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David H. Koch Institute for Integrative Cancer Research

Massachusetts Institute of Technology

Cambridge, Ma

Bryan Donovan

Project Team

Owner	*Massachusetts Institute of Technology*
Architect	*Ellenzweig Architecture*
MEP Engineer	*Bard, Rao + Athanas Engineers, LLC*
Structural Engineer	*LeMessurier Consultants, Inc.*
Lighting Consultant	*Lam Partners, Inc.*
Plumbing/Fire Protection/Codes	*R.W. Sullivan Engineering*
Civil Engineer	*Nitsch Engineering, Inc.*
LEED/Sustainable Design	*The Green Engineer, LLP*
Landscape Architect	*Reed Hilderbrand Associates, Inc.*
Telecommunications	*Communications Design Group, Inc.*

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Project Site

- MIT Campus in Cambridge, Ma
- Parallel to Main Street
- Design provides a new quad for Campus

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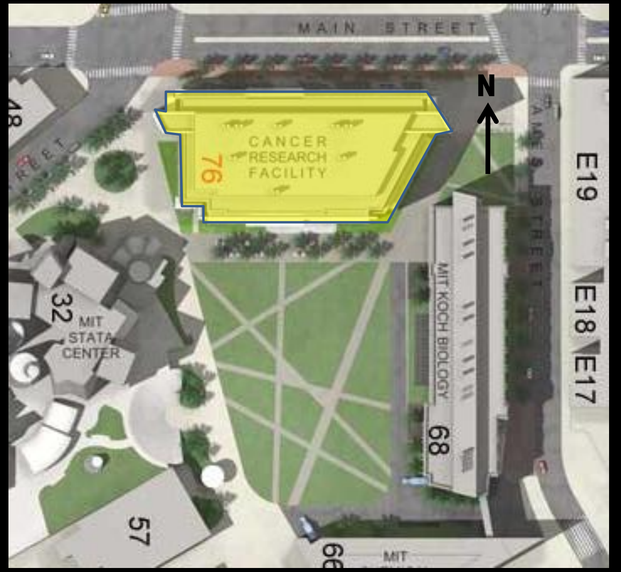

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Project Site

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Architectural Features

- 360,000 GSF $190 million
- 7 Stories, Penthouse & Basement
- Transparent glass curtain wall facades
- Solar Shading on South Facade

Project Overview

North Facade

South Facade

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- Levels B-1 – Administrative Offices and Meeting Facilities
- Levels 2-6 – Research and Core Laboratories, Classrooms
- Level 7 - Vivarium

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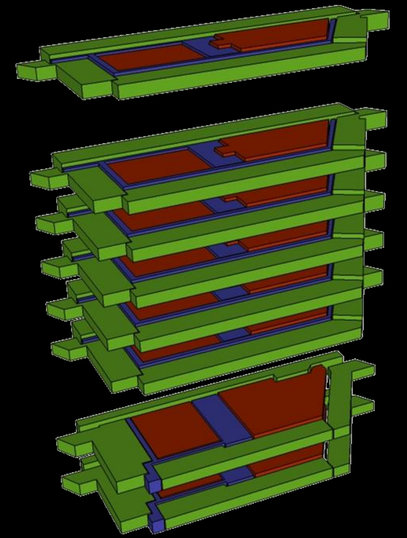

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Project Goals

- House both Engineers and Cancer Biologists
- Achieve LEED Gold Certification

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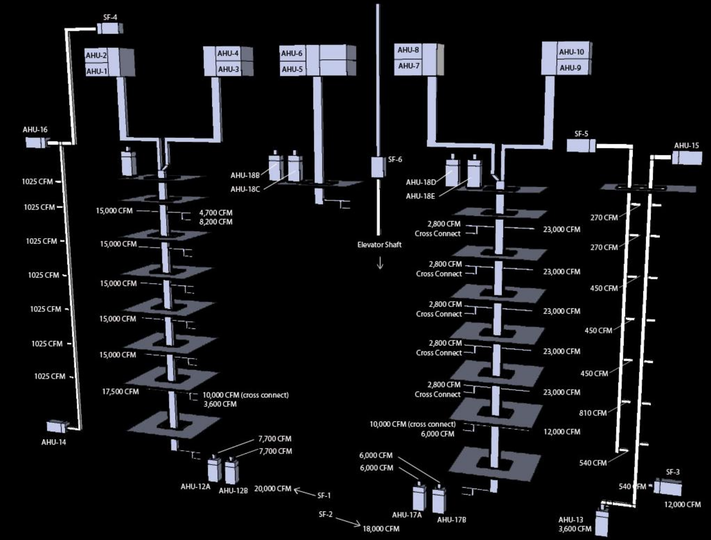
Existing Mechanical Systems

Air Supply

- 100% OA VAV Ventilation/Cooling System
- (10) 50,000 CFM Factory Built-Up AHU's
- (13) Packaged Modular AHU's

Existing Mechanical Systems



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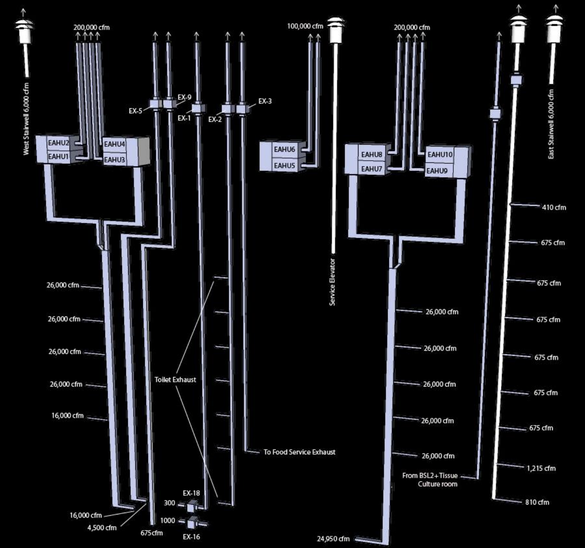
Air Exhaust

- (10) 50,000 CFM Factory Built-Up EAHU's
- Heat Pipe Heat Recovery Between Airstreams
- (18) Individual Exhaust Fans

Existing Mechanical Systems



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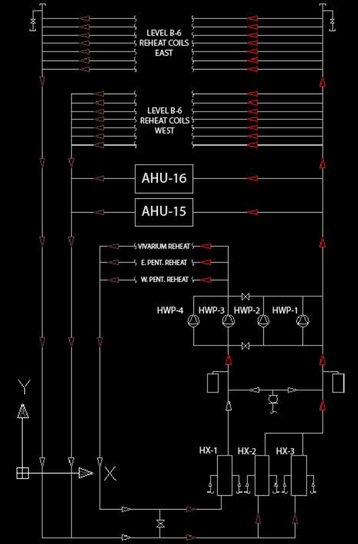
Hot Water

