Technical Assignment 3

Mechanical Systems and Existing Conditions Report

David H. Koch Institute for Integrative Cancer Research

Massachusetts Institute of Technology

Cambridge, Ma

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Executive Summary

The David H. Koch Institute for Integrative Cancer research lab presents a multitude of HVAC design challenges. With the MIT's expectation of achieving LEED Gold Certification, design engineers were forced to provide innovative design solutions, resulting in an energy efficient HVAC system. In this technical report, the mechanical systems of the Koch Institute are evaluated, critiqued and ultimately found to be extremely well designed.

A central VAV ventilation/cooling system provides fully conditioned 98% outdoor air to the Koch Institute, utilizing heat recovery between the supply and exhaust air streams. The remaining 2% is made up with two small return fans that dump a total of 30,000 cfm into the outdoor air plenum that the large units pull from. The central VAV ventilation/cooling system is made up of (10) 50,000 cfm factory built-up AHU's coupled with (10) 50,000 cfm EAHU's, and is responsible for supplying and exhausting the entire building. The building is heated through hot water reheat coils and a perimeter radiant panel heating system. High intensity load and perimeter spaces are conditioned with fan coil units and chilled beam induction cooling to supplement the central VAV system.

Supplying energy to this system is MIT's cogeneration plant which utilizes a 25MW Combustion Turbine Generator. This generator provides 80% of the electricity consumed by the campus by burning Natural Gas purchased from NSTAR based on a large commercial service rate (G-43). MIT's plant is also responsible for supplying the Koch Institute with chilled water and steam which it will do through an existing campus system that has been designed with future expansion in mind.

The initial cost of the mechanical systems in the Koch Institute totals to $37,474,136 which is approximately 18% of the total construction cost. This cost includes HVAC and Automatic Temperature Controls and equates to $100.12/square foot. If you include plumbing it raises to $47,991,949, roughly 22% of the total construction cost.

When considering Leadership in Energy and Environmental Design (LEED) Rating System, the owner required a Gold Certification level be achieved. The LEED section of this report shows that the project is projected to receive 42 of the possible 69 LEED credits, qualifying it for Gold Certification.

The mechanical system designed for this project responds well to all the challenges presented by the project objectives. It efficiently utilizes the spaces provided by the architect and adequately conditions the entire building in an energy conscious approach. The reports to follow will attempt to continue to improve upon the design's innovative approach as well as incorporate feasible renewable energy sources.

Mechanical Summary

Introduction

A central VAV ventilation/cooling system provides fully conditioned 98% outside air to the Koch Institute, utilizing heat recovery between the supply and exhaust air streams. The remaining 2% is made up with two small return fans that dump a total of 30,000 cfm into the outdoor air plenum that the large units pull from. The central VAV ventilation/cooling system is made up of (10) 50,000 cfm factory built-up AHU's coupled (10) 50,000 cfm EAHU's, and is responsible for supplying and exhausting the entire building. The building is heated through hot water reheat coils and a perimeter radiant panel heating system. High intensity load and perimeter spaces are conditioned with fan coil units and chilled beam induction cooling to supplement the central VAV system.

Design Criteria and Objectives

It is essential in the design of any HVAC System to ensure that all spaces are properly ventilated, meeting all requirements of the occupants. A good design can meet these ventilation requirements while also creating comfortable space conditions by controlling temperature and humidity to pre-determined levels. Due to the diversity of building and space types, every project presents new challenges which results in uniquely designed HVAC systems.

In the case of the Koch Institute, a number of critical space types and occupancy requirements drove the design. A large amount of laboratory and classroom spaces demanded that the HVAC system should be capable of delivering large amounts of outdoor air to properly ventilate all spaces. Very large equipment loads required the design to adjust quickly to increased loads during equipment operation. Also, the nature and importance of the research being performed in the building called for a sophisticated, reliable emergency power system.

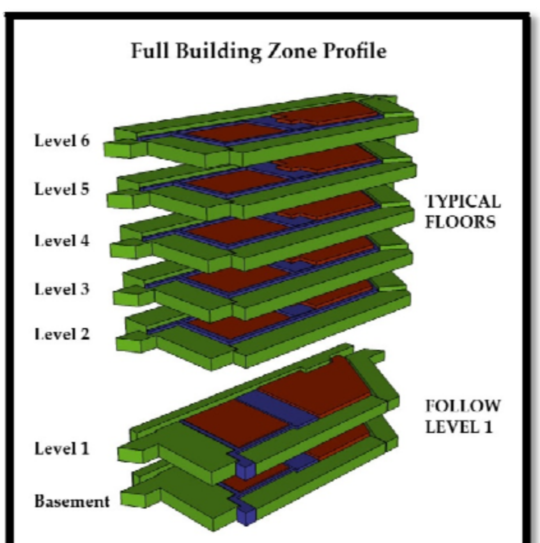

Figure 1 *–Building Zone Profile (level 7 not shown)*

Along with these space and occupancy criteria, the architecture of the Koch Institute presents additional challenges. The glass enclosed building is subjected to large amounts of solar gain, making all perimeter spaces critical. With a mechanical penthouse and two main shafts in the East and West sections of the building, the mechanical design engineers chose to employ a large centralized system that is divided between East and West service. With the exception of the seventh level, the spaces on each level were nearly identical and therefore could be treated similarly. Therefore, the architectural layout of the building dictated that the vivarium space on the seventh floor be conditioned separately than the other levels.

With all of these challenges comes another extremely important factor of the design, and that is the owners design intent. The Koch Institute is designed with the goal of achieving LEED Gold Certification. Energy conscious design makes up a large portion of LEED Credits, and therefore, the mechanical system must be very efficient in all areas.

Having all of these challenges and design requirements in mind, the design engineer has all the tools needed to design the optimum system for the owner. The components of the system must be selected to operate efficiently over the buildings lifetime to reduce large energy costs for the owner.

Outdoor and Indoor Design Conditions

The desired indoor conditions and the location specific outdoor conditions heavily influence the design of a building. The Koch Institute is located in Cambridge, MA where a New England climate produces harsh winters and hot summers. This area experiences the same outdoor conditions as Boston, MA which has the following ASHRAE Weather Data:

Outdoor Design Conditions	
Weather Location	Boston, MA
Summer Dry Bulb (°F)	88
Summer Wet Bulb (°F)	74
Winter Dry Bulb (°F)	9
Summer Clearness	0.85
Winter Clearness	0.85
Summer Ground Reflectiveness	0.2
Winter Ground Reflectiveness	0.2
Carbon Dioxide Level	400

Figure 2 *–Outdoor Design Conditions*

With summer temperatures in the high 80's and winter in the single digits, the building will exposed to high heating and cooling loads. The system will have to overcome these loads to condition the spaces to the desired thermal conditions, while also maintaining proper humidity levels. With laboratories and classroom space making up a large portion of the building, the indoor design conditions follow the requirements associated with these space types.

Thermostat Settings	
Cooling Dry Bulb (°F)	74
Heating Dry Bulb (°F)	72
Relative Humidity %	50
Cooling Driftpoint (°F)	90
Heating Driftpoint (°F)	55

Sensor Locations	
Thermostat	Room

Humidity	
Moisture Capacitance	Medium
Humidistat Location	Room

Figure 3 *–Indoor Design Conditions*

Those temperatures and humidity's are shown in ***Figure 3*** to the left. The individual room temperatures may vary based on zone set points or changes in thermostat settings.

The humidity levels in the spaces are controlled by dehumidification performed in the main air handling system in the penthouse. The only floor to need additional humidification is level seven due to its vivarium spaces and specific space needs. Therefore, level seven has its own dedicated air handlers AHU-5 and AHU-6 that are supplemented by individual ducted humidifiers that provide the appropriate humidity levels for the spaces they serve.

System Design and Equipment Summaries

As outlined above, there were many design objectives, requirements and conditions that drove the engineers to the current MEP design for the Koch Institute. The system that resulted from these driving forces is well structured and efficiently laid out. To best portray the system in this report, numerous diagrams and equipment summaries were created.

