment	0¢
Customer Service Credit (per kWh)***	0.2¢ per KWh
System Benefits Charge (per kWh)	.1619¢
Renewable Portfolio Surcharge (per kWh)	.0491¢
Electricity Supply Charge	0.05585¢

Figure III: National Grid Electric Tariffs
(Courtesy of National Grid, Inc, Oct. 2006)

The Natural Gas Service for the Hauptman-Woodward Medical Research Institute is provided by National Fuel, which serves residential buildings and businesses in Western New York and Northern Pennsylvania. The building falls under the category SC-3: General Sales for buildings of like size and occupancy.

SC-3 General Sales & Transportation Service (Non-Residential)								
First 1 Mcf	$17.55		$2.00	($5.71)	$0.03	$13.87	$6.53	$20.40
Next 49 Mcf	$2.57806	/Mcf	$0.00	$0.0000	$0.02901	$2.60707	$6.52575	$9.13282
Next 950 Mcf	$1.99656	/Mcf	$0.00	$0.0000	$0.02901	$2.02557	$6.52575	$8.55132
All Over 1,000 Mcf	$1.62309	/Mcf	$0.00	$0.0000	$0.02901	$1.65210	$6.52575	$8.17785

Figure IV: National Fuel Natural Gas Tariffs (courtesy of National Fuel, Oct. 2006)

As shown in Figure IV, natural gas is provided on a tier basis, with a base charge of $17.55.

Cost Factors

The design of Hauptman-Woodward Medical Research Institute Mechanical System was influenced by many design considerations. First and foremost, the building mechanical system must provide an adequate environment to conduct laboratory experiments and everyday office and research activities. Due to these restraints, the mechanical systems at HWI are quite specialized. Despite the complex nature of the mechanical system, other cost factors could have influenced design and control decisions. Such factors include First cost, operation and maintenance costs, life cycle costs and rebates and incentives.

Since utility data was not available for the project, it is unknown whether or not utility rebates or energy incentives were offered for the Hauptman-Woodward Medical Research Institute project. Due to the specialized nature of the building, it is unlikely that even if incentives were offered, they would have dictated the design of the mechanical system.

Based upon initial conversation with the mechanical engineer at Cannon Design, it was determined that operation and maintenance costs, in addition to first cost were the primary factors which dictated the design of the mechanical system. The building was originally designed such that a facilities manager would not be required on-site, in the hopes of reducing such operation costs. Although operational cost was considered in the design phase, the institute has hired personnel to monitor building equipment since the building has gone into operation.

Without the sacrifice of quality in regards to laboratory HVAC design, Mechanical first cost was the basis for design at the Hauptman Woodward Medical Research Institute. According to contract documents provided by Cannon Design, Inc, the first cost for all HVAC and Plumbing work at the Hauptman Woodward Medical Research Institute was $2,956,003. These two divisions were lumped together under one contract. After determining the total cost of the mechanical system, the cost per square foot was calculated. For the Hauptman Woodward Institute, The cost per square foot is approximately $40.33 per square foot and was approximately 12.3% of the total budget for the Project.

Site Factors

The Hauptman-Woodward Medical Research Institute is located in the heart of the Buffalo-Niagara Medical campus – an area of the city of Buffalo, NY that is quickly revitalizing itself. Its close proximity to the Roswell Park Cancer Institute, Buffalo General Hospital, as well as the downtown theatre district gave the owners and designers the opportunity to provide an architecturally-stunning building in an area that had been in decline over the past few decades. As such, it was necessary to take added precautions to shield the mechanical systems from public view. A mechanical penthouse was built in keeping with the radical design of the building, and as such masks the majority of the equipment. The two rooftop units (RTU-1,2) and the chiller were both hidden from view by means of architectural screening, as shown in Figure V below.

Figure V: View of Mechanical Penthouse and Equipment Screening
(Cannon Design, May 2005)

Outdoor Design Conditions

Outdoor design criteria was determined from the 2001 ASHRAE Fundamentals Handbook. Chapter 27 provides climatic design information for cities in the United States, Canada and other countries. The data required at the Hauptman-Woodward Medical Research Institute was found for the extreme conditions provided by the Fundamentals handbook for Buffalo, New York. Figure VI, which provides Heating and Wind Design Conditions, followed by Figure VII, which provides Cooling and Humidification Design Conditions, are found below.

Station	Latitude	Longitude	Elevation (ft)	Std. Pressure (psia)	Dates
New York - Buffalo	42.93	78.73	705	14.325	6193

Heating	Extreme Wind	Coldest Month		MWS/PWD to DB				Extreme Annual Daily			
Dry Bulb	Speed (mph)	1.00%		99.60%		0.40%		Mean DB		Std Dev DB	
99.60%	1.00%	WS	MDB	MWS	PWD	MWS	PWD	Max	Min	Max	Min
2	29	30	24	12	270	13	240	91	-6	2.3	5.3

Figure VI – Heating and Wind Design Conditions
(ASHRAE- 2001 Fundamentals Handbook)

Cooling DB/MWB		Evap WB/MDB		Dehumid DP/MDB and HR			Range of DB
0.40%		0.40%		0.40%			
DB	MWB	WB	MDB	DP	MDB	HR	
86	70	74	82	71	118	78	17.7

Figure VII – Cooling and Humidification Design Conditions
(ASHRAE- 2001 Fundamentals Handbook)

Trane TRACE-700 was used to simulate the energy usage at the Hauptman-Woodward Medical Research Institute. Buffalo, New York was selected as both the design and simulation city. In addition, proper weather requirements were selected based upon the values from the ASHRAE handbook, as summarized above.

Indoor Design Conditions

The indoor design conditions at the Hauptman Woodward Medical Research Institute were defined in the Sequence of Operations, located in the building specifications supplied by Cannon Design. The sequence of operations defines the dry bulb temperature setpoint for heating and cooling while the building is occupied and unoccupied. It was assumed that the building maintains a constant relative humidity of 50%. Each VAV box is supplied with an adjustable thermostat that makes it possible for individuals to override these zone setpoints based on personal comfort. Figure VIII shows a summary of the indoor design conditions based upon the Sequence of Operations in the design documents.

Indoor Design Conditions				
	Summer		Winter	
	Occupied	Unoccupied	Occupied	Unoccupied
DBT	72	82	70	65
% RH	50	50	50	50

Figure VIII – Indoor Heating and Cooling Design Setpoints
(HWI Specifications, Cannon Design)

Design Ventilation Requirements

The minimum ventilation rates at the Hauptman Woodward Medical Research Institute were estimated using the Ventilation Rate Procedure (VRP) of ASHRAE Standard 62.1-2004. The supply air to the building is conditioned by two Rooftop Units (RTU's) which provide 14,175 cfm and 28,300 cfm respectively. In addition, the critical laboratory spaces are supplied with 100% outdoor air from two air handling units (AHU's) which each provide 29,000cfm and are connected together in parallel.

The Ventilation Rate Procedure, as described in Technical Assignment 1, was used to calculate the minimum required amount of outside air for each space. Occupancy and space requirements were taken directly from design documents. Once the required volume of outside air was calculated for each space, it was then possible to determine the total required volume of outside air for each system.

Finally, using the calculated required outside air for each system and comparing that with the design documents supplied by Cannon Design, it was possible to determine the system compliance based on ASHRAE Standard 62.1-2004.

System	Max Zp	Ev	Vou (cfm)	ΣVoz (cfm)	Vot	Min OA (cfm)	Total SA (cfm)	Complies to Standard 62.1-2004
RTU-1	0.77	0.95	2,003	2,504	2,635	3,500	14,175	Yes
RTU-2	0.31	0.6	2,823	3,530	5,885	7,075	28,300	Yes
AHU-1,2	n/a	n/a	4,713	5,892	5,892	58,000*	58,000	Yes
*AHU-1,2 is a 100% Outdoor Air System								

Figure IX – AHU Ventilation Compliance Summary

As shown in Figure IX, each system was found to be in compliance with ASHRAE Standard 62.1-2004. Since AHU-1 and AHU-2 supply 100% OA to the laboratory space, this system passed the compliance procedure quite easily. In addition, the rooftop units (RTU-1 and RTU-2) that supply the remainder of the building each provide approximately 20% more outside air than is required by Standard 62.1.

Design Heating and Cooling Loads

Design heating and cooling loads at the Hauptman-Woodward Medical Research Institute were taken directly from the Air Handling equipment schedule in the design documents. The equipment that was analyzed includes the rooftop units which serve the west offices (RTU-1) and south offices (RTU-2). In addition, the 100% outdoor air handling units that serve the laboratory space (AHU-1,2) were analyzed. A summary of design conditions are summarized in the following Figure X.

Equipment Design Loads		
System	Heating Capacity (MBH)	Cooling Capacity (MBH)
AHU-1	1906	1740
AHU-2	1906	1740
RTU-1	250	520
RTU-2	500	1033

Figure X –Design Heating and Cooling Loads at HWI

Design heating and cooling loads at the Hauptman-Woodward Medical Research Institute were also estimated through extensive use of Trane TRACE-700. A complete breakdown of these estimated loads can be found in Appendix A, however a brief comparison between design and modeling estimates are shown in the following Figure XI.

Equipment Load Comparison				
System	Design Heating Capacity (MBH)	Estimated Heating Load (MBH)	Design Cooling Capacity (MBH)	Estimated Cooling Load (MBH)
AHU-1	1906	455	1740	1456
AHU-2	1906	455	1740	1456
RTU-1	250	196	520	470
RTU-2	500	551	1033	932

Figure XI –Comparison of Design and Model
Heating and Cooling Loads at HWI

Annual Energy Use

The annual energy consumption and operating costs were calculated with the Trane TRACE-700 simulation software. As shown previously under the section "Energy Sources and Rates," two sources of energy are utilized at the Hauptman-Woodward Medical Research Institute. After determining the utility rates from their providers; the yearly energy utilization was calculated with the Trane TRACE-700 program. As shown in Appendix B, the annual consumption of electricity (kWh) and natural gas (therm) are as follows:

Electricity: 1,323,558 kWh
Natural Gas: 55,959 therm

In addition, based on the prescribed utility rates in the previous section, an annual cost breakdown for each utility was able to be calculated. These results can be found in Appendix C.

The electrical loads took into account all mechanical equipment in addition to demand electrical and lighting loads within the building. The natural gas loads were primarily from the extensive primary and secondary boiler systems. Each of these loads was considered to operate at 100% design for the purpose of the simulation. The Trane TRACE-700 Simulation was able to simulate building schedules into the calculation as well. The building is currently scheduled during normal business hours, 5 days a week. The weather data provided by the ASHRAE Handbook of Fundamentals set climate criteria to execute the simulation for summer and winter months.

All equipment at the Hauptman-Woodward Medical Research Institute was simulated as well. Appendix D gives a detailed breakdown of monthly and annual energy consumption for the chiller and boiler plants, fans, lighting system and electrical demands. In addition, Appendix E supplements this information by providing a cost summary analysis for all equipment in the building.

Schematic Drawings of Mechanical Systems

The following section provides schematic drawings of the mechanical systems at the Hauptman-Woodward Medical Research Institute. There are numerous hydronic systems which required to suit the sensitive environment of the laboratory space. The major systems that serve the Hauptman-Woodward Medical System are found in the following figures contained in this section. For a symbol legend pertaining to these schematic drawings, refer to Appendix F.