- 3 Heat Exchangers supply 180°F from LPS
- 4 Hot Water Pumps distribute the water
- Vivarium has a separate loop for redundancy

Existing Mechanical Systems



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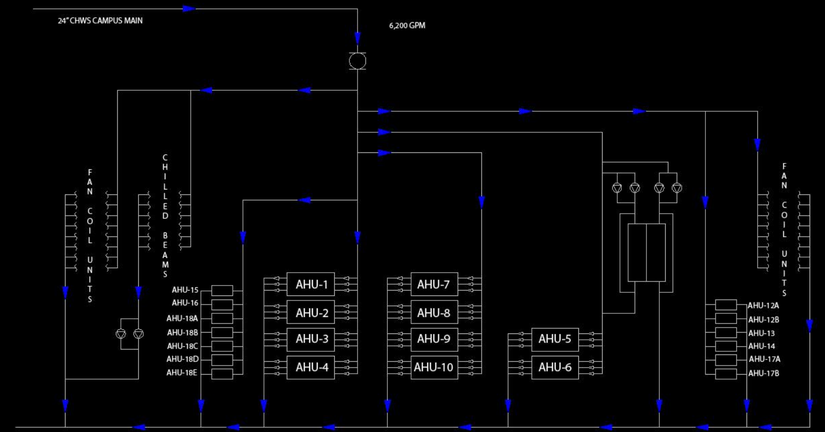
Hot Water

- 3 Heat Exchangers supply 180°F from LPS
- 4 Hot Water Pumps distribute the water
- Vivarium has a separate loop for redundancy

Chilled Water

- 6,200 gpm 43°F CHW Supply from 24" Campus Loop
- Distributed between AHU's, FCU's & Chilled Beam
- 200 ton Water Cooled Rotary Screw Chiller (Vivarium)

Existing Mechanical Systems



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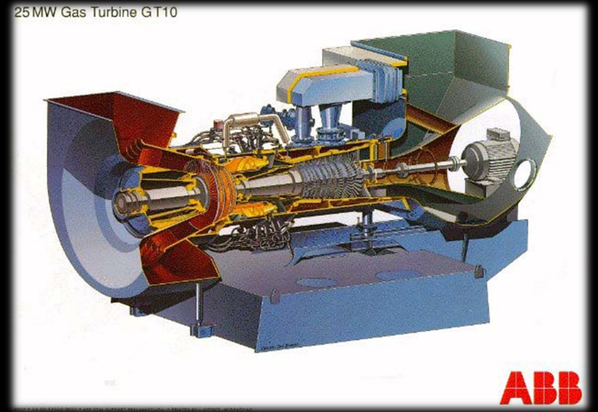
Existing Mechanical Systems

Cogeneration Plant

- ABB GT10A Combustion Generator Set
- 21 MW – Nominal Electrical Output
- 56 MW – Nominal Thermal Output
- Produces Steam for:
  - Campus Supply
  - Absorption Chillers

Existing Mechanical Systems



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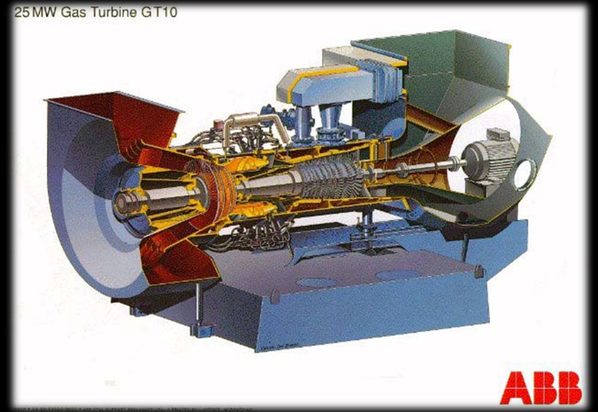
Utility Rates

- Natural Gas - $ 0.9861/therm
- Electricity - $ 0.00429/kWh

Existing Mechanical Systems



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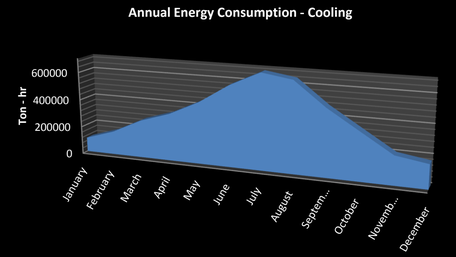
Existing Design Loads

Peak Cooling Load

- 2,746 ton peak cooling load

Existing Design Loads

	Peak Cooling Load
	Tons
Level 2-7 Laboratory	2,114
Intense Load Areas	440
Penthouse/Stairs/Equip. Rms	160
Level 1 Offices	32
	2,746



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Existing Design Loads

Peak Cooling Load

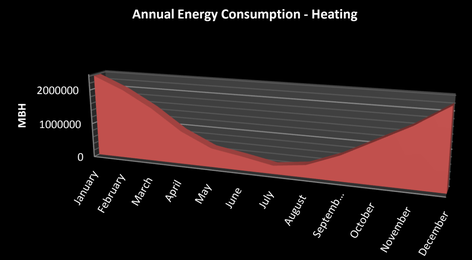
- 2,746 ton peak cooling load

Peak Heating Load

- 9,588 MBH peak heating load

Existing Design Loads

	Peak Heating Load
	MBH
Building Heat Loss	1,528
Level B-6 Reheat	3,927
Level 7 Reheat	1,122
Hood Makeup Reheat	1,010
Level 1 Unit Heaters	400
Basement Unit Heaters	350
	9,588



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Existing Design Loads

Peak Cooling Load

- 2,746 ton peak cooling load

Peak Heating Load

- 9,588 MBH peak heating load

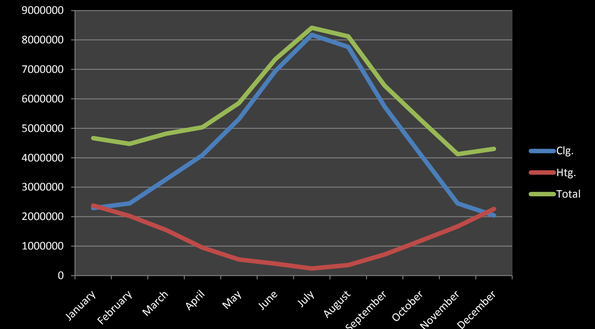
Annual Energy Consumption

- Heating – 26.6 BTUh/ft^2
- Cooling – 131 ft^2/ton

- $19,600 /year HEATING
- $830,000 /year COOLING

- **$860,000/year**

Existing Design Loads



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Redesign Goals & Objectives

Overall Goals

- Add renewable energy sources to the project
- Reduce the load on the Cogeneration Plant
- Increase Efficiency of Packaged AHU's

Redesign Goals & Objectives

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- Utilize Recovered Energy to heat the stair shafts