Air Supply System

The Primary air supply system utilizes (10) 50,000 CFM Factory Built-Up AHU's that utilize 98% outdoor air and 2% return air to the entire building. These units make up the entire central VAV ventilation/cooling system that was described in the introduction of this report. These air handlers are divided up into 3 groups, AHU – 1 to 4; AHU-5 & 6; and AHU-7 to 10. AHU's 1-4 deliver 200,000 cfm of conditioned air down the west shaft to the west zones of levels B-6. AHU-5 & 6 serve the seventh level vivarium spaces and AHU's-7-10 deliver 200,000 cfm of conditioned air down the east shaft to the east zones of levels B-6. These AHU's are summarized in the following table shown in ***Figure 4***. As can be seen, these are cooling units that utilize a heat recovery system from their respective exhaust airstream to pre-condition the incoming outdoor air.

Built-Up Air Handling Units

Unit	Service	Fan		Heat Recovery System (winter)						Preheat Coil (bank of 4 coils)						Cooling Coil (bank of 3 coils)								
										Air Side			Total MBH	Steam Side		Air Side					Total MBH	Water Side		
		CFM	Type	Vel. Fpm	EDB °F	EWB °F	LDB °F	LWB °F	Total MBH	Vel. Fpm	EDB °F	LDB °F		In. Pres. Psig	Flow lb/hr	Vel. Fpm	EDB °F	EWB °F	LDB °F	LWB °F		Flow gpm	EWT °F	LWT °F
AHU-1	Laboratory	50000	Plenum	535	7	6	36	28	1680	745	0	40	2220	5	2150	430	88	74	51	50.7	3700	480	43	60
AHU-2	Laboratory	50000	Plenum	535	7	6	36	28	1680	745	0	40	2220	5	2150	430	88	74	51	50.7	3700	480	43	60
AHU-3	Laboratory	50000	Plenum	535	7	6	36	28	1680	745	0	40	2220	5	2150	430	88	74	51	50.7	3700	480	43	60
AHU-4	Laboratory	50000	Plenum	535	7	6	36	28	1680	745	0	40	2220	5	2150	430	88	74	51	50.7	3700	480	43	60
AHU-5	Vivarium	50000	Plenum	595	7	6	30	23	1260	745	0	40	2220	5	2150	430	88	75	50.1	50	4150	480	43	60
AHU-6	Vivarium	50000	Plenum	595	7	6	30	23	1260	745	0	40	2220	5	2150	430	88	75	50.1	50	4150	480	43	60
AHU-7	Laboratory	50000	Plenum	535	7	6	36	28	1680	745	0	40	2220	5	2150	430	88	74	51	50.5	3700	480	43	60
AHU-8	Laboratory	50000	Plenum	535	7	6	36	28	1680	745	0	40	2220	5	2150	430	88	74	51	50.5	3700	480	43	60
AHU-9	Laboratory	50000	Plenum	535	7	6	36	28	1680	745	0	40	2220	5	2150	430	88	74	51	50.5	3700	480	43	60
AHU-10	Laboratory	50000	Plenum	535	7	6	36	28	1680	745	0	40	2220	5	2150	430	88	74	51	50.5	3700	480	43	60

Figure 4 *–Built-Up Air Handling Unit Summary*

On the following page (page 7), a drawing of the supply system shows the three groups of built up AHU's without the exhaust system for simplification and reading purposes.

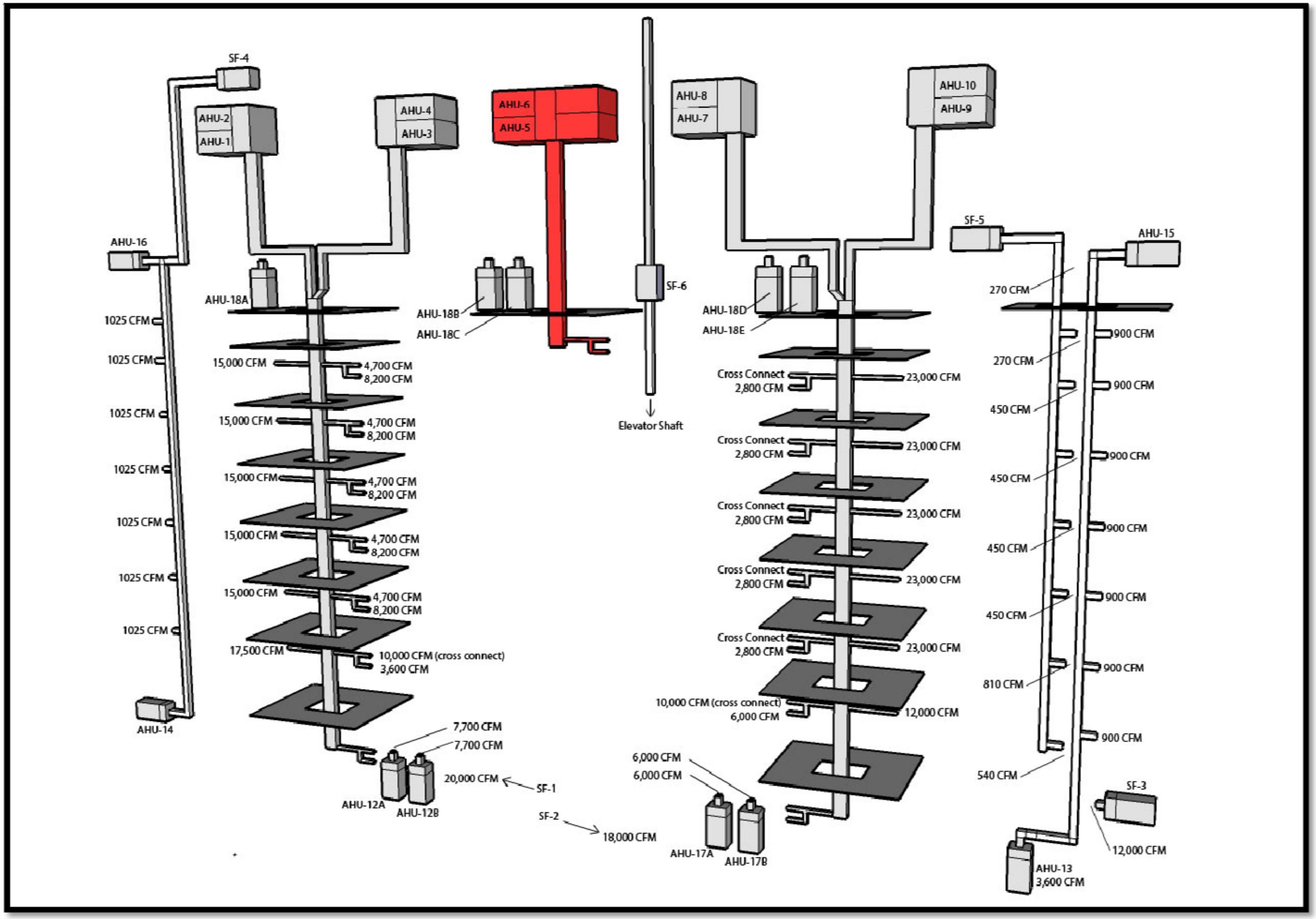

Figure 5 *–Supply Air Riser Diagram*

Figure 5 on the previous page shows the full layout of the central VAV ventilation/cooling system. The 10 large air handling units that make up this system are depicted in what will be the penthouse level of the Koch Institute. The air handling units shown in red (AHU-5 & 6) are not completely depicted in this picture due to their extensive humidification system. To simplify the drawing and maintain readability, a separate drawing for these air handling units was created and is shown below in ***Figure 6***.