System 1: Laboratory:

Figure XII: AHU 1,2 Heat Recovery System

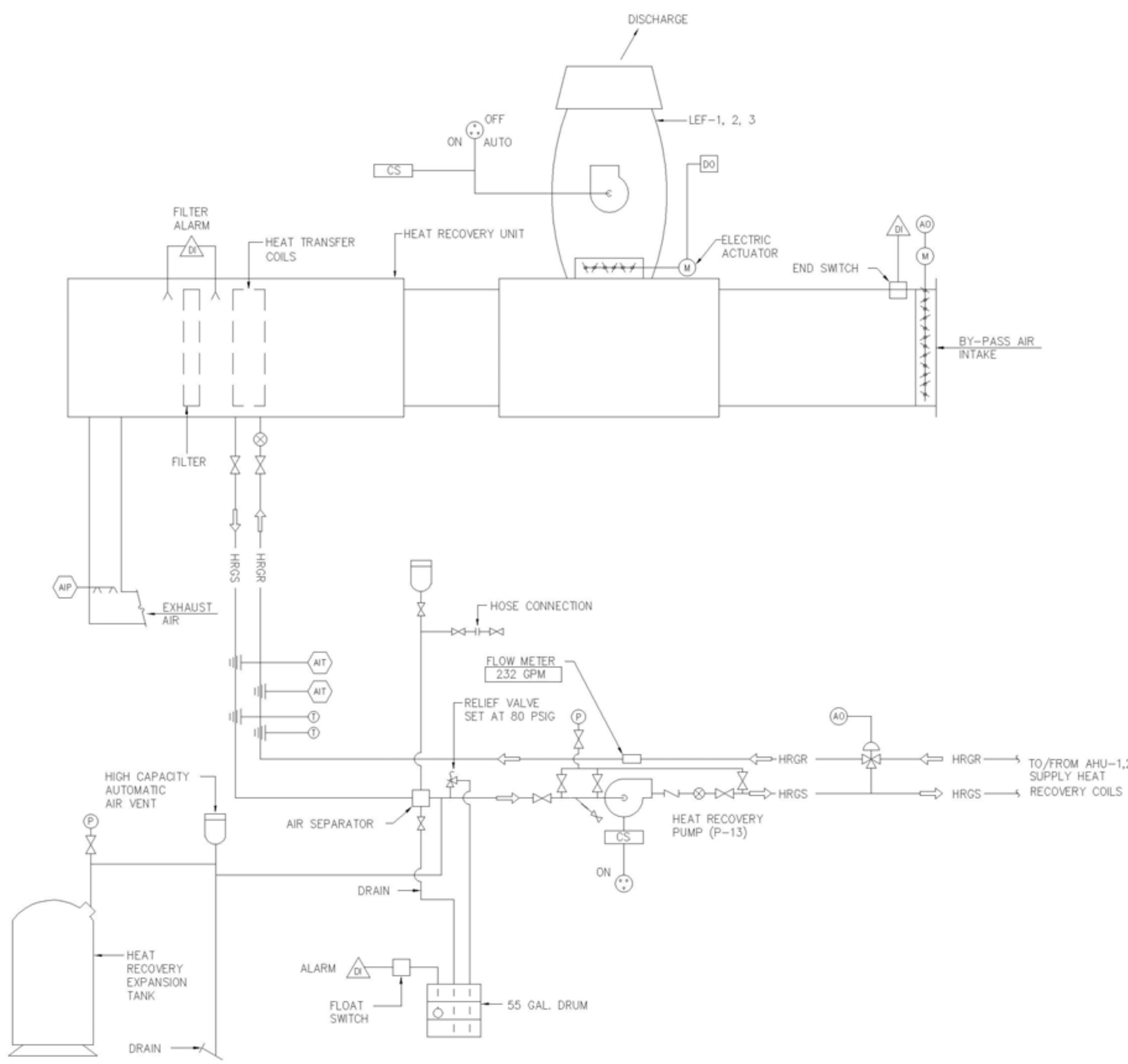


Figure XIII: AHU-1 and AHU-2 Flow and Control

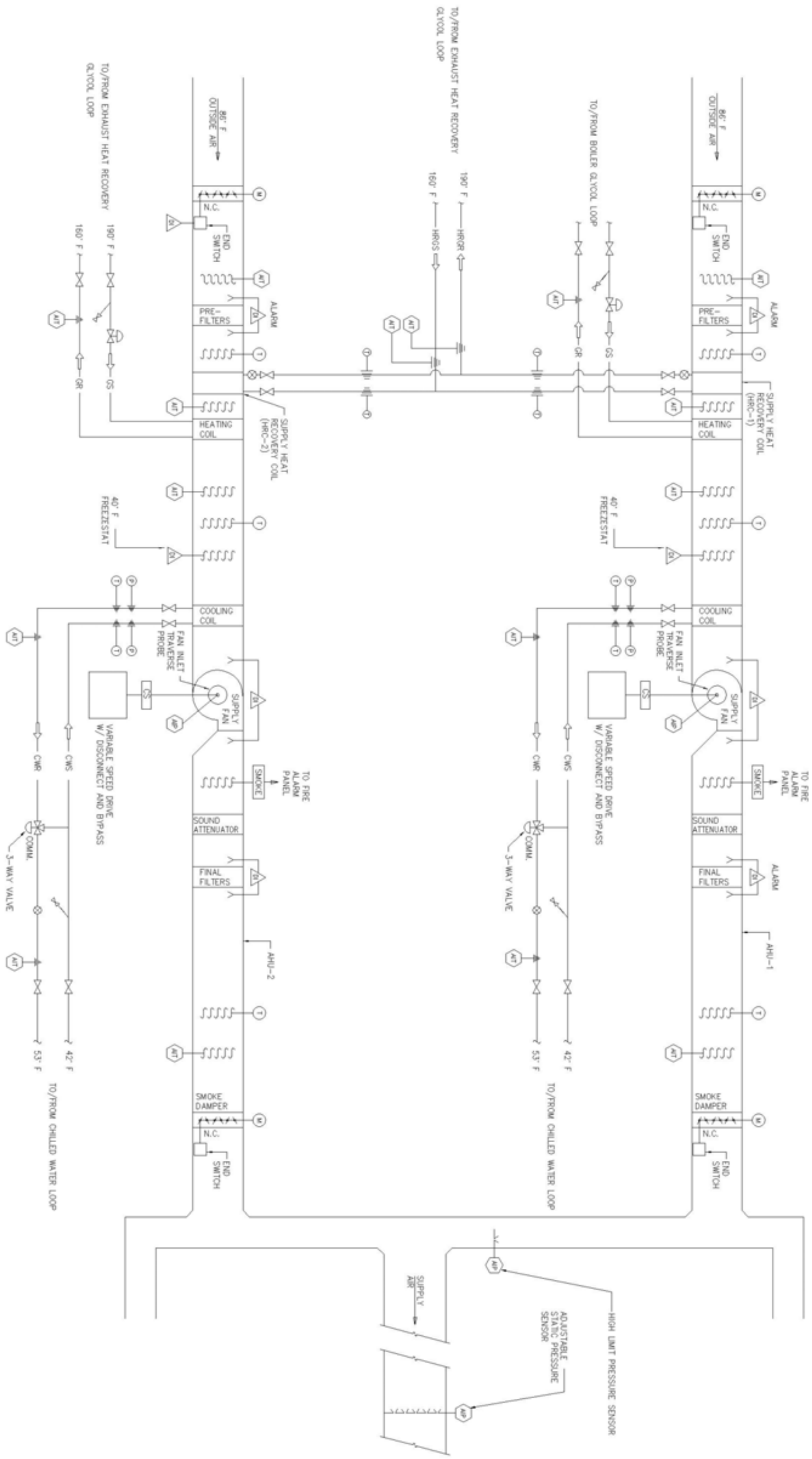


Figure XIV: Boiler Glycol System for AHU1,2 Heating Coils