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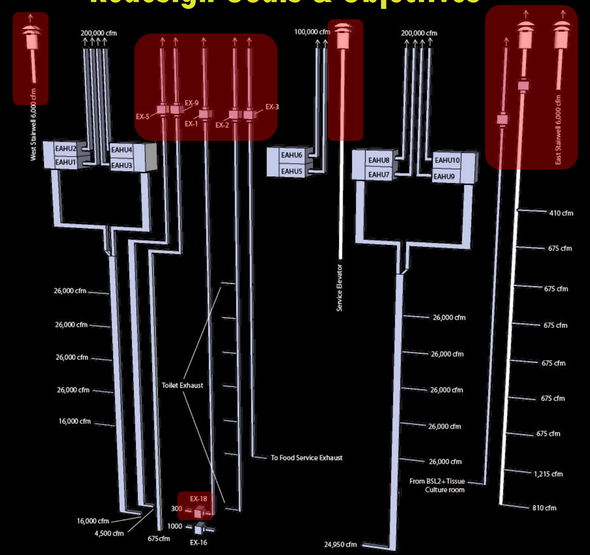

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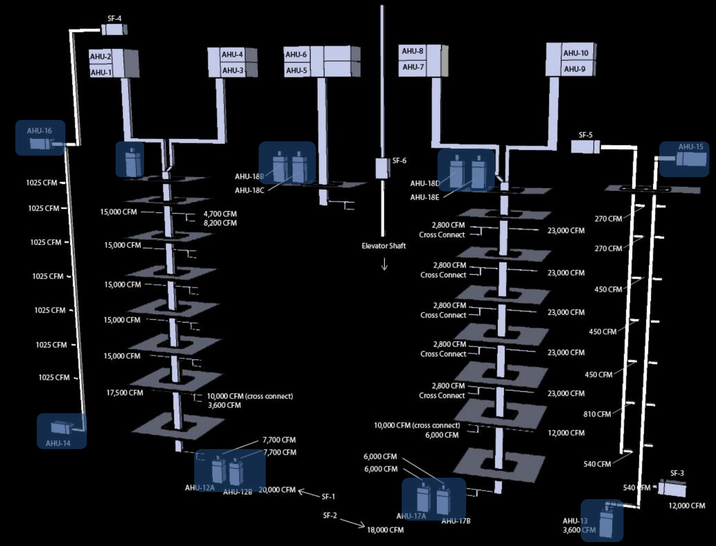
Ground Source Heat Pump Objectives

- Provide CHW to Packaged AHU's,
- Size system to fit in quad adjacent to building

Redesign Goals & Objectives



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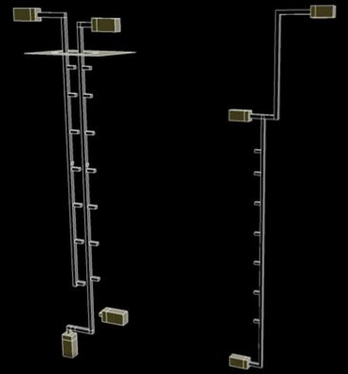
Mechanical Depth – Run Around Heat Recovery

Available Airstreams

- 12 Exhaust Airstreams
- Ducted to roof through the penthouse
- Targeted stair shafts



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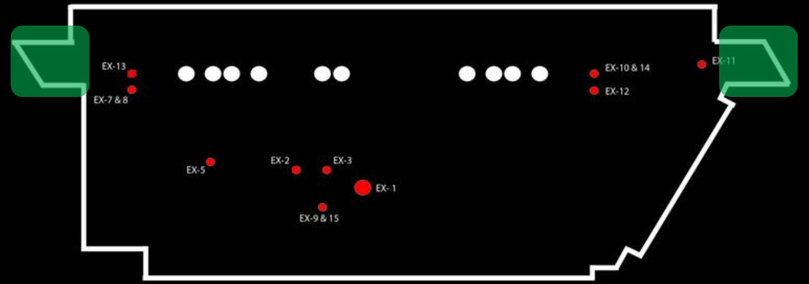

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Recoverable Energy

- 49,150 CFM Total
- Unknown Temps – Conservatively Assume 72°F
- Differing Coil Configurations compared to reduce ΔP

Mechanical Depth – Run Around Heat Recovery

	Recoverable Energy Comparison (Differing Coil Effectiveness)									
	cfm	Exh.Temp Pre-Coil °F	40% Effective		50% Effective		60% Effective		70% Effective	
			Exh.Temp Post-Coil °F	MBH Recovered	Exh.Temp Post-Coil °F	MBH Recovered	Exh.Temp Post-Coil °F	MBH Recovered	Exh.Temp Post-Coil °F	MBH Recovered
EX-1	20000	72	43	622	36	778	29	933	22	1,089
EX-2	8000	72	43	249	36	311	29	373	22	435
EX-3	3900	72	43	121	36	152	29	182	22	212
EX-5	1500	180	108	117	90	146	72	175	54	204
EX-7	1800	180	108	140	90	175	72	210	54	245
EX-8	1800	180	108	140	90	175	72	210	54	245
EX-9	675	72	43	21	36	26	29	31	22	37
EX-10	1800	72	43	56	36	70	29	84	22	98
EX-11	6000	72	43	187	36	233	29	280	22	327
EX-12	2400	72	43	75	36	93	29	112	22	131
EX-13	800	72	43	25	36	31	29	37	22	44
EX-14	475	72	43	15	36	18	29	22	22	26
				1,767		2,208		2,650		3,092

	MBH
40% Effective Coil	1,767
50% Effective Coil	2,208
60% Effective Coil	2,650
70% Effective Coil	3,092

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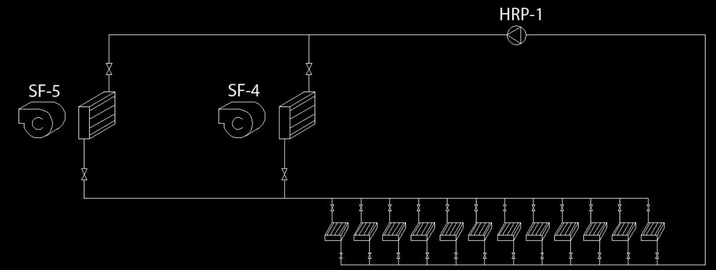
Loop Configuration

- 12 Exhaust Airstreams with Heat Recovery Coils
- Added Pre-heat Coils to Existing SF-4 & 5
- 3 HP Loop Pump Added

Mechanical Depth – Run Around Heat Recovery



Heat Recovery Pumps

Unit	Manufact.	Frame Size	Service	Type	GPM	Total Head (f.t. H_20)	VFD	Emer. Power	Min Casing Size Disc x Inlet x Impel.	Motor Data at 60 Hz			
										HP	RPM	Volts	Phase
HRP-1	Bell & Goss.	182T	HE-4	End Suction	100	60	Y	Y	1.5"x2"x8"	3	1750	480	3