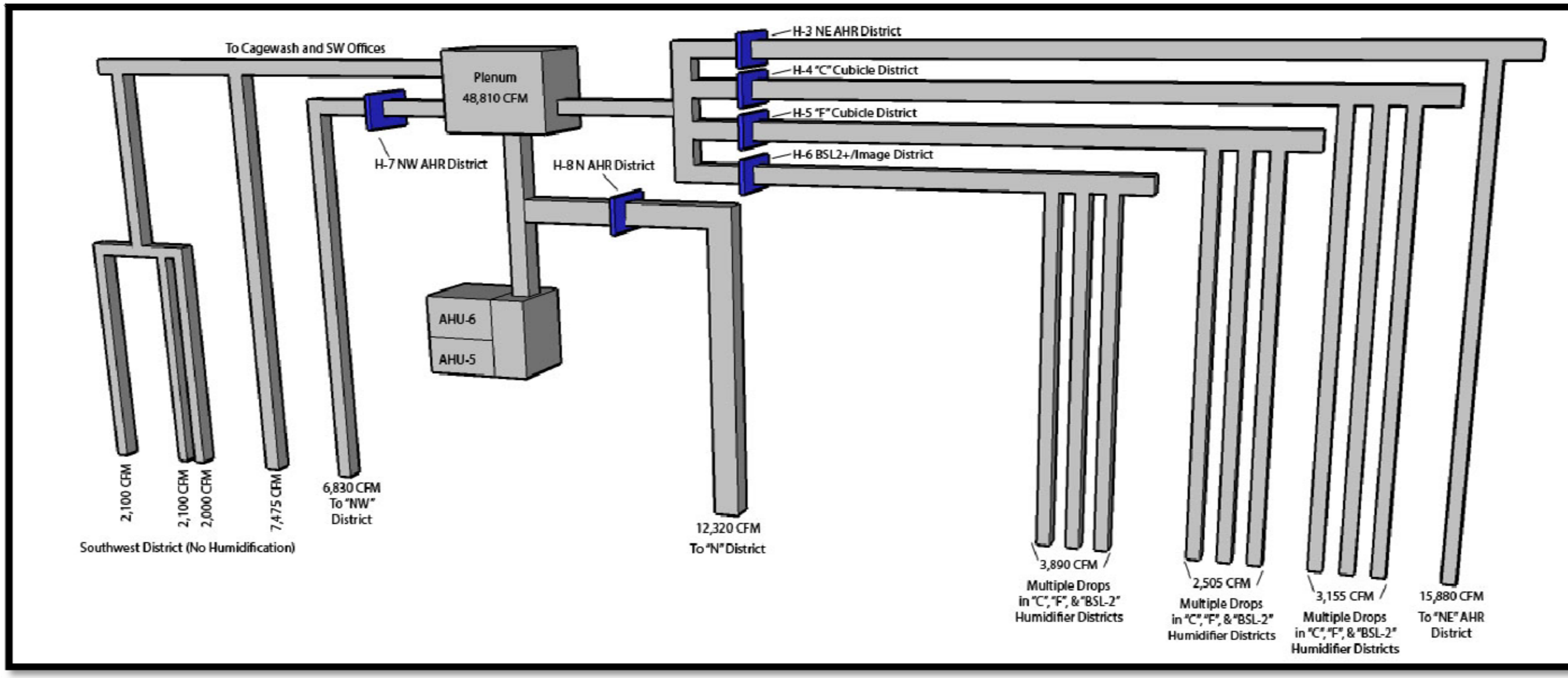

Figure 6 *–AHU 5 & 6 Supply Air Riser Diagram*

To maintain the desired space conditions on level 7, after leaving the (2) 50,000 cfm air handlers, the supply air is humidified by its respective humidifier shown in ***Figure 6***. Each humidifier is controlled by the space it is supplying described in the following table in ***Figure 7*** as "districts". AHU 5 & 6 have internal humidifiers that are also summarized in the table in ***Figure 7***.

Humidifiers															
Unit	Service	Location	CFM	Steam Supply		Max Dis. Dist. (ft)	Duct WxH (in)	Duct Velocity (fpm)	Entering Air Condition		Leaving Air Condition		Space Design Cond.	
				psig	lbs/hr.				°F	%RH	°F	%RH	°F	%RH
Primary															
H-1A	AHU-5 (Upper)	Vivarium	25000	3	525	3	168x66	325	55	10	55	50	70	30
H-1B	AHU-5 (Lower)	Vivarium	25000	3	525	3	168x67	325	55	10	55	50	70	30
H-2A	AHU-6 (Upper)	Vivarium	25000	3	525	3	168x68	325	55	10	55	50	70	30
H-2B	AHU-6 (Lower)	Vivarium	25000	3	525	3	168x69	325	55	10	55	50	70	30
Secondary															
H-3	Penthouse	Lev. 7 NE AHR District	15880	10	400	4	100x33	693	55	20	55	76	70	45
H-4	Penthouse	Lev. 7 "C" Cubicle District	3155	10	80	4	66x22	316	55	20	55	76	70	45
H-5	Penthouse	Lev. 7 "F" Cubicle District	2505	10	65	4	62x20	291	55	20	55	76	70	45
H-6	Penthouse	Lev. 7 BSL-2+/Imaging District	3890	10	100	4	88x32	199	55	20	55	76	70	45
H-7	Penthouse	Lev. 7 NW AHR District	6830	10	170	4	90x24	455	55	20	55	76	70	45
H-8	Penthouse	Lev. 7 North AHR District	12320	10	320	5	76x46	507	55	20	55	76	70	45

Figure 7 *–Humidifier Summary*

The smaller packaged air handling units shown in the main supply drawing (***Figure 5***) are responsible for spot cooling the penthouse and basement, as well as heating/cooling the East and West Stair Shafts. These units are packaged AHU's that are summarizes in the following table in ***Figure 8***. The four air handlers that have heating coils (AHU-13-15) are responsible for heating and cooling the stair shafts. The remaining units are utilized to cool the penthouse and electric service room.

Packaged Modular Air Handling Units																			
Unit	Service	Location	Fan		Heating Coil						Cooling Coil								
					Air Side			Total MBH	Water Side		Air Side					Total MBH	Water Side		
			CFM	Type	Vel. Fpm	EDB °F	LDB °F		EWT °F	LWT °F	Vel. Fpm	EDB °F	EWB °F	LDB °F	LWB °F		Flow gpm	EWT °F	LWT °F
AHU-12A	Electrical Service Rm.	Basement	7700	DWDI CENT	-	-	-	-	-	-	400	80	70	62	61	200	45	52	60
AHU-12B	Electrical Service Rm.	Basement	7700	DWDI CENT	-	-	-	-	-	-	400	80	70	62	61	200	45	52	60
AHU-13	East Stair Htg./Clg.	Basement	3600	DWDI CENT	400	70	90	78	180	140	400	75	63	57	56	75	19	52	60
AHU-14	West Stair Htg./Clg.	Basement	3600	DWDI CENT	400	70	90	78	180	140	400	75	63	57	56	75	19	52	60
AHU-15	East Stair Htg./Clg.	Basement	3600	DWDI CENT	400	70	90	78	180	140	400	75	63	57	56	75	19	52	60
AHU-16	West Stair Htg./Clg.	Basement	3600	DWDI CENT	400	70	90	78	180	140	400	75	63	57	56	75	19	52	60
AHU-17A	Basement Spot Cooling	Basement	6000	DWDI CENT	-	-	-	-	-	-	400	80	70	62	61	187	45	52	60
AHU-17B	Basement Spot Cooling	Basement	6000	DWDI CENT	-	-	-	-	-	-	400	80	70	62	61	187	45	52	60
AHU-18A	Penthouse Spot Cooling	Basement	6000	DWDI CENT	-	-	-	-	-	-	400	80	70	62	61	187	45	52	60
AHU-18B	Penthouse Spot Cooling	Basement	6000	DWDI CENT	-	-	-	-	-	-	400	80	70	62	61	187	45	52	60
AHU-18C	Penthouse Spot Cooling	Basement	6000	DWDI CENT	-	-	-	-	-	-	400	80	70	62	61	187	45	52	60
AHU-18D	Penthouse Spot Cooling	Basement	6000	DWDI CENT	-	-	-	-	-	-	400	80	70	62	61	187	45	52	60
AHU-18E	Penthouse Spot Cooling	Basement	6000	DWDI CENT	-	-	-	-	-	-	400	80	70	62	61	187	45	52	60