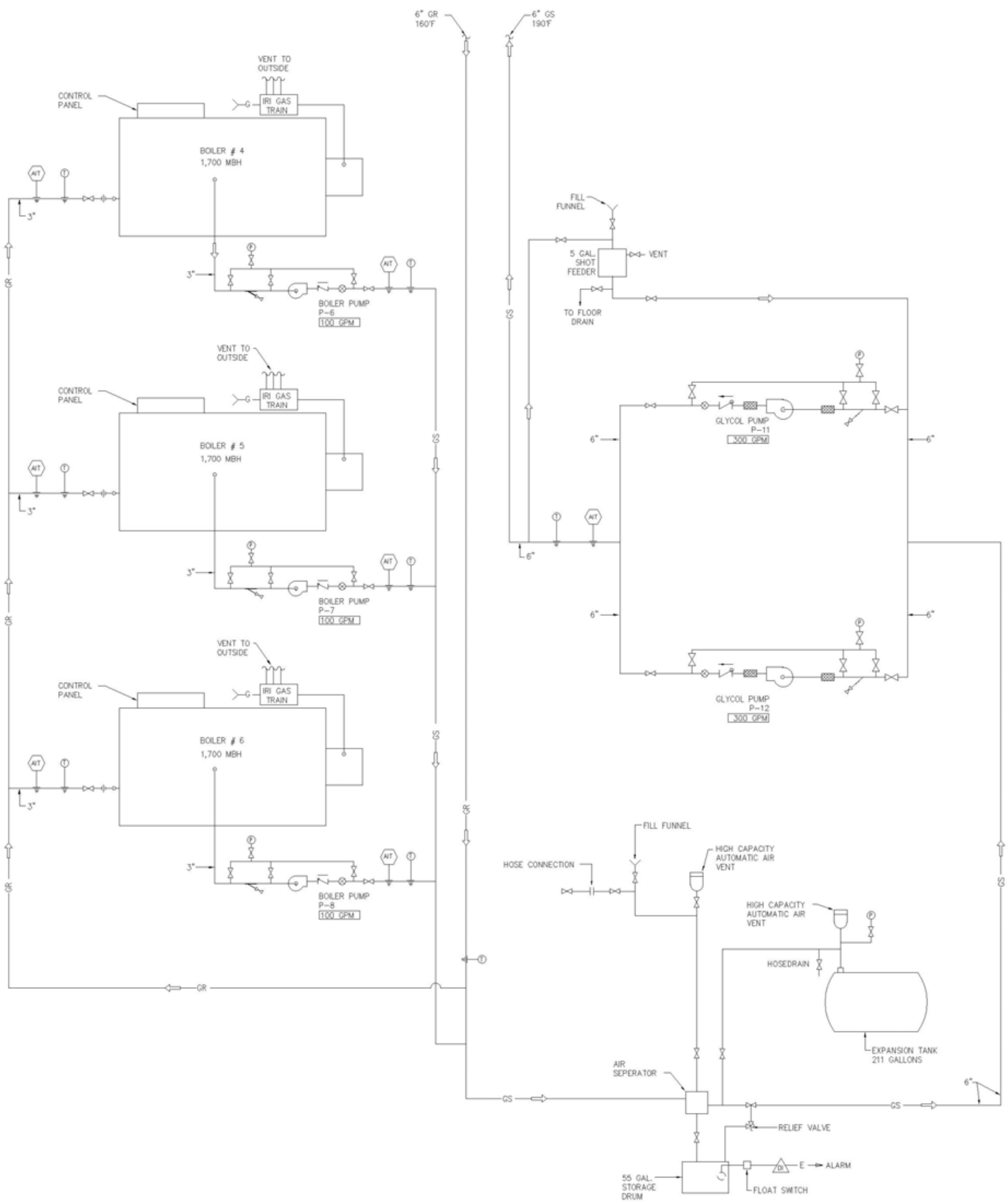
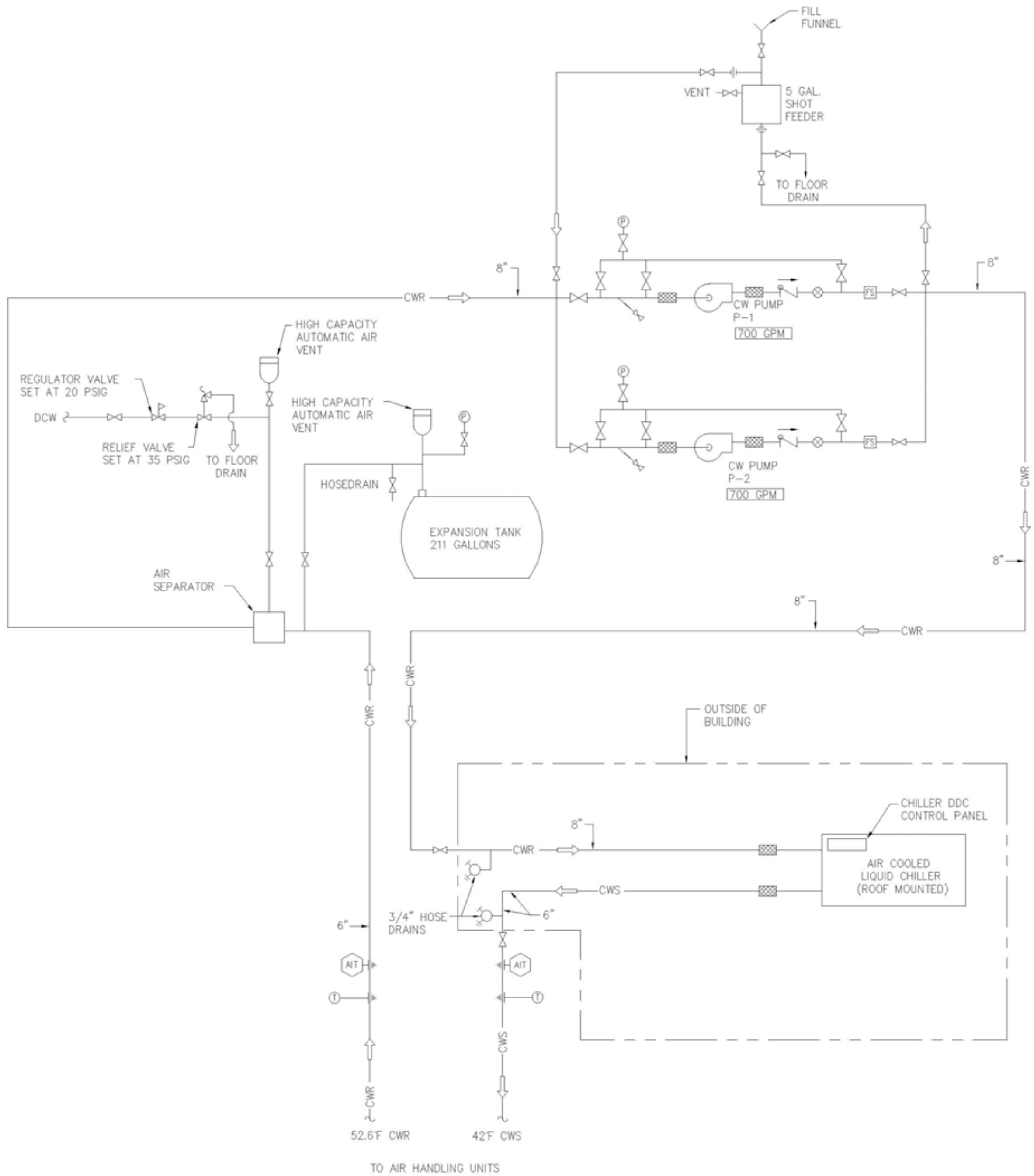
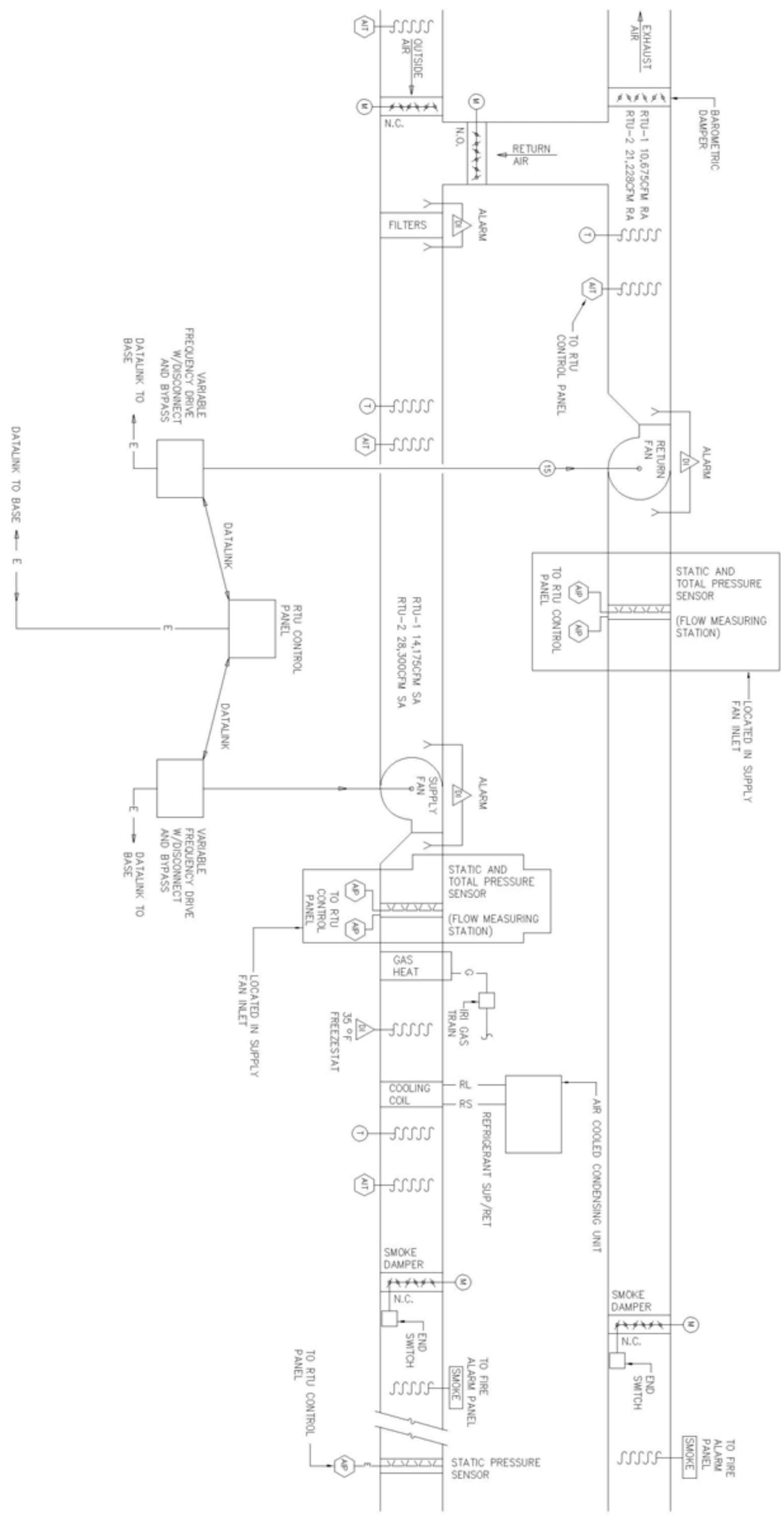


Figure XV: Chilled Water System for AHU-1,2 Cooling Coils



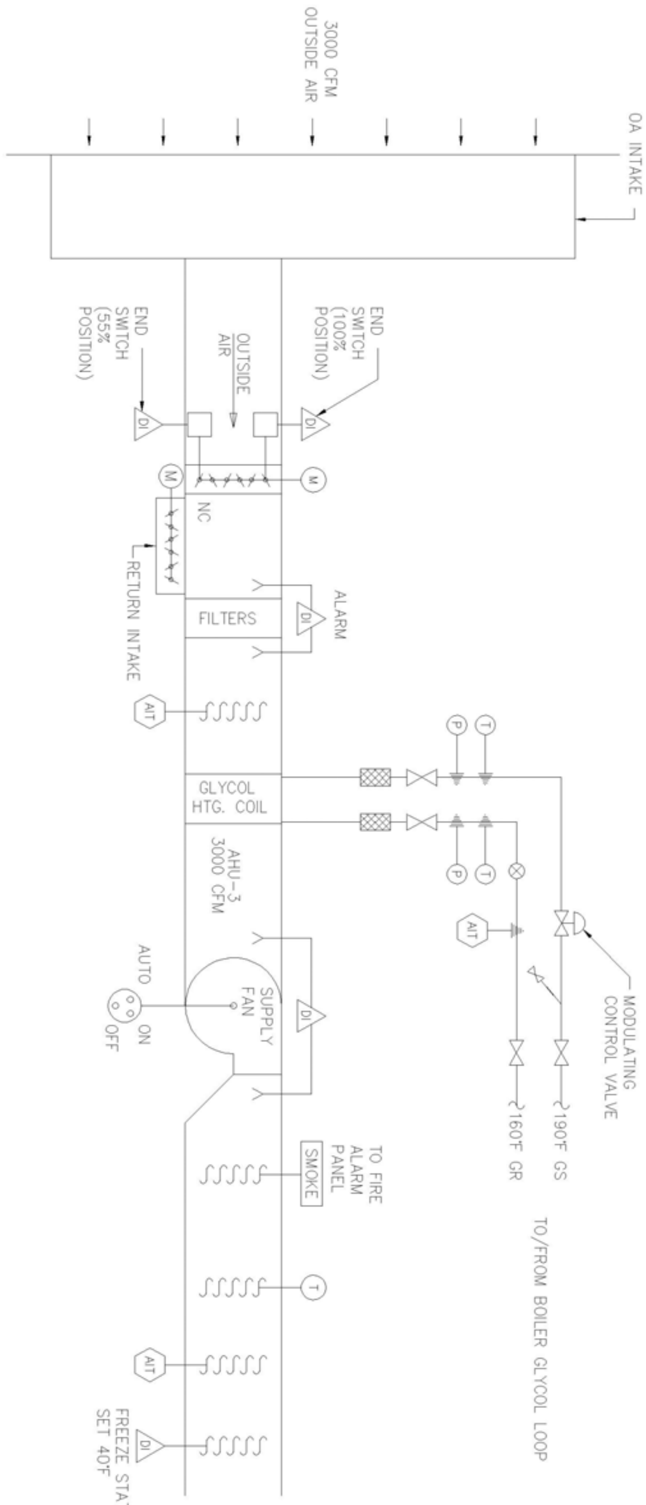
System 2 and System 3: Offices and Atrium