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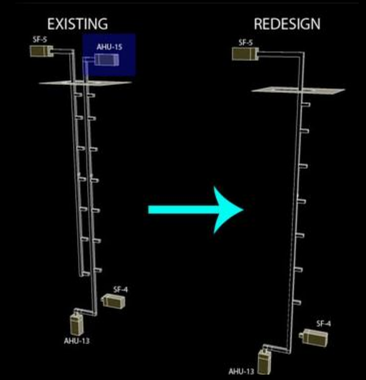
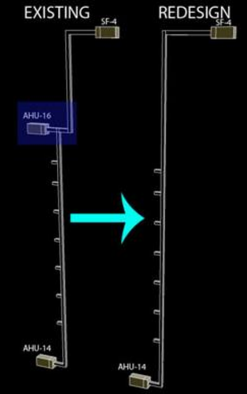
Airside Redesign

- Removal of (2) 3,600 CFM AHU's
- Removal of Ductwork

Mechanical Depth – Run Around Heat Recovery



East Stair Shaft



West Stair Shaft

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Mechanical Depth – Run Around Heat Recovery

Added Equipment Cost

- $18,843

Removed Equipment Cost

- $14,700

Annual Energy Saved

- 400 MBH
- $953/year

Estimated Payback

- 4.3 Years

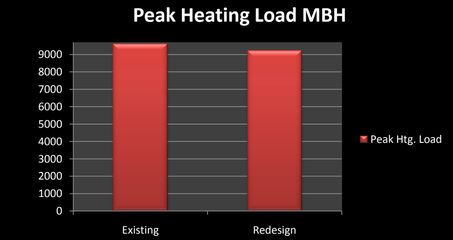
Mechanical Depth – Run Around Heat Recovery

Heat Recovery System Cost & Payback Calculations

Cost Incurred	
HRP-1	$2,593
Coils	$6,000
Piping	$10,250
	$18,843

Cost Averted	
AHU-14	$6,350
AHU-15	$6,350
Ductwork	$2,000
	$14,700

Total Cost	$4,143
Annual Savings	$965
Payback (years)	4.29



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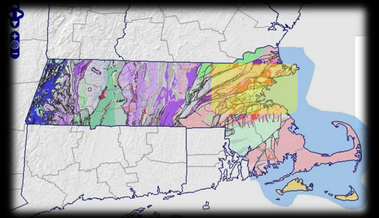
Mechanical Depth – Ground Source Heat Pump

Site Geology

- USGS State Geological Maps
- Ground Temperature – 50°F

Mechanical Depth – Ground Source Heat Pump



Massachusetts

Cambridge Area

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Mechanical Depth – Ground Source Heat Pump

Site Geology

- USGS State Geological Maps
- Ground Temperature – 50°F

Required Bore Length Equation

- Three Heat Pulses – Annual, Monthly, Daily
- $T_{wi} = 60°F \quad T_{wo} = 52°F$
- 40,586 ft Required

Mechanical Depth – Ground Source Heat Pump

$$L_c = \frac{q_a \cdot R_{ga} + [q_{lc} - 3.142 \cdot W_c] \cdot [R_p + PLF_m \cdot R_{gm} + R_{gd} \cdot F_{sc}]}{t_g - \left[\frac{t_{wi} - t_{wo}}{2}\right] - t_p}$$

F_{sc}= *short circuit heat loss factor*
L_c= *required bore length for cooling, ft*
q_a= *net annual average heat transfer to ground, Btu/h*
q_{lc}= *building design cooling block load, Btu/h*
R_{ga}= *effective thermal resistance of ground (annual pulse), h-ft-°F/Btu*
R_{gd}= *effective thermal resistance of ground (daily pulse) , h-ft-°F/Btu*
R_{gm}= *effective thermal resistance of ground (monthly pulse) , h-ft-°F/Btu*
R_p= *thermal resistance of pipe and borehole, h-ft-°F/Btu*
t_g= *undistributed ground temperature, °F*
t_p= *temperature penalty for interference of adjacent bores, °F*
t_{wi}= *liquid temperature at heat pump inlet, °F*
t_{wo}= *liquid temperature at heat pump at outlet, °F*
W_c= *power input at design cooling load, Btu/h*
PLF_m= *part load factor during design month*

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Mechanical Depth – Ground Source Heat Pump

Site Geology

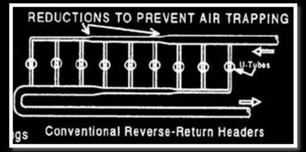
- USGS State Geological Maps
- Ground Temperature – 50°F

Required Bore Length Equation

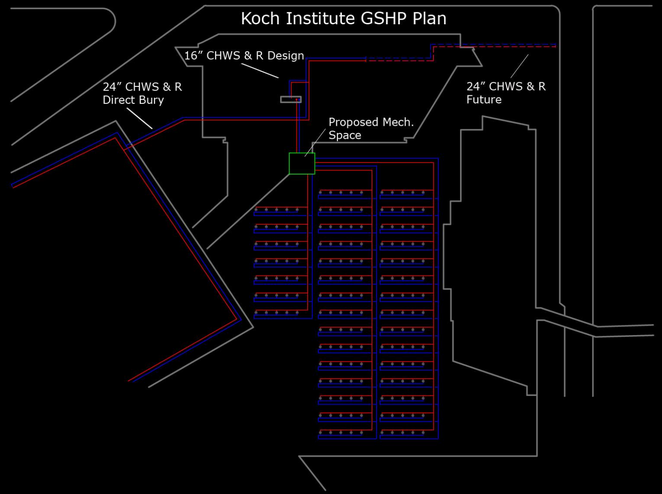
- Three Heat Pulses – Annual, Monthly, Daily
- T_{wi} = 60°F T_{wo} = 52°F
- 40,586 ft Required

System Layout

- 185 Bores @ 219 ft Depth
- (37) Sets of 5 Boreholes
- Reverse-Return Configuration



Mechanical Depth – Ground Source Heat Pump



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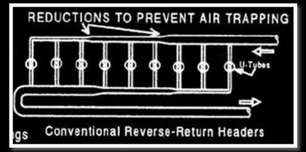
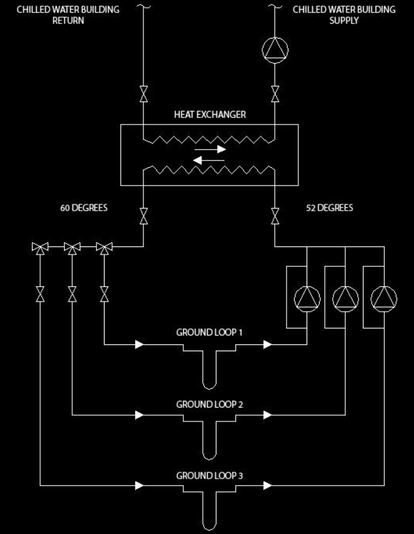