Figure 8 *–Packaged Modular Air Handling Unit Summary*

Supply Fans												
Unit	Service	CFM	S.P. (in. H_2O)	Type	Drive	VFD	Emer. Power	Motor Data at 60 Hz				
								MBHP	MHP	RPM	Volts	Phase
SF-1	Loading Dock	20000	2	Mixed Flow	Belt	Y	N	9.5	15	1750	480	3
SF-2	Pass. Elev. Pressurization	18000	2	Mixed Flow	Belt	N	Y	8.7	15	1750	480	3
SF-3	East Stair Pressurization	12000	1.5	Mixed Flow	Belt	N	Y	5.5	10	1750	480	3
SF-4	West Stair Pressurization	12000	1.5	Mixed Flow	Belt	N	Y	5.5	10	1750	480	3
SF-5	East Stair Vestibule Supply	4100	3	Mixed Flow	Belt	N	Y	3.3	7.5	1750	480	3
SF-6	Pass. Elev. Pressurization	12000	1.5	Mixed Flow	Belt	N	Y	5.5	10	1750	480	3

Figure 9 *–Supply Fan Summary*

The remaining supply fans shown in ***Figure 5*** are used to pressurize the loading dock, stairwells and passenger elevator shafts. These fans are summarized in the table to the left in ***Figure 9***.

Air Exhaust/Return System

The exhaust/return system utilizes (10) 50,000 CFM Factory Built-Up EAHU's to exhaust air from entire building. These exhaust air handlers are paired up with their respective AHU and exhaust air from the same spaces.

Built-Up Exhaust Air Handling Units									
Unit	Service	Fan		Heat Recovery System (winter)					
		CFM	Type	Vel. Fpm	EDB °F	EWB °F	LDB °F	LWB °F	Total MBH
EAHU-1	Laboratory	50000	SWSI	505	70	48	36	31	1680
EAHU-2	Laboratory	50000	SWSI	505	70	48	36	31	1680
EAHU-3	Laboratory	50000	SWSI	505	70	48	36	31	1680
EAHU-4	Laboratory	50000	SWSI	505	70	48	36	31	1680
EAHU-5	Vivarium	50000	SWSI	533	70	53	44	41	1260
EAHU-6	Vivarium	50000	SWSI	533	70	53	44	41	1260
EAHU-7	Laboratory	50000	SWSI	505	70	48	36	31	1680
EAHU-8	Laboratory	50000	SWSI	505	70	48	36	31	1680
EAHU-9	Laboratory	50000	SWSI	505	70	48	36	31	1680
EAHU-10	Laboratory	50000	SWSI	505	70	48	36	31	1680

Figure 10 *–Exhaust Air Handling Unit Summary*

Similar to the supply system, the exhaust system has the 10 main EAHU'S along with a number of smaller Exhaust Fans to deal with smaller spaces. The table to the left in ***Figure 10*** summarizes the main EAHU's, and the table in ***Figure 11*** summarizes these smaller exhaust fans. Lastly, two small return fans that return air directly into the Outdoor Air Plenum are shown in ***Figure 12***. This system is depicted on the following page similar to the supply air system previously outlined. There are a number of future special exhaust fans on the design documents that were not shown in this drawing.

Exhaust Fans												
Unit	Service	CFM	S.P. (in. H_2O)	Type	Drive	VFD	Emer. Power	Motor Data at 60 Hz				
								MBHP	MHP	RPM	Volts	Phase
EX-1	Materials Handling	20000	2	Mixed Flow	Belt	Y	N	9.5	15	1750	480	3
EX-2	Toilet Exhaust	8000	3	Mixed Flow	Belt	N	N	5.4	7.5	1750	480	3
EX-3	Servery	3900	2.5	Mixed Flow	Belt	Y	N	2.55	5	1750	480	3
EX-5	Basement Glasswash	1500	1.25	SWSI Cent.	Belt	Y	N	1.25	3	1750	480	3
EX-9	Basement R.I. Hood&Hot Waste	675	4.5	7-IPA	Belt	N	Y	0.85	2	3600	480	3
EX-10	Basement BSL-2+ Exh.	1800	4	12-BISW	Belt	Y	Y	1.9	3	3600	480	3
EX-11	East Stair Vestibule	6000	3	QEI-18	Belt	N	Y	4.3	7.5	1750	480	3
EX-16	Vac. Equipment Room	1000	0.5	BSQ-120-3	Belt	N	N	0.1	0.33	1750	120	1
EX-18	Fuel Oil Storage Room	300	0.5	BSQ-120-4	Belt	N	Y	0.1	0.33	1750	120	1

Figure 11 *–Exhaust Fan Summary*

Return Fans												
Unit	Service	CFM	S.P. (in. H_2O)	Type	Drive	VFD	Emer. Power	Motor Data at 60 Hz				
								MBHP	MHP	RPM	Volts	Phase
RF-1	Building Return Air (West Shaft)	15000	3	Mixed Flow	Direct	Y	N	1156	1.5	1750	480	3
RF-2	Level 1 Return Air (East Shaft)	15000	3	Mixed Flow	Direct	Y	N	1156	1.5	1750	480	3