Figure XVI: RTU-1 and RTU-2 Flow and Control

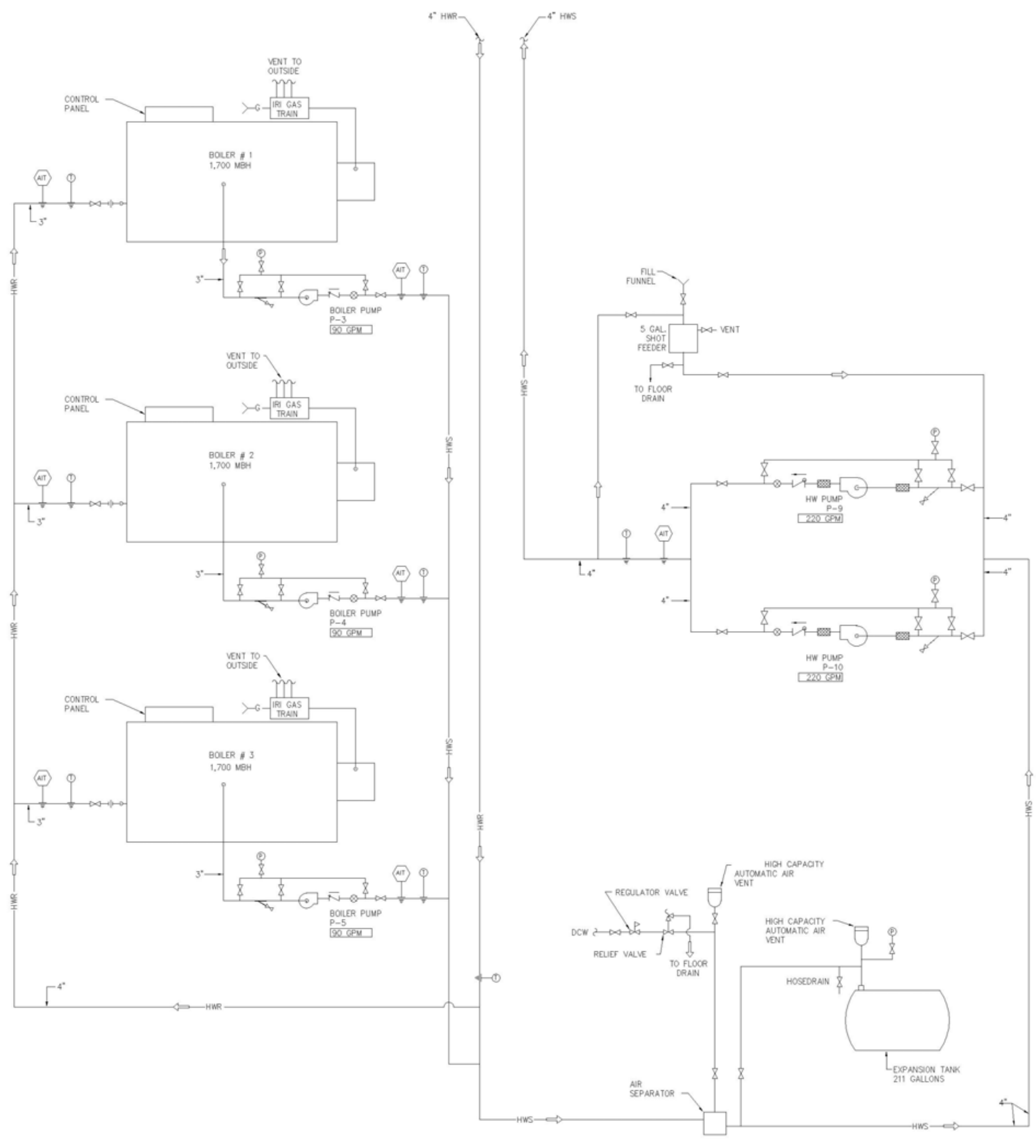


System 4: Penthouse

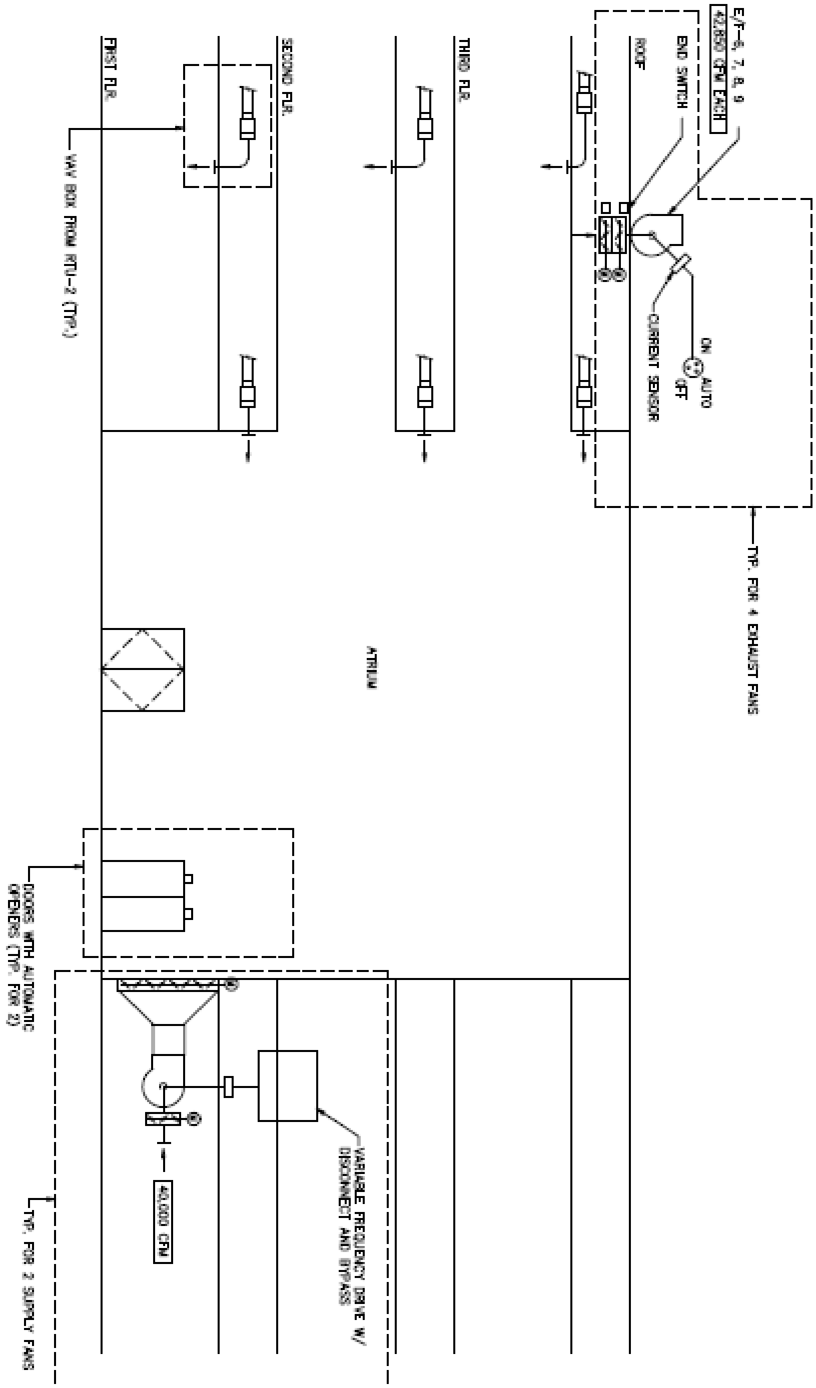
Figure XVII: AHU-3



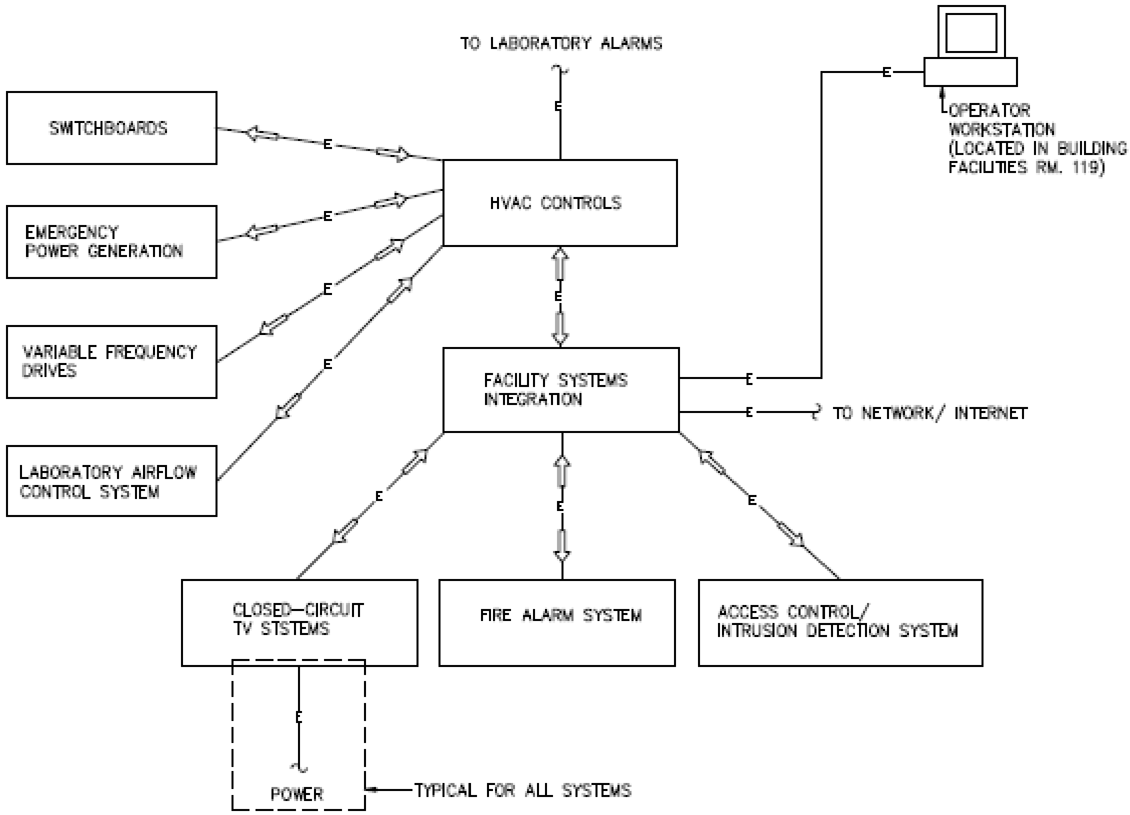
System 5: Boiler Hot Water Heating System (Figure XVIII)



System 6: Atrium Smoke Control Ventilation System (Figure XIX)



System 7: Integrated Facility Control System Diagram (Figure XX**)**



Major Equipment Summary

As shown in the schematic drawings, The Hauptman-Woodward Medical Research Institute has a variety of major mechanical equipment loops in order to isolate the laboratory space from the remainder of the building. In this section, each of the major pieces of equipment is described. For a complete breakdown of the equipment schedules for the building, refer to Appendix G.

Air Handling Units

The laboratory areas at the Hauptman-Woodward Medical Research Institute are served by 2 variable air volume (VAV) air handling units which are located in the 4^{th} floor mechanical penthouse (Figure XXI, below), and provide 100% outdoor air to the space. They serve critical lab space on all three floors of the building. The two units are connected in parallel; however both units are required to fully serve the space. Together, they provide 58,000CFM of conditioned air to the space. In addition, a third air handling unit is located in the penthouse and provides approximately 3000 cfm of outside air to the penthouse. The primary purpose of this unit is to provide make-up air for the 6 boilers that are located within the space. For additional information in regards to the air handling units, refer to Figure XXV in Appendix G.

Figure XXI –AHU-1 and AHU-2 Located in Mechanical Penthouse

Rooftop Units

The west offices, south offices, and atrium are served by two variable air volume (VAV) Rooftop Units, RTU-1 and RTU-2. RTU-1, which serves primarily office and meeting space, supplies 14,100 cfm supply air to the space. It is equipped with a DX cooling coil for space conditioning. In addition, natural gas provides preliminary heat before the air is sent to the variable air volume boxes. RTU-2 supplies offices to the south as well as the 3 story atrium. It has the same characteristics as RTU-1, however it supplies 28,300 cfm supply air to the space. The location of these units are visualized below in Figure XXII. For additional information in regards to the rooftop units, refer to Figure XXV in Appendix G.