Loop Configuration

- 3 Individual Loops

Mechanical Depth – Ground Source Heat Pump



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Mechanical Depth – Ground Source Heat Pump

Pumps

- 3 Ground Loop Pumps
  - (2) – 200 gpm, 7.5 HP
  - (1) – 100 gpm, 3 HP
- 1 Chilled Water Pump
  - 500 gpm, 15 HP

Ground Chilled Water Pumps

Unit	Manufact.	Frame Size	Service	Type	GPM	Total Head (f.t. H_2O)	VFD	Emer. Power	Min Casing Size Disc x Inlet x Impel.	Motor Data at 60 Hz			
										HP	RPM	Volts	Phase
GCHWP-1	Bell & Goss.	213T	HE-4	End Suction	200	80	Y	Y	2"x2.5"x9.5"	7.5	1750	480	3
GCHWP-2	Bell & Goss.	213T	HE-4	End Suction	200	80	Y	Y	2"x2.5"x9.5"	7.5	1750	480	3
GCHWP-3	Bell & Goss.	182T	HE-4	End Suction	100	60	Y	Y	1.5"x2"x8"	3	1750	480	3

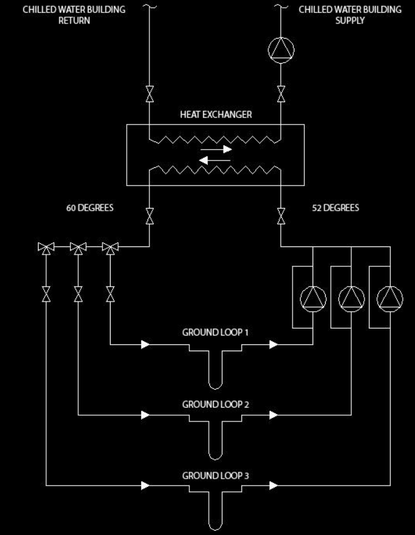
Assumptions

20% Ethylene Glycol based Water Solution with Specific Gravity @ 50 °F = 1.07 adjusting horsepowers accordingly

Chilled Water Pumps

Unit	Manufact.	Frame Size	Service	Type	GPM	Total Head (f.t. H_2O)	VFD	Emer. Power	Min Casing Size Disc x Inlet x Impel.	Motor Data at 60 Hz			
										HP	RPM	Volts	Phase
CHWP-3	Bell & Goss.	245T	HE-4	End Suction	500	80	Y	Y	4"x5"x9.5"	15	1750	480	3

Mechanical Depth – Ground Source Heat Pump



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Mechanical Depth – Ground Source Heat Pump

Added Equipment and Construction Cost

- $191,765

Annual Energy Saved

- Shaves 160 tons off Peak Cooling Load
- $86,651/year

Estimated Payback

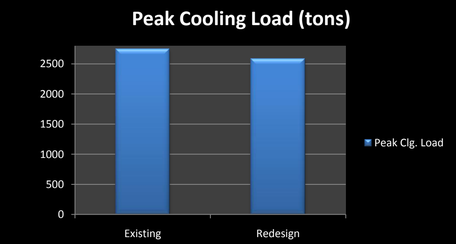
- 2.2 Years

Mechanical Depth – Ground Source Heat Pump

Ground Source Heat Pump Cost & Payback Calculations

Cost Incurred	
Drilling	$82,935
Piping	$51,223
Grouting	$8,900
Miscellaneous	$35,000
Pumps	$11,208
Heat Exchanger	$2,500

Total Cost	$191,765
Annual Savings	$86,651
Payback (years)	2.21



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Construction Management Breadth

Goals and Objectives

- Optimize the Construction of GSHP
- Determine Cost of GSHP

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Construction Management Breadth

Goals and Objectives

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- Determine Cost of GSHP

Estimation Assumptions

- Drilling Cost – *RS Means Mechanical Cost Data 2009*

	Daily Output (ft/day)	Rental ($/wk)
L_{bore}>325	900	16960
225≤ L_{bore}≤ 325	1200	14840
L_{bore}<225	1800	12190

- Piping Cost
  - $0.66/ft² – 1 ½" HDPE Pipe
  - $1.32/ft² – 3" HDPE Pipe
- Grouting Cost
  - $8,900 Based on Total Borehole Length
- Miscellaneous Cost
  - Increases w/ number of Boreholes

Construction Management Breadth

	L_{total}	Number of Bores	Bore Depth	day/ bore	days	weeks	Drilling Cost	Piping Cost	Grouting Cost	Misc Cost	Total Cost
L_{bore}>325	40586	80	507	0.564	50.056	10.01	$169,788	$50,639	$8,900	$24,500	**$253,827**
	40586	85	477	0.531	50.366	10.07	$170,840	$50,720	$8,900	$25,000	**$255,460**
	40586	90	451	0.501	50.676	10.14	$171,891	$50,802	$8,900	$25,500	**$257,093**
	40586	95	427	0.475	50.986	10.20	$172,943	$50,883	$8,900	$26,000	**$258,726**
	40586	100	406	0.451	51.296	10.26	$173,995	$50,965	$8,900	$26,500	**$260,359**
	40586	105	387	0.429	51.606	10.32	$175,046	$51,046	$8,900	$27,000	**$261,992**
	40586	110	369	0.410	51.916	10.38	$176,098	$51,128	$8,900	$27,500	**$263,625**
	40586	115	353	0.392	52.226	10.45	$177,149	$51,209	$8,900	$28,000	**$265,258**
	40586	120	338	0.376	52.536	10.51	$178,201	$51,291	$8,900	$28,500	**$266,891**

	L_{total}	Number of Bores	Bore Depth	day/ bore	days	weeks	Drilling Cost	Piping Cost	Grouting Cost	Misc Cost	Total Cost
225≤ L_{bore}≤ 325	40586	125	325	0.271	41.572	8.31	$123,385	$50,808	$8,900	$29,000	**$212,093**
	40586	130	312	0.260	41.882	8.38	$124,305	$50,890	$8,900	$29,500	**$213,595**
	40586	135	301	0.251	42.192	8.44	$125,225	$50,971	$8,900	$30,000	**$215,096**
	40586	140	290	0.242	42.502	8.50	$126,145	$51,053	$8,900	$30,500	**$216,598**
	40586	145	280	0.233	42.812	8.56	$127,065	$51,134	$8,900	$31,000	**$218,099**
	40586	150	271	0.225	43.122	8.62	$127,985	$51,216	$8,900	$31,500	**$219,601**
	40586	155	262	0.218	43.432	8.69	$128,905	$51,297	$8,900	$32,000	**$221,103**
	40586	160	254	0.211	43.742	8.75	$129,825	$51,379	$8,900	$32,500	**$222,604**
	40586	165	246	0.205	44.052	8.81	$130,745	$51,460	$8,900	$33,000	**$224,106**
	40586	170	239	0.199	44.362	8.87	$131,665	$51,542	$8,900	$33,500	**$225,607**
	40586	175	232	0.193	44.672	8.93	$132,586	$51,623	$8,900	$34,000	**$227,109**
	40586	180	225	0.188	44.982	9.00	$133,506	$51,705	$8,900	$34,500	**$228,610**