Figure 12 *–Return Fan Summary*

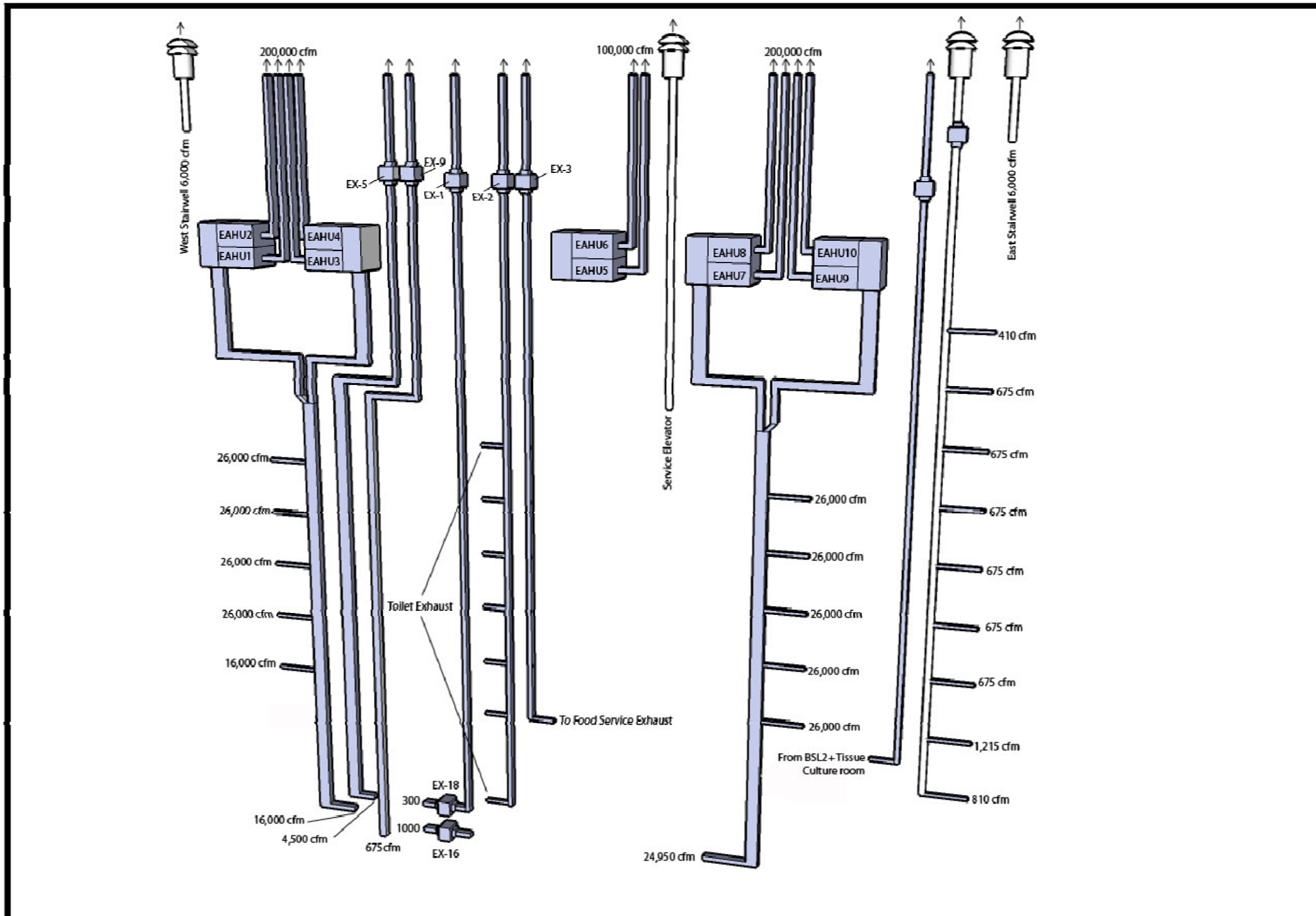

Figure 13 *–Exhaust Air Riser Diagram*

Chilled Water System

The chilled water system for the Koch Institute is fed through an existing MIT Campus chilled water loop. A maximum flow of 6,200 gpm chilled water enters the building through a 24" directly buried supply line and passes through the MIT Standard Meter. The chilled water is then distributed throughout the building. One 200 ton water cooled rotary screw chiller was added to the design to provide redundancy for the vivarium spaces. The ten large AHU's require three cooling coils and therefore 450 gpm of chilled water is piped to each through (3) 6" pipes to each unit, which is shown in ***Figure 14***. Chilled water also serves fan coil units and process loads on all floors through East and West Risers. The chilled water and condenser water pumps are summarized on the following page in ***Figure 15.***

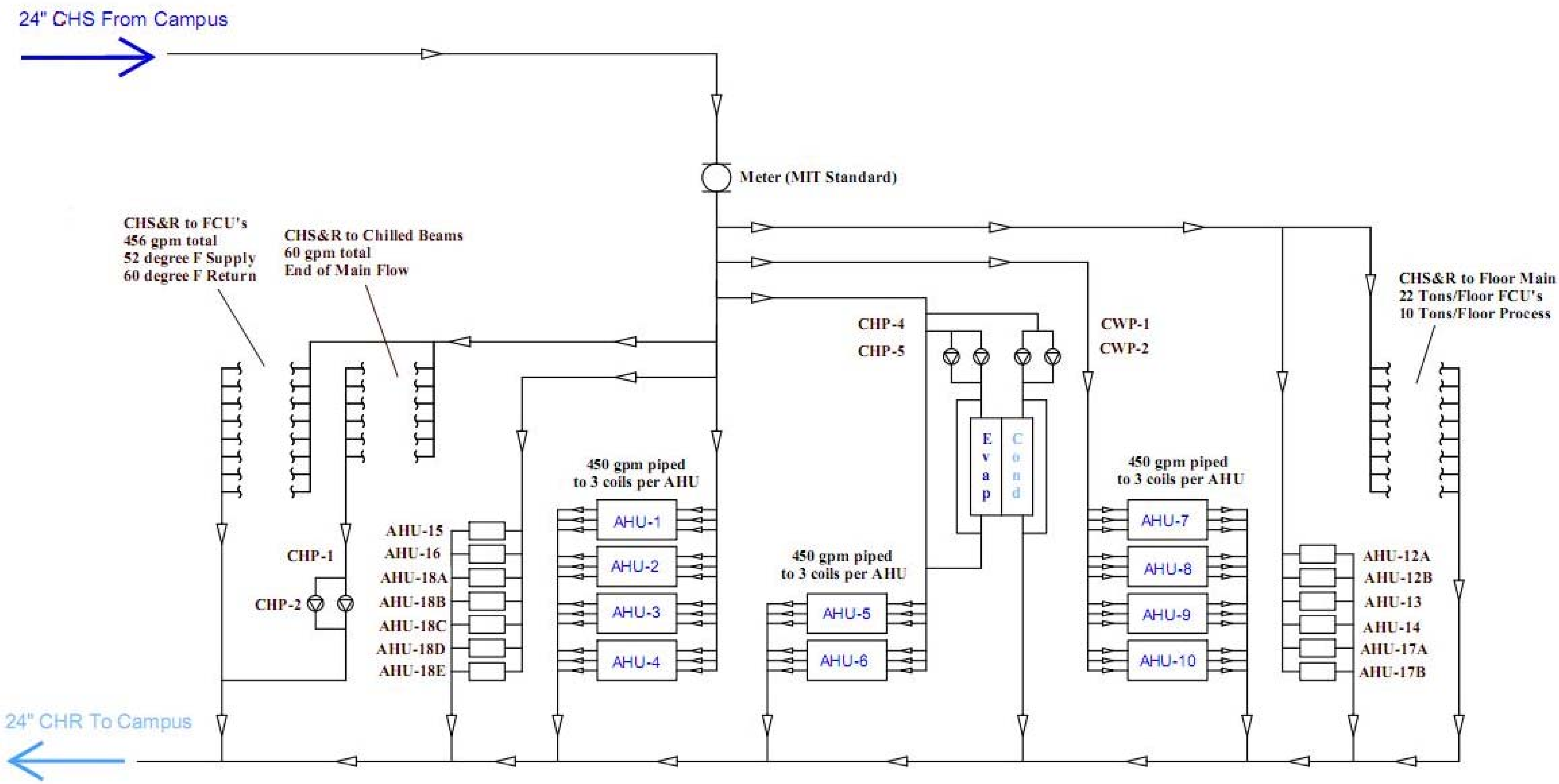

Figure 14 *–Chilled Water Riser Diagram*

Chilled/Condenser Water Pumps											
Unit	Service	Type	GPM	Total Head (f.t. H_2O)	VFD	Emer. Power	Motor Data at 60 Hz				
							BHP	MHP	RPM	Volts	Phase
CHP-1	Chilled Beams	End Suction	120	60	Y	N	3	5	1750	480	3
CHP-2	Chilled Beams (Stand-By)	End Suction	120	60	Y	N	3	5	1750	480	3
CHP-4	Vivarium Chiller	End Suction	900	80	Y	Y	22	25	1780	480	3
CHP-5	Vivarium Chiller (Stand-By)	End Suction	900	80	Y	Y	22	25	1780	480	3
CWP-1	Vivarium Chiller Condenser	End Suction	600	60	Y	Y	11	15	1780	480	3
CWP-2	Vivarium Chiller (Stand-By)	End Suction	600	60	Y	Y	11	15	1780	480	3

Figure 15 *–Chilled/Condenser Water Pump Summary*

Hot Water System

The hot water system for the Koch Institute consists of three shell and tube heat exchangers that produce 180 degree F hot water from low pressure steam (4 psig). As shown in ***Figure 16*** on the following page, the hot water is then pumped to building reheat, vivarium reheat and AHU's 15 & 16. To maintain separation from the other systems, the vivarium space has its own heat exchanger HE-3.

The three valves shown in the drawing, which are normally closed, are used to either isolate the vivarium from the rest of the hot water system or vice versa. Prior to the expansion tanks (ET-1 & 2) is a connection to the campus hot water system that will act to initially fill the system as well as provide make-up hot water for the system. The following two tables shown in ***Figure 16 & 15*** summarize the heat exchangers and hot water pumps respectively.