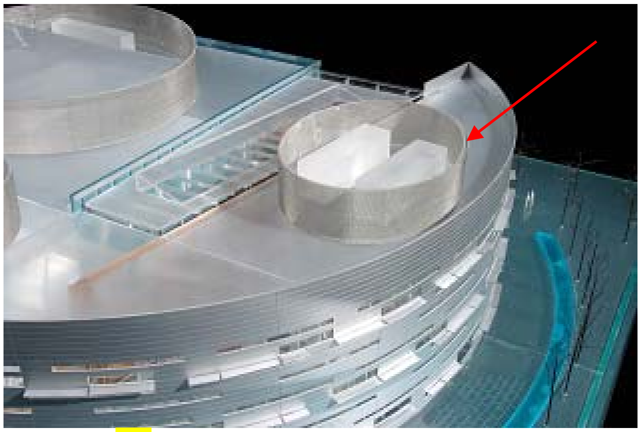


Figure XX – Location of Rooftop Units on South Roof

Variable Air Volume Boxes

Conditioned air from AHU's and RTU's is ducted to variable air volume (VAV) boxes that are located within ceiling plenum spaces on each floor of the building. Each VAV box has varying amounts of air flowing through; therefore the reheat coils are all sized appropriately for the space. VAV boxes have been sized to reheat supply air from 55^{O}F to approximately 95^{O}F.

Fans Units

The specialized nature of the building requires a number of fans to supplement the air handling equipment. In addition to supply and return fans, the 100% outdoor air laboratory system requires four 27,000 cfm exhaust fans to remove the excess air (Figure XXIII). Due to the high volume of air being exhausted, the system has a heat recovery coil to gain back some of the heat from the exhaust air without contaminating the outside air coming in.

Additionally, an elaborate smoke exhaust system has been installed in the atrium space. Four exhaust

Figure XXIII – Lab Exhaust Fans

fans remove approximately 168,000 cfm of air in the event of an emergency. In order to for the system to function, supply fans on the ground level provide approximately 52,000 cfm of makeup air to the space. These supply fans are equipped with variable frequency drives to increase efficiency. For a complete list of all fan units in the building, refer to Figure XXVI in Appendix G.

Chillers

The Hauptman-Woodward Medical Research Institute is equipped with a 300 ton, air cooled screw chiller that is located next to the mechanical penthouse on the roof of the building. Its purpose is to supply 52^{O}F chilled water to the cooling coils installed in AHU-1 and AHU-2. In addition, a second process liquid chiller was installed to provide additional cooling to the X-Ray and Crystallography Labs which have excessive equipment loads. For a complete breakdown of each chiller, refer to Figure XXVII in Appendix G.

Boilers

The building is equipped with two boiler loops, each with 3 natural gas-fired boilers connected in parallel. Both boiler loops are located within the mechanical penthouse (Figure XXIV). The first loop provides hot water to the entire building, with each unit providing 1700 MBH heating output. The second loop also consists of 3 natural gas-fired boilers, each providing 1700 MBH heating output. This loop provides a water/glycol mix to heating coils in AHU-1 and AHU-2. For a complete breakdown of the boiler properties, refer to Figure XXVIII in Appendix G.

Figure XXIV – Boiler Systems located in Mechanical Penthouse

Pumps

There are 13 major pumps at the Hauptman-Woodward Medical Research Institute. For the Laboratory System, Boiler pumps serve each of the 3 natural gas-fired boilers that supply the air handling unit heating coils. In addition, the chilled water system has 2 pumps for the air handling unit cooling coils. To provide heat recovery from the laboratory exhaust fans, 2 additional pumps serve a glycol heat recovery loop. An additional 3 natural gas-fired boilers require pumps to supply hot water to the building. For a complete breakdown of the pump design specifications, refer to Figure XXIX in Appendix G.

Computer Room Cooling Units

Two 5 ton nominal air cooled cooling units provide space conditioning for the computer and server rooms at HWI. For a complete breakdown of the Computer Room AC unit specifications, refer to Figure XXX in Appendix G.

Description of System Operation

Air Handling Units (AHU-1,2) with VAV Control

This 100% outdoor air system is by far the most complex system at the Hauptman-Woodward Medical Research Institute. As shown in Figure XIII (AHU-1,2 Flow and Control), the system consists of 2 air handlers, each with pre and final filters, chilled water cooling coil, glycol preheat coil, glycol heat recovery coil, supply fans, and variable speed VAV control. The system operates continuously to serve HVAC requirements at each individual zone. Scheduling is programmed on a zone by zone basis. The two units operate in parallel and serve a common supply duct. The units operate together, simultaneously varying temperature and airflow to meet SA requirements. The Supply air temperature is adjustable between 55^{O}F and 60^{O}F, however design dictates that 55^{O}F is the standard for sequence with the VAV terminals. Low temperature controllers provide freeze protection to the supply air fan when the air temperature drops before 53^{O}F. The SA fan is equipped with variable air volume control, which requires static pressure sensors to keep the flow rate at 1 inch WC.

Laboratory Heat Recovery Exhaust System

The laboratory general exhaust system consists of three exhaust fans (LEF-1,2,3) as shown in Figure XII. These three exhaust fans share a common intake plenum and together provide 81,000 cfm removal of exhaust air. Velocity Sensors modulate air dampers in order to maintain 4,000 FPM velocity though the exhaust stack. The heat recovery system recovers heat from the general exhaust to preheat or pre-cool the incoming supply air. The system uses a single pump to circulate a 40% glycol solution between coils located in the exhaust and supply air streams. The pump is controlled via temperature sensor to operate continuously when the outside air is below 55^{O}F or above 80^{O}F. The system is equipped with a bypass in the event that the temperature drops below 10^{O}F to prevent freezing of the system.

Cooling Chilled Water System

As shown in Figure XV, the chilled water system consists of an air cooled water chiller and chilled water pumping system. The system supplies chilled water to the building in addition to serving the cooling coils located in AHU-1 and AHU-2. The system operates when the air outside is above 55^{O}F and is monitored by temperature sensors. The chiller is set to maintain a constant 44°F chilled water supply. The pumping system is staged to run continuously when chilled water is needed. The system consists of 2 pumps, of which only one is needed. They are controlled automatically to alternate to maintain equal run time.

Hot Water Boiler Systems

The hot water and glycol heating systems each consist of three hot water boilers with dedicated hot water pumps, and a secondary pumping system, as shown in Figure XIV and Figure XVIII. The system is DDC controlled and utilized electric actuation. Boilers are sequenced to equalize equipment runtime. Selection of the lead boiler will be evaluated on a weekly basis, with the boiler having the least runtime becoming the lead boiler.

For the hot water boiler system, the lead boiler shall start when the outdoor temperature drops below 65°F. The lead boiler is sequenced to maintain the loop temperature at 190°F. Should additional heating be required to maintain this temperature, the lag boilers will come online. Temperature sensors monitor loop temperature and dictate system operation.

The glycol hot water system operates in much the same way. When the outdoor air temperature drops below 55°F, the lead boiler shall start. The lead boiler is sequenced to maintain the loop temperature at 190°F. Again, should additional heating be required to maintain loop temperature, the lag boilers will be automatically enabled.

Rooftop Units (RTU-1,2) w/ VAV Control

Figure XVI provides a detailed flow and control diagram of the two rooftop units at HWI. Although they are significantly different in size, each provides operate under the same conditions. Each are equipped with variable air volume control which are monitored by traverse fan inlet probes and static pressure sensors at supply and return fans. Heating is provided by natural gas and cooling is provided by DX cooling units, which maintain 55°F supply air to each zone. VAV terminal reheat boxes are installed in each zone and space temperature sensors modulate the terminal unit supply air damper in sequence with the reheat coil to maintain space temperature. During occupied periods, the space shall be maintained at 72°F, and when it is unoccupied, the system shall automatically maintain a minimum temperature of 55°F. Each zone is supplied with a manual thermostat to adjust the temperature for comfort.

Penthouse Air Handling Unit (AHU-3)

The boiler make-up air unit is set up to run continuously and provide fresh air to the mechanical penthouse. According to the system schematic in Figure XVII, the unit provides 3000 cfm of outside air to the space and a space temperature sensor modulates outdoor air dampers to maintain space conditions at 70°F. Controls will override space sensor and open outdoor air dampers when boilers are started, allowing for additional make-up air to the penthouse and removal of excess boiler exhaust gases.

Atrium Smoke Control Ventilation System

As shown in Figure XIX, the atrium smoke control system consists of four exhaust fans (E/F-6,7,8,9), make-up air from RTU-2, and two supply fans (SF-1,2). The system is designed to exhaust smoke from the atrium in order to keep smoke above an interface level of 42ft. Upon signal from the fire alarm, the system will open exhaust fan dampers and OA dampers from the air handling units, in addition to automatically opening all atrium entry doors. The rooftop unit return fan shall shut down and associated smoke dampers will shut. Once these procedures have been initiated, the four exhaust fans shall exhaust the required 160,000 cfm of air until deactivated at the firefighter control center (FCC).

Critique of System and Preliminary Conclusions

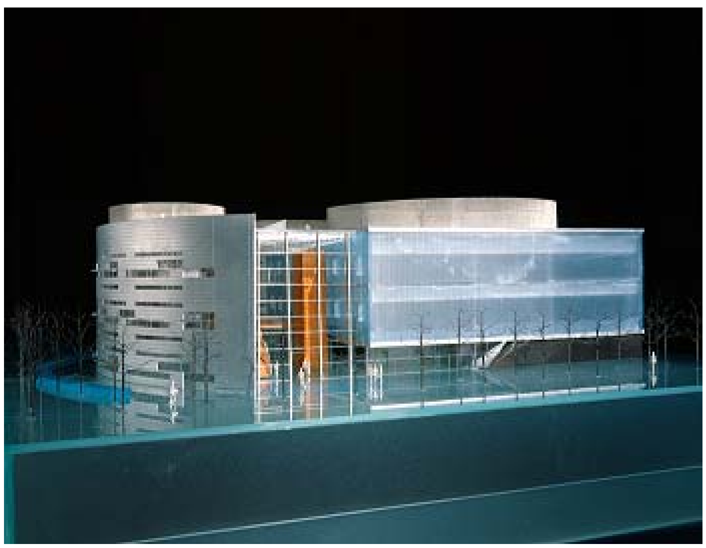
The main design objective at the Hauptman-Woodward Medical Research Institute is to provide a safe, accommodating atmosphere for improving human health through molecular studies of the causes and potential cures of many diseases. In contrast to clinical research, the focus of Hauptman-Woodward's basic research is to determine the structures of individual substances such as proteins that play a role in the development of specific diseases. In order to achieve this task, the Institute required a biomolecular research lab that would minimize outside contamination, in addition to office, library and classroom space that would support the program faculty, staff and students who frequent the facility on a daily basis.

Ensuring that clean, fresh air was supplied to laboratory spaces was critical. The solution presented by the designers in the case of this multi-use space was to use 100% outdoor air systems for the critical laboratory space, and return-air systems for the atrium and office spaces. This solution ensures that the air from the laboratory will not be contaminated by other spaces. This solution ensures air quality control, however it consumes much more energy than other possible solutions. 100% outdoor air systems will use more energy because all air that is brought in must be conditioned to the desired supply conditions. Return air systems theoretically could be used in this space, however heavy filtration and conditioning of the return air would need to take place to ensure that contaminants were removed. Something to think about would be the optimal point between the cost and energy usage of filtration and conditioning of return air of these spaces compared to the cost and energy usage of conditioning 100% outdoor air.

In addition to specific systems within the building, ease of maintenance was another important concern at HWI. The owners were keen on reducing maintenance costs as much as possible, and even maintain a system without the need of a facilities manager. The reason for this was due to the fact that HWI is a not-for-profit organization and the goal is to allocate as much of the funds as possible to the research. Along these lines, the owners wanted to reduce first cost as much as possible while still maintaining a high level of air quality. Although there are many systems which comprise the mechanical system at HWI, their functions are quite straightforward. The inherent problem with simple equipment is that despite the first cost benefits, these pieces of equipments tend to consume more energy. The initial cost of the building's mechanical systems for the building is $2,956,603 according to documents provided by Cannon Design. This accounts for approximately 12% of the buildings overall first cost. Laboratory buildings tend to have complex systems and consume a great deal of energy. The term complex systems does not necessarily apply to the individual pieces of equipment used but more in terms of how much equipment is used and how it is all interrelated. The simplicity of the equipment used at the Hauptman-Woodward Medical Research Institute keeps the first cost of the building down however, as stated above; due to the strict laboratory requirements of the program, the building consumes a great deal more energy.