	L_{total}	Number of Bores	Bore Depth	day/ bore	days	weeks	Drilling Cost	Piping Cost	Grouting Cost	Misc Cost	Total Cost
L_{bore}<225	40586	185	219	0.122	34.018	6.80	$82,935	$51,223	$8,900	$35,000	**$178,058**
	40586	190	214	0.119	34.328	6.87	$83,691	$51,304	$8,900	$35,500	**$179,395**
	40586	195	208	0.116	34.638	6.93	$84,447	$51,386	$8,900	$36,000	**$180,733**
	40586	200	203	0.113	34.948	6.99	$85,203	$51,467	$8,900	$36,500	**$182,070**
	40586	205	198	0.110	35.258	7.05	$85,958	$51,549	$8,900	$37,000	**$183,407**
	40586	210	193	0.107	35.568	7.11	$86,714	$51,630	$8,900	$37,500	**$184,744**
	40586	215	189	0.105	35.878	7.18	$87,470	$51,712	$8,900	$38,000	**$186,082**
	40586	220	184	0.102	36.188	7.24	$88,226	$51,793	$8,900	$38,500	**$187,419**
	40586	225	180	0.100	36.498	7.30	$88,982	$51,875	$8,900	$39,000	**$188,756**

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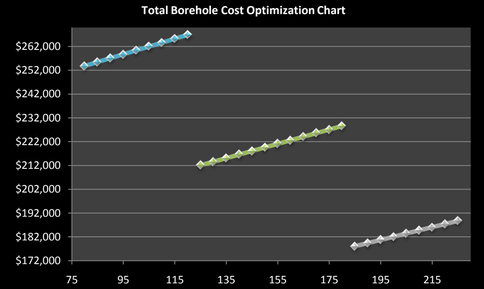
Construction Management Breadth

Results

- Optimum at 185 Boreholes @ Depths 219 ft
- Construction Duration – 7 weeks
- Total Construction Cost – $178,000
- Added Equipment Cost – $13,700

- System Cost - $191,700

Construction Management Breadth



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Electrical Breadth Overview

New Distribution Panel – D4B-1

- Serves 4 New Pumps
- 110A Breaker
- 225A Main Bus

Electrical Breadth Overview

VOLTAGE:	277/ 480	3 PHASE	4 WIRE	TOTAL WATTS L1	23,432	DESIGNATION D4B1	
MAIN BREAKER:	110A	FRAME 110A	TRIP: 110A	TOTAL WATTS L2	23,432		1 OF 1 TUBS
MAIN BUS:	225A	MOUNTING:		TOTAL WATTS L3	23,432	LOCATION:	BASEMENT
NOTE:				TOTAL WATTS	70,296		

DIRECTORY	WATTS LOAD L1	L2	L3	CKT.	AMPS	L1 L2 L3 Y Y Y	AMPS	CKT.	WATTS LOAD L1	L2	L3	DIRECTORY
GCHWP-1	2,740			1	20		50	2	15,694			CHWP-3
		2,740		3	20		50	4		15,694		
			2,740	5	20		50	6			15,694	
GCHWP-2	2,740			7	20		20	8				
		2,740		9	20		20	10				
			2,740	11	20		20	12				
GCHWP-3	1,129			13	20		20	14				
		1,129		15	20		20	16				
			1,129	17	20		20	18				
HRP-1	1,129			19	15		20	20				
		1,129		21	15		20	22				
			1,129	23	15		20	24				
				25	20		20	26				
				27	20		20	28				
				29	20		20	30				
				31	20		20	32				
				33	20		20	34				
				35	20		20	36				
				37	20		20	38				
				39	20		20	40				
				41	20		20	42				
SUBTOTAL	7,738	7,738	7,738						15,694	15,694	15,694	SUBTOTAL

RECEPTACLE LOADS:	0	W
EQUIPMENT LOADS:	70,296	W
LIGHTING LOADS:	0	W
DEMAND LOADS:	70,296	W

TOTAL AMPS x 125%= 105.8 AMPS

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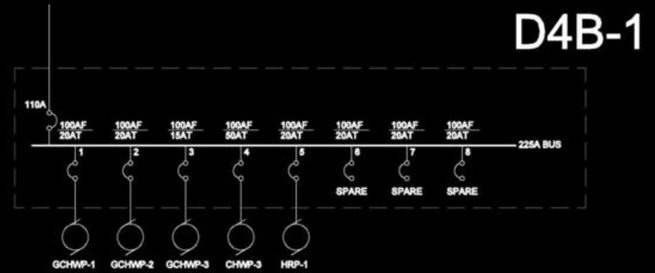
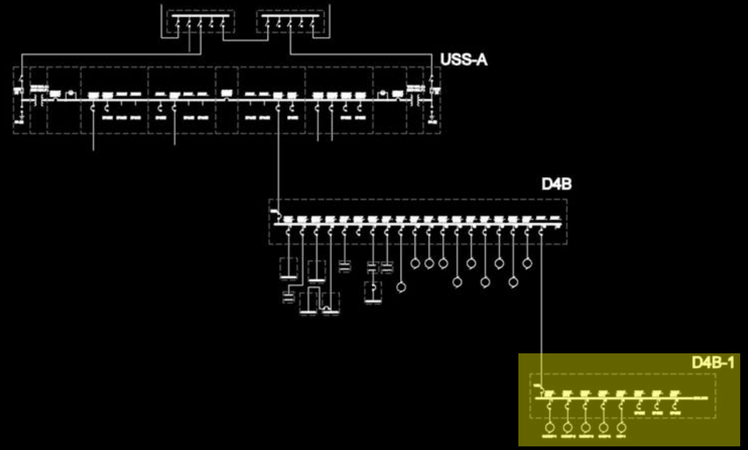
Integration into System

- Tied into D4B



Electrical Breadth Overview



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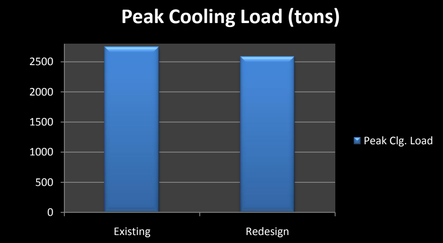
Summary