Heat Exchangers									
Unit	Service	Tube Length (ft.)	Tube Length (ft.)	Water Side (Tube)				Steam Side (Shell)	
				EWT °F	LWT °F	GPM	Min MBH	Oper. Pres.	Oper. Temp.
HE-1	Building Reheat	7	20	152	180	600	9600	4	360
HE-2	Building Reheat (Stand-By)	7	20	152	180	600	9600	4	360
HE-3	Vivarium Reheat	6	10	152	180	120	1920	4	360

Figure 16 *–Heat Exchanger Summary*

Hot Water Pumps											
Unit	Service	Type	GPM	Total Head (f.t. H_2O)	VFD	Emer. Power	Motor Data at 60 Hz				
							BHP	MHP	RPM	Volts	Phase
HWP-1	Hot Water Reheat	End Suction	600	75	Y	Y	13.6	20	1750	480	3
HWP-2	Hot Water Reheat (Stand-By)	End Suction	600	75	Y	Y	13.6	20	1750	480	3
HWP-3	Vivarium Reheat	End Suction	120	60	Y	Y	3	5	1780	480	3
HWP-4	Vivarium Reheat (Stand-By)	End Suction	120	60	Y	Y	3	5	1780	480	3

Figure 17 *–Hot Water Pump Summary*

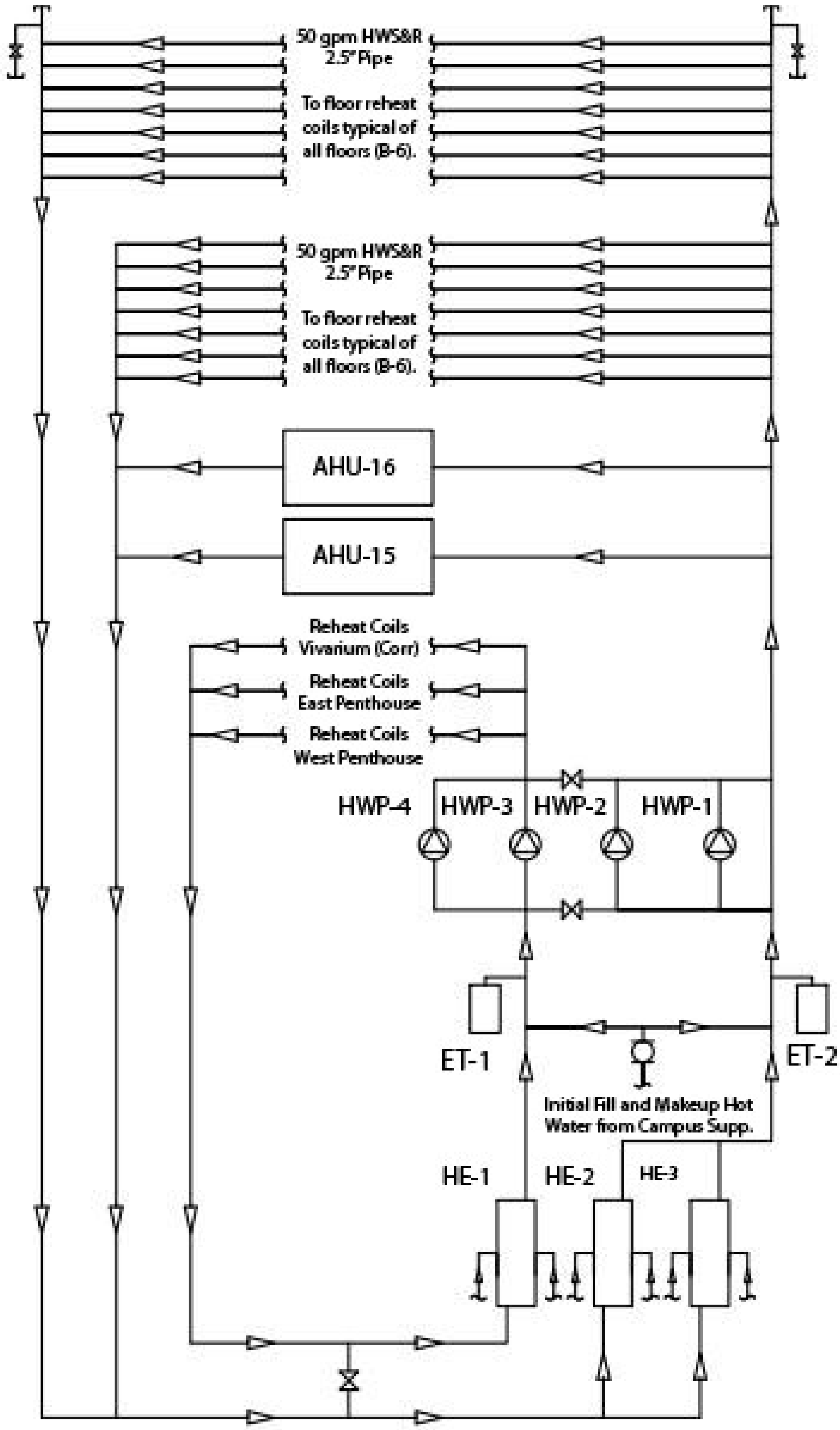

Figure 18 *–Hot Water Riser Diagram*

Mechanical System Initial Cost

The approximate initial cost for the Mechanical and Plumbing system of the project, as specified in the official estimate are as follows:

	Total GMP	Cost/GSF	Percent of Total Cost
Plumbing	$10,517,813	$ 26.16	5%
HVAC	$30,765,936	$ 82.16	14.70%
Automatic Temp. Controls	$ 6,708,200	$ 17.96	3.20%
Electrical	$18,327,265	$ 49.06	8.80%

***Figure 19** –Initial Cost of Mechanical System*

The HVAC and Automatic Temperature Controls total to **$37,474,136**, which equates to **$100.12/square foot** and accounts for **18%** of the total construction cost. If you include plumbing it raises to $47,991,949, roughly 22% of the total construction cost. Therefore, it is a significant portion of the total cost of the building.

Lost Usable Space

The mechanical systems designed for the Koch Institute very efficiently utilize the area allocated for them. With a penthouse dedicated to house all major mechanical systems and two strategically located mechanical shafts, the mechanical system does not encroach into usable space significantly. The use of chilled beam, fan coils and radiant panel heating reduced the size of fans while treating the spaces with very little mechanical space necessary. Also, with campus supply of steam, chilled water and electricity no usable space is lost to incorporate boilers, chillers or large generators.

Ventilation Requirements

In Technical Report I – "ASHRAE Standard 62.1 Ventilation and Standard 90.1 Energy Design Evaluations" an analysis for compliance with ASHRAE 62.1 was performed. In that report it was concluded on page 12 that:

"*The analysis of the design's compliance to ASHRAE Standard 62.1 was an overall success. The Standard is meant to ensure proper ventilation rates and acceptable indoor air quality. In this report, Sections 5 and 6 of the ASHRAE Standard made up the bulk of the analysis.*

Section 5 ensures that the systems and equipment are properly designed and located to achieve an acceptable indoor air quality. No areas of this section were found to be inadequate according to the requirements set forth by the ASHRAE Standard. In fact, many areas of the design went above and beyond, aiding in the goal of achieving LEED Gold Certification."

Heating and Cooling Loads

In Technical Report II – "Building and Plant Energy Analysis" a Trane Trace model was built and analyzed to estimate the heating and cooling loads on the building and project estimated consumption rates. Throughout this process the following table below in ***Figure 20*** was generated.

Estimated		Designed	% Difference
248,984	Floor Area	280,000	
352,298	cfm	400,000	
1,812	ton	2,464	
Cooling			
1.41	cfm/ft²	1.43	0.95
194.42	cfm/ton	162.34	-19.77
137.41	ft²/ton	113.64	-20.92

Figure 20 *–Estimated and Design Loads*

This table compares the estimated cooling loads with the designed cooling loads. Due to the complexity of the model and time restraints, the 7th level was not modeled, which would most likely account for the discrepancy between the values. It does not show the heating loads because they were determined to be significantly lower than cooling loads and therefore did not drive the design.