The trick to designing a building such as this lies in the balance of first cost, operation cost, energy consumption and maintenance. The Hauptman-Woodward Medical Research Institute emphasizes ease of maintenance and low first cost. The result is a building that consumes a considerable amount of energy and has mechanical systems that take up approximately 15% of the building (according to Figure VII: Summary of Lost Rentable Space at HWI in Tech Report 2). A point worth analyzing in the future would be the benefit of a more complex system that would provide lower operating cost in the future, versus a simple system with low initial cost but greater energy consumption.

Appendices



Appendix A:
Design Heating and Cooling Load Summary

Description **		Floor Area ft²	People #	Coil Cooling Sensible Btu/h	Coil Cooling Total Btu/h	Space Design Max SA cfm	Air Changes ach/hr	VAV Minimum SA cfm	Main Coil Heating Sensible Btu/h	Heating Fan Max SA cfm	Percent OA Clg	Percent OA Htg
103 - Seminar Room	Rm/Zn Tot	830	54.0	28,221	59,527	963	6.96	553	-11,104	0	84.1	100.0
104 - Lecture Room	Rm/Zn Tot	550	27.0	15,104	30,919	537	5.86	367	-7,358	0	75.4	100.0
115 - Storage	Rm/Zn Tot	290	0.0	4,140	4,337	193	4.00	193	-6,125	0	0.0	0.0
116 - Storage	Rm/Zn Tot	490	0.0	7,932	8,370	327	4.00	327	-9,053	0	0.0	0.0
117 - Purchasing	Rm/Zn Tot	350	1.0	5,081	6,184	233	4.00	233	-6,573	0	8.6	8.6
119 - Building Facilities	Rm/Zn Tot	210	1.0	3,135	4,070	140	4.00	140	-3,965	0	14.3	14.3
120 - Recieving	Rm/Zn Tot	310	1.0	5,507	6,200	255	4.93	207	-5,224	0	7.9	9.7
202 - Lunch Room	Rm/Zn Tot	1,250	50.0	46,686	86,022	1,747	8.39	833	-19,398	0	57.2	100.0
219 - IT Office	Rm/Zn Tot	120	1.0	5,709	6,417	244	12.21	80	-2,609	0	8.2	25.0
220 - IT Office	Rm/Zn Tot	120	1.0	5,709	6,417	244	12.21	80	-2,609	0	8.2	25.0
221 - Computer Lab/Visual Room	Rm/Zn Tot	270	6.0	12,104	15,910	508	11.28	180	-5,619	0	23.6	66.7
262 - Storage	Rm/Zn Tot	60	0.0	1,286	1,316	49	4.94	40	-1,147	0	0.0	0.0
223 - Conference Room	Rm/Zn Tot	440	44.0	27,758	55,778	995	13.57	293	-9,552	0	88.5	100.0
224 - Server Room	Rm/Zn Tot	350	1.0	4,677	5,299	233	4.00	233	-4,682	0	0.0	7.5
227 - Corridor	Rm/Zn Tot	780	0.0	10,501	11,441	520	4.00	520	-11,222	0	0.0	7.5
229 - Elevator Vestibule	Rm/Zn Tot	780	0.0	10,543	11,462	520	4.00	520	-13,319	0	0.0	7.5
230 - Telephone	Rm/Zn Tot	60	1.0	1,022	1,776	40	4.00	40	-803	0	50.0	50.0
231 - Electrical	Rm/Zn Tot	60	0.0	842	986	40	4.00	40	-803	0	7.5	7.5
227A - Corridor	Rm/Zn Tot	330	0.0	4,409	4,806	220	4.00	220	-4,415	0	0.0	7.5
328A - Corridor	Rm/Zn Tot	330	0.0	5,552	5,793	222	4.03	220	-4,415	0	0.0	7.5
331 - Electrical	Rm/Zn Tot	60	0.0	991	1,120	40	4.03	40	-803	0	7.4	7.5
332 - Telephone	Rm/Zn Tot	60	1.0	1,142	1,896	40	4.03	40	-803	0	49.6	50.0
330 - Elevator Vestibule	Rm/Zn Tot	780	0.0	12,937	13,530	520	4.00	520	-13,319	0	0.0	7.5
328 - Corridor	Rm/Zn Tot	330	0.0	5,552	5,793	222	4.03	220	-4,415	0	0.0	7.5
325 - IT Room	Rm/Zn Tot	350	2.0	5,798	7,582	235	4.03	233	-4,682	0	17.0	17.1
324 - Conference Room	Rm/Zn Tot	440	44.0	28,634	56,653	995	13.57	293	-9,552	0	88.5	100.0
310 - Library	Rm/Zn Tot	1,200	8.0	23,159	30,075	1,037	5.19	800	-18,729	0	15.4	20.0
319 - ACA Office	Rm/Zn Tot	120	1.0	5,709	6,417	244	12.21	80	-2,609	0	8.2	25.0
320 - ACA Office	Rm/Zn Tot	120	1.0	5,709	6,417	244	12.21	80	-2,609	0	8.2	25.0
321 - IT Office	Rm/Zn Tot	120	1.0	5,678	6,256	240	11.99	80	-2,609	0	8.3	25.0
322 - IT Office	Rm/Zn Tot	120	1.0	5,579	6,157	236	11.80	80	-2,609	0	8.5	25.0
323 - IT Office	Rm/Zn Tot	120	1.0	5,455	6,034	231	11.55	80	-2,609	0	8.7	25.0
RTU-1	Sys Tot/Ave	11,800	248.0	316,315	485,012	12,515			-195,338	0	36.5	39.3
RTU-1	Sys Block	11,800	248.0	296,992	470,346	12,456			-195,375	0	36.5	39.3
121 - Open Office	Rm/Zn Tot	1,115	9.0	18,096	26,617	743	4.00	743	-14,466	0	24.2	24.2
122 - Personnel Manager	Rm/Zn Tot	110	1.0	2,523	3,303	112	6.10	73	-2,196	0	17.9	27.3
123 - Accounting	Rm/Zn Tot	110	1.0	2,530	3,310	111	6.06	73	-2,196	0	18.0	27.3
124 - Accounting	Rm/Zn Tot	110	1.0	2,523	3,303	112	6.10	73	-2,196	0	17.9	27.3
125 - Development	Rm/Zn Tot	110	1.0	2,530	3,310	111	6.06	73	-2,351	0	18.0	27.3
126 - Development	Rm/Zn Tot	110	1.0	2,463	3,328	111	6.03	73	-2,351	0	18.1	27.3
127 - Conference	Rm/Zn Tot	190	8.0	7,713	13,785	284	8.98	127	-3,611	0	56.2	100.0
128 - Development	Rm/Zn Tot	200	1.0	4,668	5,509	192	5.76	133	-3,737	0	10.4	15.0
129 - Board Member	Rm/Zn Tot	200	1.0	4,590	5,645	192	5.77	133	-3,737	0	10.4	15.0
130 - CFO Office	Rm/Zn Tot	200	1.0	4,697	5,752	196	5.87	133	-3,737	0	10.2	15.0
131 - Vice President Office	Rm/Zn Tot	200	1.0	4,871	5,846	196	5.89	133	-3,737	0	10.2	15.0
133 - Executive Vice President	Rm/Zn Tot	200	1.0	4,871	5,846	196	5.89	133	-3,737	0	10.2	15.0
204 - Open Office	Rm/Zn Tot	2,325	24.0	38,653	60,451	1,550	4.00	1550	-29,458	0	31.0	31.0
302 - Open Office	Rm/Zn Tot	2,325	24.0	44,570	66,367	1,550	4.00	1550	-29,458	0	31.0	31.0
205 - PI Office	Rm/Zn Tot	120	1.0	2,593	3,385	114	5.72	80	-2,013	0	17.5	25.0
206 - PI Office	Rm/Zn Tot	120	1.0	2,601	3,392	114	5.69	80	-2,013	0	17.6	25.0
207 - PI Office	Rm/Zn Tot	120	1.0	2,535	3,413	113	5.67	80	-2,013	0	17.6	25.0
208 - PI Office	Rm/Zn Tot	120	1.0	2,535	3,413	113	5.67	80	-2,013	0	17.6	25.0
209 - PI Office	Rm/Zn Tot	120	1.0	2,604	3,532	115	5.73	80	-2,013	0	17.5	25.0
210 - PI Office	Rm/Zn Tot	120	1.0	2,658	3,585	115	5.75	80	-2,013	0	17.4	25.0
211 - PI Office	Rm/Zn Tot	120	1.0	2,766	3,707	118	5.89	80	-2,013	0	17.0	25.0
212 - PI Office	Rm/Zn Tot	120	1.0	2,849	3,790	119	5.93	80	-2,013	0	16.9	25.0
213 - PI Office	Rm/Zn Tot	120	1.0	2,919	3,860	121	6.06	80	-2,013	0	16.5	25.0
214 - PI Office	Rm/Zn Tot	120	1.0	2,926	3,867	121	6.07	80	-2,013	0	16.5	25.0
215 - PI Office	Rm/Zn Tot	120	1.0	2,970	3,911	122	6.12	80	-2,013	0	16.3	25.0
216 - PI Office	Rm/Zn Tot	120	1.0	2,980	3,921	122	6.11	80	-2,013	0	16.4	25.0
217 - PI Office	Rm/Zn Tot	120	1.0	3,073	3,946	123	6.14	80	-2,013	0	16.3	25.0
218 - PI Office	Rm/Zn Tot	120	1.0	3,095	3,967	124	6.18	80	-2,013	0	16.2	25.0