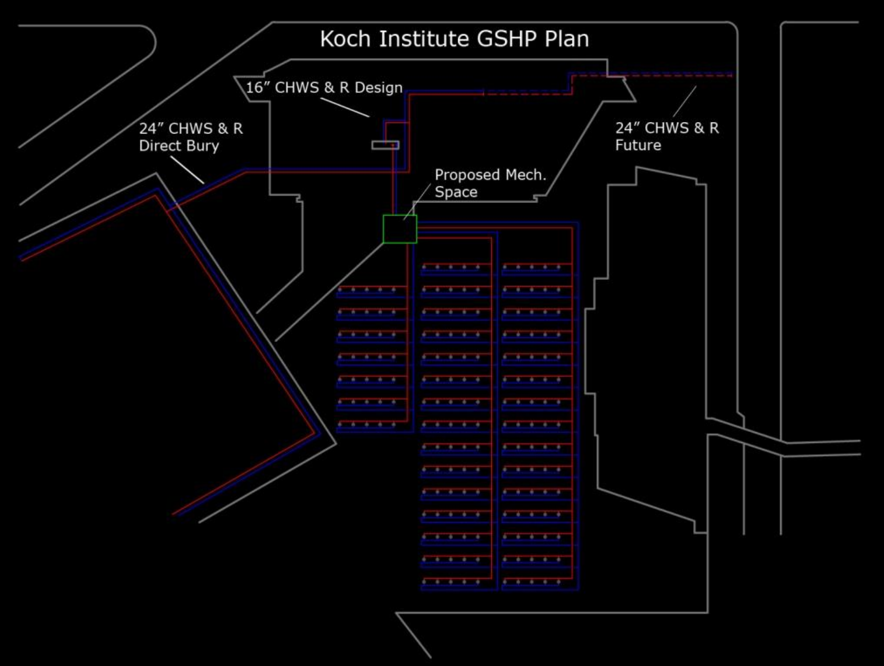
- Both Reasonable Paybacks
- Renewable Energy Added to Project
- Reductions on Cogeneration Plant
  - 400 MBH $965/year
  - 160 Ton $87,000/year

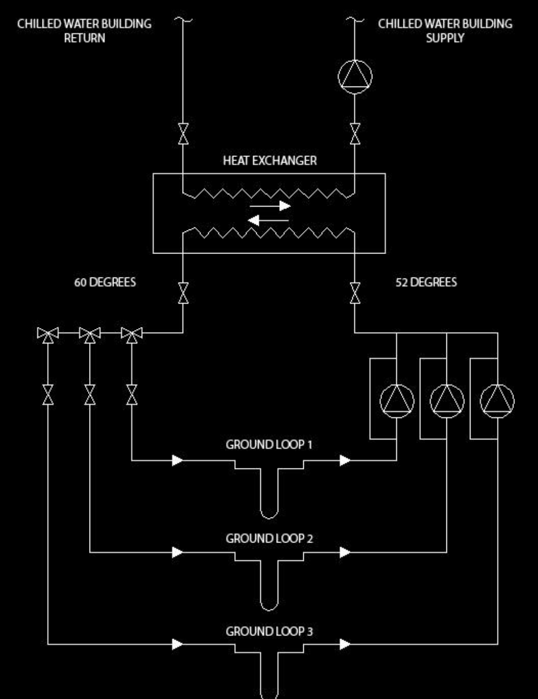
Conclusions

- Ground Source Heat Pump = WORTHWHILE
- Heat Recovery = NEED MORE APPLICATION
  - Up to 3000 MBH Recoverable
  - Only 400 MBH Needed for Stairs