Energy – Consumption, Cost & Sources

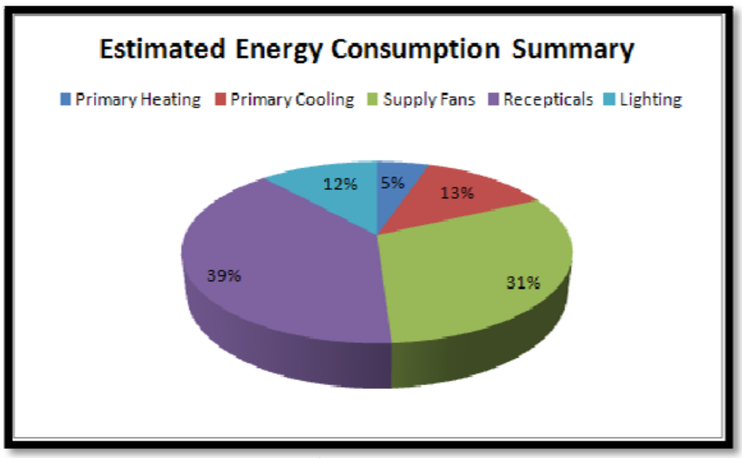

Figure 21 *–Estimated Energy Consumption Summary*

Figure 21 shows the breakdown of estimated energy consumption throughout the Koch Institute. A research facility of its magnitude is expected to have a high equipment load, which is modeled above as a 39% receptacle load. The 100% outdoor air cooling system is also anticipated to contribute to large cooling loads due to the energy consumed during dehumidification in summer months.

The Supply Fans and Primary Cooling load fractions make up the total cooling load for the cooling system. This represents 44% of the total building energy consumption which is high, yet the heat pipe system was not modeled. This preconditioning of the outdoor airstream would reduce this load significantly.

MIT's cogeneration plant utilizes a 25MW Combustion Turbine Generator. This generator provides 80% of the electricity consumed by the campus. The turbine runs on Natural Gas purchased from NSTAR based on a large commercial service rate (G-43). The electrical service to the building comes through a 15KV rated existing manhole.

To estimate the energy cost incurred on the University the monthly energy consumption was exported from TRACE. Electric energy consumption was converted from kWh to Therms and added to the Purchased Steam. The estimated total yearly energy consumption is roughly $460,000. No utility bills are available yet because the building is not yet operable so a baseline consumption cost is not yet known.

	Energy Cost Analysis - Utilizes MIT's 25MW Steam Turbine Generated Electricity Natural Gas Rates Based on Low Load Factor General Service - Large (G-43)								
	On-Peak Natural Gas $0.4571 per therm					Off-Peak Natural Gas $0.3241 per therm			
	Electric		Purchased Steam			Electric		Purchased Steam	
	kWh	Therms	Therms			kWh	Therms	Therms	
January	804,336	34,305	7.00	$ 15,683.98	January	1,087,260	46,372	339.00	$ 21,351.43
February	725,369	30,937	148.00	$ 14,208.95	February	934,579	39,860	785.00	$ 18,578.74
March	894,152	38,136	0.00	$ 17,431.77	March	1,022,659	43,616	0.00	$ 19,937.06
April	793,222	33,831	0.00	$ 15,464.11	April	1,092,452	46,593	0.00	$ 21,297.70
May	903,845	38,549	0.00	$ 17,620.74	May	1,104,994	47,128	0.00	$ 21,542.21
June	962,544	41,053	0.00	$ 18,765.10	June	1,088,359	46,419	0.00	$ 21,217.90
July	894,085	38,133	0.00	$ 17,430.47	July	1,291,034	55,063	0.00	$ 25,169.11
August	1,018,389	43,434	0.00	$ 19,853.81	August	1,128,107	48,114	0.00	$ 21,992.80
September	831,319	35,456	0.00	$ 16,206.83	September	1,135,509	48,429	0.00	$ 22,137.11
October	898,652	38,328	0.00	$ 17,519.50	October	1,101,999	47,000	0.00	$ 21,483.82
November	830,615	35,426	0.00	$ 16,193.10	November	1,053,594	44,936	0.00	$ 20,540.15
December	760,308	32,427	25.00	$ 14,833.87	December	1,118,783	47,716	609.00	$ 22,089.40
			On-Peak Total	$201,212.25				Off-Peak Total	$257,337.42

Note: Therm=kWh*0.03412 conversion was utilized as well as an efficiency of 80% was assumed for the steam turbine

Figure 22 *– Energy Cost Analysis Table*

Energy Cost Breakdown		
End User	**Yearly Cost of Operation**	**$/ft²**
Primary Heating	$ 23,844.58	0.066
Primary Cooling	$ 58,235.81	0.162
Supply Fans	$ 142,608.95	0.396
Recepticals	$ 180,210.02	0.501
Lighting	$ 53,650.31	0.149
Building Total	$ 458,549.66	**1.274**

Figure 23 *– Energy Cost Breakdown*

In ***Figure 23*** to the left, the total estimated yearly consumption cost is broken down into categories. This breakdown applies an estimated annual cost to each system making it quite clear where the owner's money will be going to operate the building in the future.

LEED NC Discussion

The Koch Institute has been designed with the intent of achieving LEED Gold Certification. With a projected total of 42 total credits out of a possible 69, the Koch Institute is on track to achieve this goal. A brief breakdown of these 42 LEED Credits is shown below which shows what areas they were received in.

Sustainable Sites	**9 credits**
Water Efficiency	**3 credits**
Energy and Atmosphere	**8 credits**
Materials and Resources	**6 credits**
Indoor Environmental Quality	**11 credits**
Innovation & Design Process	**5 credits**

Of these categories, the credits that related to the HVAC system directly are found in the *Energy and Atmosphere* and *Indoor Environmental Quality*. Therefore, a more in depth view of these sections and the credits achieved is shown below. A full LEED NC Checklist can also be found in the Appendix of this report.

Energy & Atmosphere		
Yes	No	LEED NC Credit Description
6		Optimize Energy Performance
	3	On-Site Renewable Energy
1		Enhanced Commissioning
1		Enhanced Refrigerant Management
	1	Measurements & Verification
	1	Green Power

Figure 24 *– Energy and Atmosphere LEED Credits*

Indoor Environmental Quality		
Yes	No	LEED NC Credit Description
1		Outdoor Air Delivery Monitoring
1		Increased Ventilation
1		Construction IAQ Management Plan (During Const.)
1		Construction IAQ Management Plan (Before Occup.)
1		Low Emitting Materials (Adhesives & Sealants)
1		Low Emitting Materials (Paints and Coatings)
1		Low Emitting Materials (Carpet Systems)
1		Low Emitting Materials (Composit Wood & Agrifiber Products)
1		Indoor Chemical & Pollutant Source Control
	1	Controllabitlity of Systems (Lighting)
	1	Controllabitlity of Systems (Thermal Confort)
1		Thermal Comfort (Design)
1		Thermal Comfort (Verification)
	1	Daylight and Views (Daylight 75% of Spaces)
	1	Daylight and Views (Views from 90% of Spaces)

Figure 25 *– Indoor Environmental Quality LEED Credits*

Evaluation of System

The Koch Institutes original program presented to the mechanical design engineers contained a number of challenges and high expectations. As a result, the systems designed for MIT's new Integrative Cancer Research Lab are extremely sophisticated and have exceeded all expectations. The air and water systems in the building are efficient and have been designed with the future in mind.

Air System

To meet all internal ventilation requirements and indoor air quality requirements, a nearly 100% outdoor air ventilation/cooling system was necessary for the design. With this type of system in the

Boston, MA climate, a large amount of energy is needed to dehumidify and cool the incoming airstream in summer months. The decision to use factory built-up AHU and EAHU's allowed for an efficient heat pipe heat recovery system to be employed, making it possible to precondition the incoming supply airstream, reducing the load on each air handler.

Also, by utilizing some supplemental systems (i.e. chilled beam induction units, fan coil units and radiant panel heating) in high load areas, the main air handlers could all be equally sized. By having ten identical AHU's, future operators of the building only must familiarize themselves with that particular AHU. This can be a very large advantage with operation as well as future maintenance costs.