Description **		Floor Area ft^2	People #	Coil Cooling Sensible Btu/h	Coil Cooling Total Btu/h	Space Design Max SA cfm	Air Changes ach/hr	VAV Minimum SA cfm	Main Coil Heating Sensible Btu/h	Heating Fan Max SA cfm	Percent OA Clg	Percent OA Htg
305 - PI Office	Rm/Zn Tot	120	1.0	2,658	3,536	114	5.69	80	-2,013	0	17.6	25.0
306 - PI Office	Rm/Zn Tot	120	1.0	2,705	3,583	113	5.67	80	-2,013	0	17.6	25.0
307 - PI Office	Rm/Zn Tot	120	1.0	2,743	3,621	114	5.69	80	-2,013	0	17.6	25.0
308 - PI Office	Rm/Zn Tot	120	1.0	2,773	3,651	114	5.68	80	-2,013	0	17.6	25.0
309 - PI Office	Rm/Zn Tot	120	1.0	2,841	3,769	115	5.73	80	-2,013	0	17.5	25.0
310 - PI Office	Rm/Zn Tot	120	1.0	2,913	3,841	115	5.75	80	-2,013	0	17.4	25.0
311 - PI Office	Rm/Zn Tot	120	1.0	3,071	4,013	118	5.89	80	-2,013	0	17.0	25.0
312 - PI Office	Rm/Zn Tot	120	1.0	3,133	4,074	118	5.92	80	-2,013	0	16.9	25.0
313 - PI Office	Rm/Zn Tot	120	1.0	3,201	4,143	120	6.02	80	-2,013	0	16.6	25.0
314 - PI Office	Rm/Zn Tot	120	1.0	3,255	4,196	122	6.10	80	-2,013	0	16.4	25.0
315 - PI Office	Rm/Zn Tot	120	1.0	3,275	4,216	122	6.12	80	-2,013	0	16.3	25.0
316 - PI Office	Rm/Zn Tot	120	1.0	3,395	4,268	122	6.11	80	-2,013	0	16.4	25.0
317 - PI Office	Rm/Zn Tot	120	1.0	3,442	4,314	123	6.14	80	-2,013	0	16.3	25.0
318 - PI Office	Rm/Zn Tot	120	1.0	3,463	4,336	124	6.18	80	-2,013	0	16.2	25.0
134 - Board Room	Rm/Zn Tot	775	20.0	18,077	33,685	616	4.77	517	-9,801	0	64.9	77.4
137 - Corridor/Kitchenette	Rm/Zn Tot	460	1.0	7,281	8,747	307	4.00	307	-6,196	0	7.5	7.5
139 - Workroom Storage	Rm/Zn Tot	300	2.0	4,831	6,798	200	4.00	200	-3,794	0	20.0	20.0
140 - Graphics	Rm/Zn Tot	340	2.0	5,381	7,405	227	4.00	227	-4,300	0	17.6	17.6
145 - Telephone Room	Rm/Zn Tot	90	1.0	1,521	2,419	60	4.00	60	-1,138	0	33.3	33.3
Atrium w/25% tinted skylight	Rm/Zn Tot	6,012	40.0	369,515	565,184	17,084	3.41	10020	-366,440	0	29.3	50.0
RTU-2	Sys Tot/Ave	18,842	169.0	636,464	946,453	27,459			-555,010	0	29.5	40.7
RTU-2	Sys Block	18,842	169.0	626,251	938,338	25,774			-551,817	0	29.5	40.7
105 - Electron Microscopy (Inactive)	Rm/Zn Tot	725	21.8	15,308	31,946	494	4.08	483	-9,858	0	100.0	100.0
106 - Storage	Rm/Zn Tot	175	0.0	7,053	9,944	325	11.16	117	-4,802	0	100.0	100.0
107 - Scintillation	Rm/Zn Tot	210	1.0	5,406	8,169	243	6.94	140	-4,282	0	100.0	100.0
228 - (1-5) Research Lab and Supporting	Rm/Zn Tot	5,130	154.1	146,626	290,448	5,044	5.90	3420	-85,697	0	100.0	100.0
109 - Radioisotope High	Rm/Zn Tot	125	3.8	3,725	7,267	120	5.74	83	-2,869	0	100.0	100.0
111 - Material Storage	Rm/Zn Tot	410	0.0	8,670	14,878	273	4.00	273	-7,516	0	100.0	100.0
112 - Corridor	Rm/Zn Tot	650	0.0	13,329	23,171	433	4.00	433	-8,110	0	100.0	100.0
113 - Bulk Storage	Rm/Zn Tot	410	0.0	8,670	14,878	273	4.00	273	-7,516	0	100.0	100.0
228 - (6-8) and Supporting	Rm/Zn Tot	2,295	68.9	52,440	108,175	1,708	4.46	1530	-28,636	0	100.0	100.0
228 - (9-10) Lab and Supporting	Rm/Zn Tot	2,130	64.0	55,376	111,415	2,443	6.88	1420	-31,345	0	100.0	100.0
329 - (1-5) Lab and Supporting	Rm/Zn Tot	5,130	154.1	159,483	303,305	5,044	5.90	3420	-85,697	0	100.0	100.0
329 - (6-8) Lab and Supporting	Rm/Zn Tot	2,515	75.5	63,770	124,848	1,871	4.46	1677	-31,381	0	100.0	100.0
329 - (9-10) Lab and Supporting	Rm/Zn Tot	2,200	66.1	62,489	120,228	2,492	6.80	1467	-32,219	0	100.0	100.0
232 - Support Corridor	Rm/Zn Tot	640	19.2	14,624	30,167	476	4.46	427	-7,986	0	100.0	100.0
238 - CG Robotics	Rm/Zn Tot	700	21.0	15,995	32,995	521	4.46	467	-8,734	0	100.0	100.0
239 - Shared Equipment	Rm/Zn Tot	600	18.0	13,710	28,281	446	4.46	400	-7,487	0	100.0	100.0
243 - Chromatography	Rm/Zn Tot	240	7.2	5,484	11,312	179	4.46	160	-2,995	0	100.0	100.0
252 - Autoclave	Rm/Zn Tot	115	3.5	2,628	5,421	86	4.46	77	-1,435	0	100.0	100.0
253 - Insect Room	Rm/Zn Tot	330	9.9	7,540	15,555	246	4.46	220	-4,118	0	100.0	100.0
254 - Bacteria	Rm/Zn Tot	140	4.2	3,199	6,599	104	4.46	93	-1,747	0	100.0	100.0
255- Dark Room	Rm/Zn Tot	85	2.6	1,942	4,007	63	4.46	57	-1,061	0	100.0	100.0
256 - Chromatography	Rm/Zn Tot	225	6.8	5,141	10,605	167	4.46	150	-2,807	0	100.0	100.0
257 - Yeast	Rm/Zn Tot	110	0.0	2,256	3,921	73	4.00	73	-1,373	0	100.0	100.0
245 - Writeup	Rm/Zn Tot	215	6.5	4,913	10,134	160	4.46	143	-2,683	0	100.0	100.0
333 - Support Corridor	Rm/Zn Tot	640	19.2	16,228	31,771	476	4.46	427	-7,986	0	100.0	100.0
339 - Dishwashing	Rm/Zn Tot	210	6.3	5,325	10,425	156	4.46	140	-2,620	0	100.0	100.0
340 - Autoclave	Rm/Zn Tot	110	3.3	2,789	5,461	82	4.46	73	-1,373	0	100.0	100.0
341 - Insturment	Rm/Zn Tot	170	5.1	4,311	8,439	126	4.46	113	-2,121	0	100.0	100.0
343 - Equipment	Rm/Zn Tot	345	10.4	8,748	17,126	257	4.46	230	-4,305	0	100.0	100.0
344 - Chromatography	Rm/Zn Tot	225	6.8	5,705	11,169	167	4.46	150	-2,807	0	100.0	100.0
358 - X-Ray Crystallography	Rm/Zn Tot	725	21.8	18,383	35,990	539	4.46	483	-9,046	0	100.0	100.0
360 - X-Ray Pump Room	Rm/Zn Tot	110	3.3	2,789	5,461	82	4.46	73	-1,373	0	100.0	100.0
361 - E Coli Lab	Rm/Zn Tot	110	3.3	2,789	5,461	82	4.46	73	-1,373	0	100.0	100.0
AHU-1,2	Sys Tot/Ave	28,150	787.3	749,430	1,461,560	25,254			-415,356	0	100.0	100.0
AHU-1,2	Sys Block	28,150	787.3	743,380	1,456,240	24,675			-415,355	0	100.0	100.0

Appendix B:
Annual Utility Consumption Monthly Breakdown

------- Monthly Energy Consumption -------

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Electric													
On-Pk Cons. (kWh)	97,818	88,326	97,733	95,146	113,357	123,642	141,451	148,263	125,259	99,946	94,919	97,697	1,323,558
On-Pk Demand (kW)	133	134	133	149	254	308	337	358	299	183	142	135	358
Gas													
On-Pk Cons. (therms)	11,829	9,734	8,769	4,735	1,447	763	556	678	1,058	3,259	5,615	7,517	55,959
On-Pk Demand (therms/hr)	19	19	15	11	5	3	2	2	3	7	11	13	19

Building Energy Consumption =	172,017	Btu/(ft2-year)
Source Energy Consumption =	330,720	Btu/(ft2-year)
Floor Area =	58,792	ft2

Appendix C:
Annual Utility Cost Monthly Breakdown

------- Monthly Utility Costs -------

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Electric													
On-Pk Demand ($)	52	52	52	52	52	52	52	52	52	52	52	52	619
Gas													
On-Pk Cons. ($)	1,961	1,621	1,464	809	275	155	114	138	212	570	952	1,261	9,534
Monthly Total ($):	2,013	1,673	1,516	861	327	207	166	190	264	621	1,004	1,313	10,153

Appendix D:
Annual Equipment Consumption Monthly Breakdown

------- Monthly Consumption -------

Equipment - Utility		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Lights														
	Electric (kWh)	65,369.7	59,043.6	65,369.6	63,261.0	65,369.7	63,261.0	65,369.7	65,369.6	63,261.0	65,369.7	63,261.0	65,369.7	769,675.1
	Peak (kW)	87.9	87.9	87.9	87.9	87.9	87.9	87.9	87.9	87.9	87.9	87.9	87.9	87.9
MISC LD														
	Electric (kWh)	29,099.7	26,283.6	29,099.7	28,161.0	29,099.7	28,161.0	29,099.7	29,099.7	28,161.0	29,099.7	28,161.0	29,099.7	342,625.3
	Peak (kW)	39.1	39.1	39.1	39.1	39.1	39.1	39.1	39.1	39.1	39.1	39.1	39.1	39.1
Cpl 1: Cooling plant - 001														
McQuay Air Cooled Screw Chiller (Cooling Equipment)														
	Electric (kWh)	0.0	0.0	0.0	389.0	14,201.8	26,512.3	39,940.0	45,909.5	27,499.4	1,626.9	229.4	0.0	156,308.3
	Peak (kW)	0.6	1.4	1.0	15.0	113.9	162.4	188.4	208.0	153.8	48.4	8.5	2.4	208.0
Eq5221 - Condenser fan														
	Electric (kWh)	0.0	0.0	0.0	258.6	2,329.7	3,762.4	5,337.6	6,051.8	3,949.7	700.4	171.7	0.0	22,561.8
	Peak (kW)	0.6	0.9	0.7	3.1	13.3	18.7	21.1	23.2	18.1	6.1	2.3	1.2	23.2
Eq5302 - Cntl panel & interlocks (Misc Accessory Equipment)														
	Electric (kWh)	0.0	0.0	0.0	33.0	74.4	72.0	74.4	74.4	72.0	58.9	24.0	0.0	483.1
	Peak (kW)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Hpl 1: Heating plant - 002														
Boiler - 001 (Heating Equipment)														
	Gas (therms)	11,829.4	9,733.6	8,768.7	4,735.1	1,446.9	762.6	555.6	677.6	1,057.9	3,259.4	5,615.2	7,517.3	55,959.2
	Peak (therms/Hr)	19.5	18.7	15.1	11.0	5.3	3.2	2.3	2.4	3.3	7.4	11.2	12.9	19.5
Eq5020 - Heating water circ pump (Misc Accessory Equipment)														
	Electric (kWh)	1,109.6	1,002.2	1,109.6	1,073.8	832.2	689.0	601.0	647.3	850.1	1,109.6	1,073.8	1,109.6	11,207.9
	Peak (kW)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Eq5240 - Boiler forced draft fan (Misc Accessory Equipment)														
	Electric (kWh)	1,488.0	1,344.0	1,488.0	1,440.0	1,116.0	924.0	806.0	868.0	1,140.0	1,488.0	1,440.0	1,488.0	15,030.0
	Peak (kW)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0

Hpl 1: Heating plant - 002														
Eq5307 - Boiler cntl panel & inter (Misc Accessory Equipment)														
	Electric (kWh)	372.0	336.0	372.0	360.0	279.0	231.0	201.5	217.0	285.0	372.0	360.0	372.0	3,757.5
	Peak (kW)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Eq5032 - VV Cond Wtr Pump (12 F Delta T) (Misc Accessory Equipment)														
	Electric (kWh)	379.4	316.5	294.2	169.5	54.2	29.5	21.2	26.0	40.6	121.3	198.1	257.8	1,908.3
	Peak (kW)	0.6	0.6	0.5	0.4	0.2	0.1	0.1	0.1	0.1	0.3	0.4	0.4	0.6