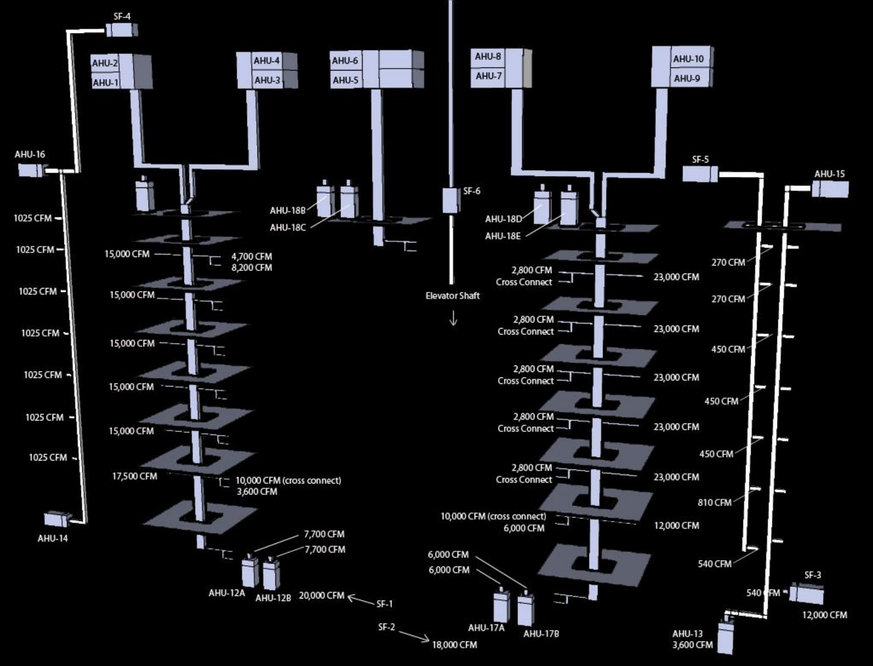
Presentation Outline

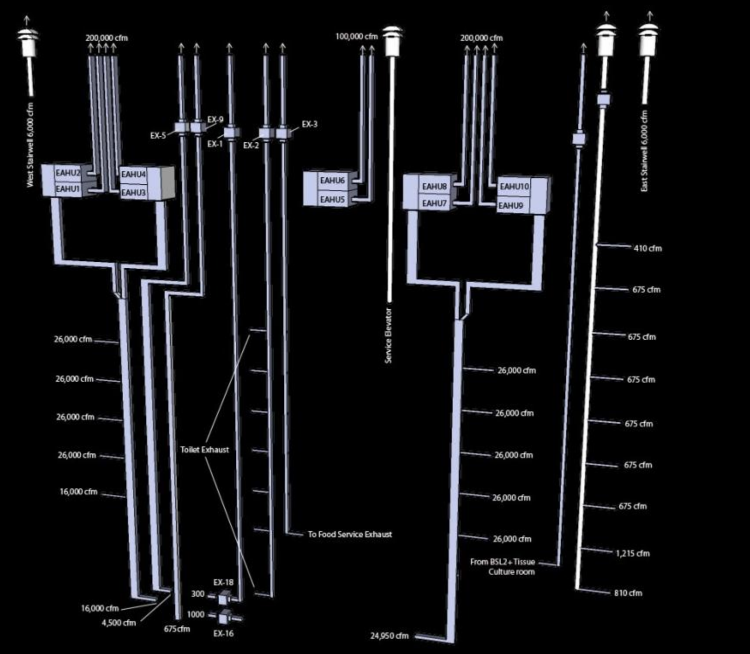


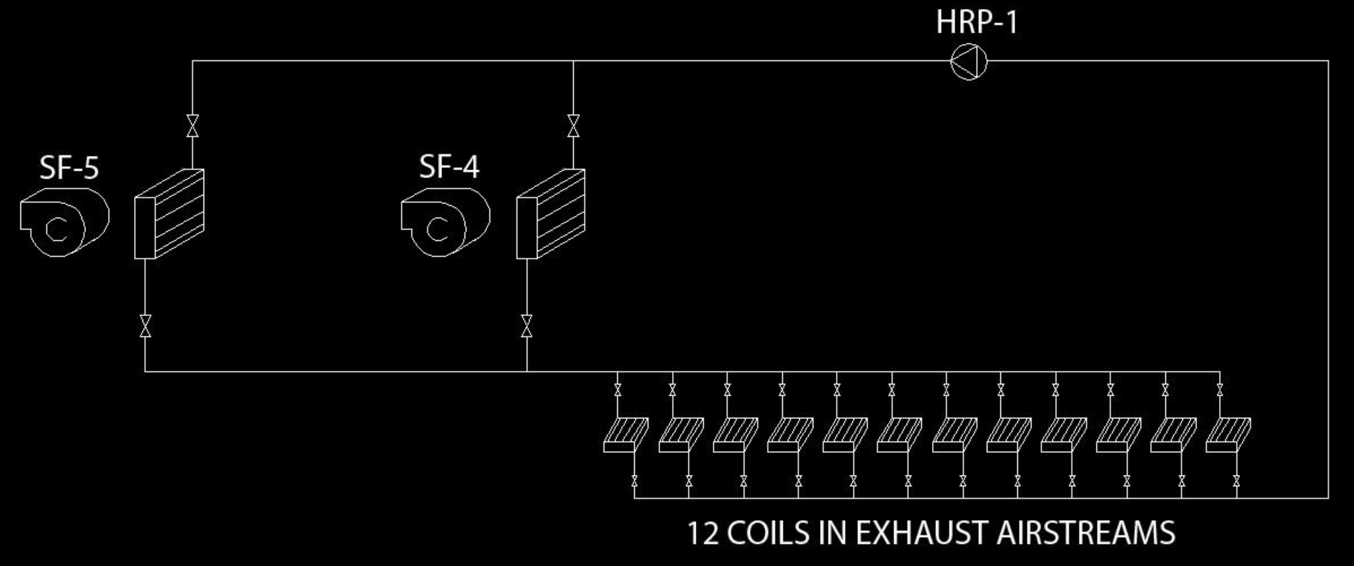

Koch Institute GSHP Plan
16" CHWS & R Design
24" CHWS & R
Direct Bury
Proposed Mech.
Space
24" CHWS & R
Future

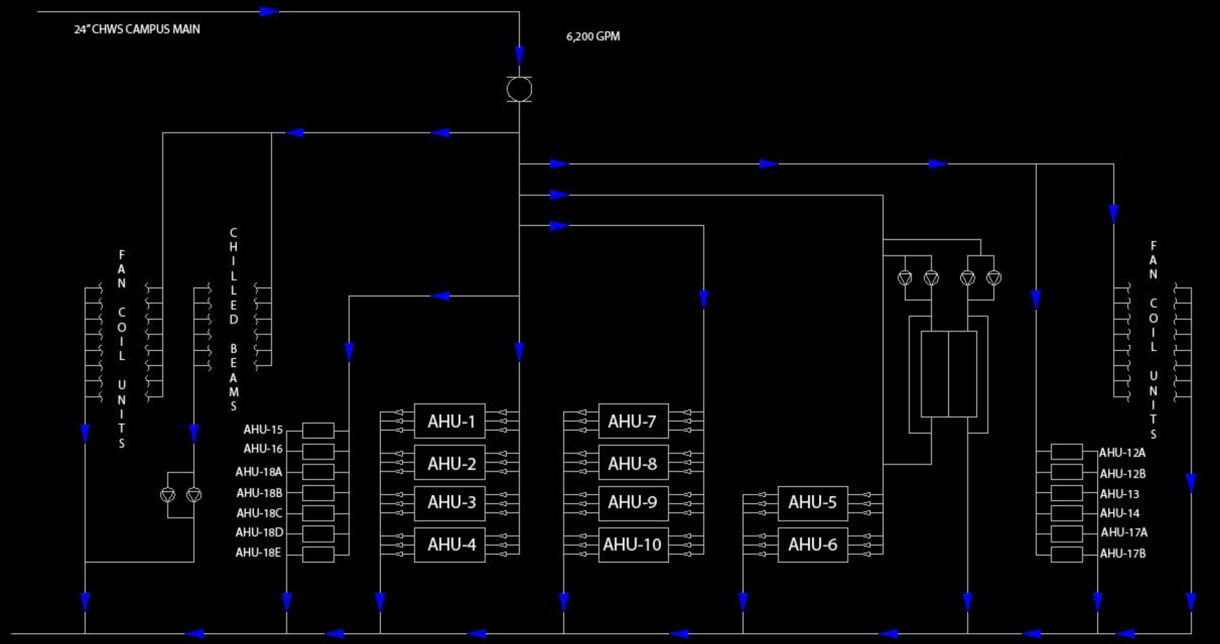

CHILLED WATER BUILDING RETURN
CHILLED WATER BUILDING SUPPLY
HEAT EXCHANGER
60 DEGREES
52 DEGREES
GROUND LOOP 1
GROUND LOOP 2
GROUND LOOP 3

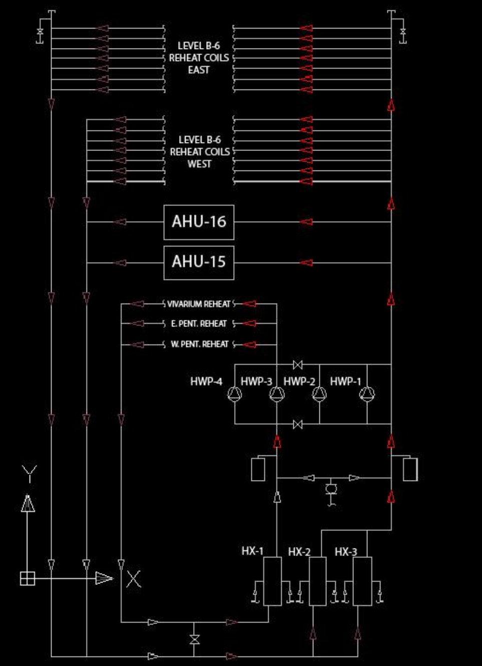
QUESTIONS






HRP-1
SF-5
SF-4
12 COILS IN EXHAUST AIRSTREAMS


24" CHWS CAMPUS MAIN
6,200 GPM
AHU-1
AHU-2
AHU-3
AHU-4
AHU-7
AHU-8
AHU-9
AHU-10
AHU-5
AHU-6


AHU-16
AHU-15