Chilled/Hot Water System

The chilled and hot water systems designed for the Koch Institute are both efficient and effective. The chilled water utilizes the campus supply of chilled water along with a single 200 tons of redundancy built in for the vivarium spaces. The hot water follows this strategy by utilizing campus supplied steam to produce hot water through shell and tube heat exchangers, maintaining the vivarium as a separate system to assure redundancy. Both systems provide ample supply to meet design loads and do so in an organized, well planned manner.

LEED NC Design

This project is projected to be awarded LEED Gold Certification after gaining 42 credits on the LEED NC 2.2 checklist. The design provides the building an energy efficient solution to HVAC and is designed to create a comfortable environment for the occupants. This project does not in fact utilize on-site renewable energy or green power, which is most likely due to initial cost restraints. It is possible however that if properly applied to the project, renewable technologies can create enough energy to achieve a reasonable payback period for the owner. In conclusion, the MEP design engineers at BR+A have succeeded in creating an innovative mechanical system that meets the needs of the owner and does so efficiently. It is possible however, that improvements can be made and different design approaches can be taken, which I hope to show in the reports to follow.

List of Figures

APPENDIX A

Supplemental Tables

LEED for New Construction v2.2
Registered Project Checklist

Project Name: MIT KIICR CD Set
Project Address: Cambridge, MA
Date: August 19, 2008

Project Score Gold

Yes	?	No			
9	0	5		**Sustainable Sites**	**14 Points**
Y			Prereq 1	**Construction Activity Pollution Prevention**	Required
1			Credit 1	**Site Selection**	1
1			Credit 2	**Development Density & Community Connectivity**	1
1			Credit 3	**Brownfield Redevelopment**	1
1			Credit 4.1	**Alternative Transportation,** Public Transportation Access	1
1			Credit 4.2	**Alternative Transportation,** Bicycle Storage & Changing Rooms	1
1			Credit 4.3	**Alternative Transportation,** Low-Emitting & Fuel-Efficient Vehicles	1
1			Credit 4.4	**Alternative Transportation,** Parking Capacity	1
		1	Credit 5.1	**Site Development,** Protect or Restore Habitat	1
1			Credit 5.2	**Site Development,** Maximize Open Space	1
		1	Credit 6.1	**Stormwater Design,** Quantity Control	1
		1	Credit 6.2	**Stormwater Design,** Quality Control	1
		1	Credit 7.1	**Heat Island Effect,** Non-Roof	1
1			Credit 7.2	**Heat Island Effect,** Roof	1
		1	Credit 8	**Light Pollution Reduction**	1

Yes	?	No			
3	0	2		**Water Efficiency**	**5 Points**
1			Credit 1.1	**Water Efficient Landscaping,** Reduce by 50%	1
		1	Credit 1.2	**Water Efficient Landscaping,** No Potable Use or No Irrigation	1
		1	Credit 2	**Innovative Wastewater Technologies**	1
1			Credit 3.1	**Water Use Reduction, 20%** Reduction	1
1			Credit 3.2	**Water Use Reduction, 30%** Reduction	1

Yes	?	No				
8	0	9			**Energy & Atmosphere**	**17 Points**
Y			Prereq 1		**Fundamental Commissioning of the Building Energy Systems**	Required
Y			Prereq 2		**Minimum Energy Performance**	Required
Y			Prereq 3		**Fundamental Refrigerant Management**	Required
*Note for EAc1: All LEED for New Construction projects registered after June 26th, 2007 are required to achieve at least two (2) points under EAc1.						
6		4	Credit 1		**Optimize Energy Performance**	1 to 10
					10.5% New Buildings or 3.5% Existing Building Renovations	1
					14% New Buildings or 7% Existing Building Renovations	2
					17.5% New Buildings or 10.5% Existing Building Renovations	3
					21% New Buildings or 14% Existing Building Renovations	4
					24.5% New Buildings or 17.5% Existing Building Renovations	5
				6	28% New Buildings or 21% Existing Building Renovations	6
					31.5% New Buildings or 24.5% Existing Building Renovations	7
					35% New Buildings or 28% Existing Building Renovations	8
					38.5% New Buildings or 31.5% Existing Building Renovations	9
					42% New Buildings or 35% Existing Building Renovations	10
		3	Credit 2		**On-Site Renewable Energy**	1 to 3
					2.5% Renewable Energy	1
					7.5% Renewable Energy	2
					12.5% Renewable Energy	3
1			Credit 3		**Enhanced Commissioning**	1
1			Credit 4		**Enhanced Refrigerant Management**	1
		1	Credit 5		**Measurement & Verification**	1
		1	Credit 6		**Green Power**	1

continued…

Yes	?	No			
6	0	7		**Materials & Resources**	**13 Points**
Y			Prereq 1	**Storage & Collection of Recyclables**	Required
		1	Credit 1.1	**Building Reuse,** Maintain 75% of Existing Walls, Floors & Roof	1
		1	Credit 1.2	**Building Reuse,** Maintain 100% of Existing Walls, Floors & Roof	1
		1	Credit 1.3	**Building Reuse,** Maintain 50% of Interior Non-Structural Elements	1
1			Credit 2.1	**Construction Waste Management,** Divert 50% from Disposal	1
1			Credit 2.2	**Construction Waste Management,** Divert 75% from Disposal	1
		1	Credit 3.1	**Materials Reuse, 5%**	1
		1	Credit 3.2	**Materials Reuse,10%**	1
1			Credit 4.1	**Recycled Content, 10%** (post-consumer + ½ pre-consumer)	1
1			Credit 4.2	**Recycled Content, 20%** (post-consumer + ½ pre-consumer)	1
1			Credit 5.1	**Regional Materials, 10%** Extracted, Processed & Manufactured Regionally	1
		1	Credit 5.2	**Regional Materials, 20%** Extracted, Processed & Manufactured Regionally	1
		1	Credit 6	**Rapidly Renewable Materials**	1
1			Credit 7	**Certified Wood**	1

Yes	?	No			
11	0	4		**Indoor Environmental Quality**	**15 Points**
Y			Prereq 1	**Minimum IAQ Performance**	Required
Y			Prereq 2	**Environmental Tobacco Smoke (ETS) Control**	Required
1			Credit 1	**Outdoor Air Delivery Monitoring**	1
1			Credit 2	**Increased Ventilation**	1
1			Credit 3.1	**Construction IAQ Management Plan,** During Construction	1
1			Credit 3.2	**Construction IAQ Management Plan,** Before Occupancy	1
1			Credit 4.1	**Low-Emitting Materials,** Adhesives & Sealants	1
1			Credit 4.2	**Low-Emitting Materials,** Paints & Coatings	1
1			Credit 4.3	**Low-Emitting Materials,** Carpet Systems	1
1			Credit 4.4	**Low-Emitting Materials,** Composite Wood & Agrifiber Products	1
1			Credit 5	**Indoor Chemical & Pollutant Source Control**	1
		1	Credit 6.1	**Controllability of Systems,** Lighting	1
		1	Credit 6.2	**Controllability of Systems,** Thermal Comfort	1
1			Credit 7.1	**Thermal Comfort,** Design	1
1			Credit 7.2	**Thermal Comfort,** Verification	1
		1	Credit 8.1	**Daylight & Views,** Daylight 75% of Spaces	1
		1	Credit 8.2	**Daylight & Views,** Views for 90% of Spaces	1

Yes	?	No			
5	0	0		**Innovation & Design Process**	**5 Points**
1			Credit 1.1	**Innovation in Design:** Chemical Handling	1
1			Credit 1.2	**Innovation in Design:** ASHRAE 110 Fume Hood Comissioning	1
1			Credit 1.3	**Innovation in Design:** Process Water Use Reduction	1
1			Credit 1.4	**Innovation in Design:** Provide Specific Title	1
1			Credit 2	**LEED® Accredited Professional**	1

Yes	?	No		
42	0	27	**Project Totals (pre-certification estimates)**	**69 Points**

Certified: 26-32 points, Silver: 33-38 points, Gold: 39-51 points, Platinum: 52-69 points