Appendix E:
Annual Equipment Consumption Summary

	Elect Cons. (kWh)	Gas Cons. (therms)	Percent of Total Energy	Total Source Energy* (kBtu/yr)
Primary heating				
Primary heating	20,695.8	55,959.2	56.0 %	61,023.7
Primary cooling				
Cooling Compressor	156,308.3		5.3 %	16,006.0
Tower/Cond Fans	22,561.8		0.8 %	2,310.3
Condenser Pump			0.0 %	0.0
Other CLG Accessories	483.1		0.0 %	49.5
Cooling Subtotal....	179,353.2		6.1 %	18,365.8
Auxiliary				
Supply Fans			0.0 %	0.0
Circ Pumps	11,207.9		0.4 %	1,147.7
Base Utilities			0.0 %	0.0
Aux Subtotal....	11,207.9		0.4 %	1,147.7
Lighting				
Lighting	769,675.1		26.0 %	78,814.9
Receptacle				
Receptacles	342,625.3		11.6 %	35,084.9
Heating plant load				
Base Utilities			0.0 %	0.0
Cogeneration				
Cogeneration			0.0 %	0.0
Totals				
Totals**	1,323,557.3	55,959.2	100.0 %	194,437.0

Appendix F:
Schematic Diagram Symbol Legend

Symbol	Description
AHU	Air Handling Unit
AIP	Analog in Pressure Sensor
AIT	Analog In Temperature Sensor
AO	Analog Output
CWR	Chilled Water Return
CWS	Chilled Water Supply
DI	Digital Input
E	Electrical Connection
FS	Flow Switch
GR	Glycol Return
GS	Glycol Supply
HRGR	Heat Recovery Glycol Return
HRGS	Heat Recovery Glycol Supply
LEF	Laboratory Exhaust Fan
M	Damper Motor
P	Pressure Sensor
OA	Outside Air
RA	Return Air
RTU	Rooftop Unit
SA	Supply Air
T	Temperature Controller

Appendix G:
Major Equipment

Figure XXV: Air Handling Unit Schedule

				AHU-1	AHU-2	AHU-3	RTU-1	RTU-2
Equipment Name				AHU-1	AHU-2	AHU-3	RTU-1	RTU-2
Manufacturer				McQuay	McQuay	McQuay	McQuay	McQuay
Area Served				Lab	Lab	Penthouse	West Offices	South Offices, Atrium
Capacity	Total (cfm)			29000	29000	3000	14175	28300
Capacity	Outside Air (cfm)			29000	29000	3000	3500	7075
Capacity	Return Air (cfm)			0	0	0	10675	21225
SP	Total Static Pressure			6.53	6.53	2.32	3.3	3.57
SP	Exterior Static Pressire			2	2	1.5	2	2
Cooling Coil	Max Face Velocity (fpm)			500	500	No Cooling Coil	524	525
Cooling Coil	EAT (°F)	Dry Bulb Temp		86	86		80	80
Cooling Coil	EAT (°F)	Wet Bulb Temp		72	72		67	67
Cooling Coil	LAT (°F)	Dry Bulb Temp		53.8	53.8		55.5	55.5
Cooling Coil	LAT (°F)	Wet Bulb Temp		53.6	53.6		55.2	55.3
Cooling Coil	Total Heat MBH			1740	1740		519.7	1032.7
Cooling Coil	30% Propylene Glycol (°F)	Temp In		42	42		DX Cooling	DX Cooling
Cooling Coil	30% Propylene Glycol (°F)	Temp Out		52.6	52.6			
Cooling Coil	30% Propylene Glycol (°F)	GPM		342	342			
Cooling Coil	Max Pressure Drop	Air (in.)		1.22	1.22		0.72	0.73
Cooling Coil	Max Pressure Drop	Water (ft.)		26.7	26.7		-	-
Heating Coil	Max Face Velocity (fpm)			515	515	571	-	-
Heating Coil	Air Temp In			0	0	0	30	30
Heating Coil	Air Temp Out			60.1	60.1	60.4	46.2	46.2
Heating Coil	Total Heat MBH			1906	1906	198.1	250	500
Heating Coil	40% Propylene Glycol (°F)	Temp In		190	190	190	Gas Fired	Gas Fired
Heating Coil	40% Propylene Glycol (°F)	Temp Out		160	160	159.8		
Heating Coil	40% Propylene Glycol (°F)	GPM		136.5	136.5	14.1		
Heating Coil	Max Pressure Drop	Air (in.)		0.14	0.14	0.19	0.26	0.39
Heating Coil	Max Pressure Drop	Water (ft.)		5.7	5.7	1.5	-	-
Heat Recovery	Summer Conditions	EAT (DB/WB)		86/72	86/72	No Heat Recovery	No Heat Recovery	No Heat Recovery
Heat Recovery	Summer Conditions	GPM		116	116			
Heat Recovery	Summer Conditions	LAT (DB/WB)		79.8/70.1	79.8/70.1			
Heat Recovery	Summer Conditions	APD (in.)		0.88	0.88			
Heat Recovery	Summer Conditions	WPD (ft.)		15.2	15.2			
Heat Recovery	Summer Conditions	MBH	Total	364.6	364.6			
Heat Recovery	Summer Conditions		Sensible	n/a	n/a			
Heat Recovery	Winter Conditions	EAT (DB/WB)		0	0			
Heat Recovery	Winter Conditions	GPM		83.1	83.1			
Heat Recovery	Winter Conditions	LAT (DB/WB)		36.3	36.3			
Heat Recovery	Winter Conditions	APD (in.)		0.88	0.88			
Heat Recovery	Winter Conditions	WPD (ft.)		16.3	16.3			
Heat Recovery	Winter Conditions	MBH	Total	1068	1068			
Heat Recovery	Winter Conditions		Sensible	n/a	n/a			
SA Fan	RPM			1377	1377	1597	1481	850
SA Fan	Motor	BHP		41.5	41.5	2.33	10.2	22.7
SA Fan	Motor	HP		50	50	15	15	25
SA Fan	Motor	VFD		Yes	Yes	Yes	Yes	Yes
SA Fan	Motor	Electrical		460/3/60	460/3/60	460/3/60	460/3/60	460/3/60

Figure XXVI: Fan Schedule

Fan Name	Service	CFM	SP (in w.g)	Manufacturer	RPM	Motor			
						BHP	HP	VFD	Elect
E/F-1	Garage Exhaust	7800	1.25	Greenheck	712	2.95	5	No	460/3/60
E/F-2	Garage Exhaust	7800	1.25	Greenheck	712	2.95	5	No	460/3/60
E/F-3	Janitor Closet/Toilets	700	1	Greenheck	1649	0.22	0.5	No	120/1/60
E/F-4	Toilets	2800	1	Greenheck	740	0.85	0.15	No	460/3/60
E/F-5	Toilets/Kitchen	925	1	Greenheck	1399	0.25	0.5	No	120/1/60
E/F-6	Smoke Exhaust	42850	0.75	Greenheck	699	13.21	15	No	460/3/60
E/F-7	Smoke Exhaust	42850	0.75	Greenheck	699	13.21	15	No	460/3/60
E/F-8	Smoke Exhaust	42850	0.75	Greenheck	699	13.21	15	No	460/3/60
E/F-9	Smoke Exhaust	42850	0.75	Greenheck	699	13.21	15	No	460/3/60
E/F-10	Elevator Machine Rm.	275	0.5	Greenheck	1550	0.1	0.25	No	120/1/60
E/F-11	Elevator Machine Rm.	275	0.5	Greenheck	1550	0.1	0.25	No	120/1/60
E/F-12	Radioisotope Hood	2200	2	Greenheck	1270	1.49	2	No	460/3/60
E/F-13	Radioisotope Hood	2200	2	Greenheck	1270	1.49	2	No	460/3/60
E/F-14	Electrical Room	700	0.25	Greenheck	1160	0.14	0.5	No	120/1/60
E/F-15	Stair 2 Relief	1500	0.25	Greenheck	947	0.18	0.25	No	120/1/60
E/F-16	Penthouse Relief	4000	0.25	Greenheck	525	0.4	0.75	No	460/3/60
SF-1	Outside Air Intake	11500	0.5	Greenheck	2089	8.59	10	Yes	460/3/60
SF-2	Outside Air Intake	40000	0.75	Greenheck	832	16.53	20	Yes	460/3/60
LEF-1	Laboratory Exhaust	27000	4	Strobic Air Corp.	1170	35.23	40	Yes	460/3/60
LEF-2	Laboratory Exhaust	27000	4	Strobic Air Corp.	1170	35.23	40	Yes	460/3/60
LEF-3	Laboratory Exhaust	27000	4	Strobic Air Corp.	1170	35.23	40	Yes	460/3/60

Figure XXVII: Chiller Schedule

Name		CH-1
Type		Screw
Make		McQuay
Refrigerant		R-132A
Evaporator	LWT(°F)	42
	EWT (°F)	52
	GPM	685
	WPD (ft.)	14.2
	Tons	270
Condensor	Ambient Air T(°F)	95
Compressor	Quantity	2
	Total Capacity	300 ton
Electrical		460/3/60

Name		CH-2
Type		Air Cooled, Self Contained
Make		Filtrine
Refrigerant		R-22
Capacity	LWT(°F)	68
	Ambient Air T(°F)	90
	GPM	15
Electrical		460/3/60

Figure XXVII: Boiler Schedule

Boiler		B-1 thru B-6 (typ.)
Type		Gas Fired Modulating
Make		Patterson-Kelley Modu-Fire
Capacity	Input	2000 BTU
	Output	1700 BTU
Gas Pressure	Min	4" w.c.
	Max	14" w.c
Options		IRI Gas Train, Low Water Cutoff, Pressure Relief Valve/Pressure

Figure XXIX: Pump Schedule

Pump Name	Service	GPM	Head (ft.)	Manufacturer	Motor			
					RPM	HP	VFD	Elect
P-1	Chilled Water	700	90	Bell & Gossett	1750	25	No	460/3/60
P-2	Chilled Water	700	90	Bell & Gossett	1750	25	No	460/3/60
P-3	Primary Hot Water	135	20	Taco	1750	1.5	No	460/3/60
P-4	Primary Hot Water	135	20	Taco	1750	1.5	No	460/3/60
P-5	Primary Hot Water	135	20	Taco	1750	1.5	No	460/3/60
P-6	Primary Glycol	150	20	Taco	1750	1.5	No	460/3/60
P-7	Primary Glycol	150	20	Taco	1750	1.5	No	460/3/60
P-8	Primary Glycol	150	20	Taco	1750	1.5	No	460/3/60
P-9	Secondary Hot Water	220	80	Bell & Gossett	1750	10	Yes	460/3/60
P-10	Secondary Hot Water	220	80	Bell & Gossett	1750	10	Yes	460/3/60
P-11	Secondary Glycol	300	50	Bell & Gossett	1750	7.5	Yes	460/3/60
P-12	Secondary Glycol	300	50	Bell & Gossett	1750	7.5	Yes	460/3/60
P-13	Glycol Heat Recovery	250	75	Bell & Gossett	1750	3	No	460/3/60

Figure XXX: Computer Room Air Conditioning Unit Schedule

Name		AC-1 and AC-2
Type		Air Cooled
Make		Leibert
Capacity	Ton	5
	Total MBH	57.7
	Sen. MBH	51
	DBT(oF)	72
	RH	50%
Fan	CFM	2800
	Motor HP	1.5
	Motor KW	15
Electrical		460/3/60
Condensing Unit	Ambient Air T(oF)	95
	Electrical	460/3/60

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