mattise senior thesis

nicholas w. mattise | mechanical option

thesis final presentation | april 15, 2014

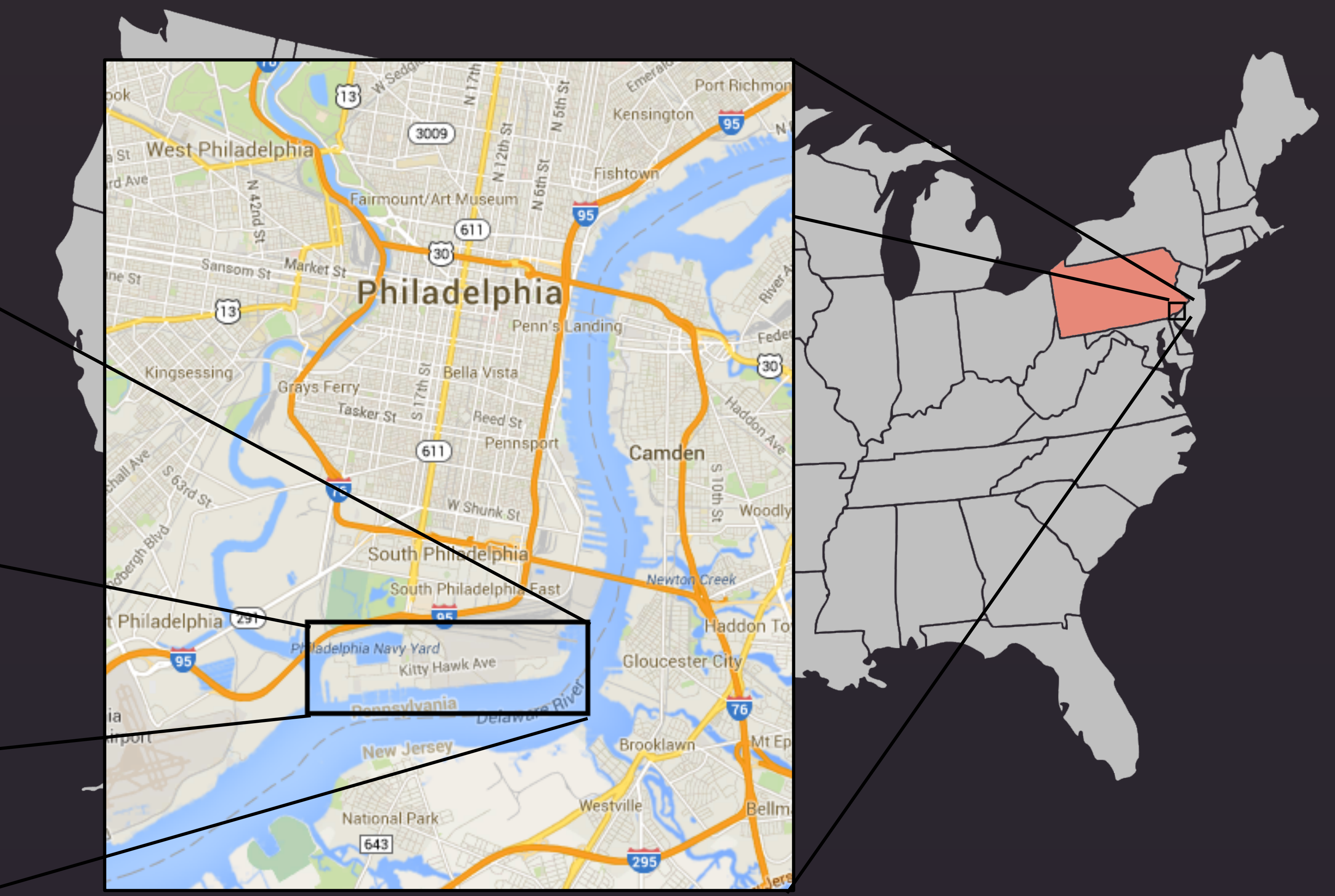
penn state | ae 482

mattise senior thesis

201 Rouse
The Navy Yard
Philadelphia PA, 19112

advisor Dr. Laura Miller

nicholas w. mattise | mechanical option


West Philadelphia
Philadelphia
Camden
South Philadelphia
Philadelphia Navy Yard

introduction

about 201 rouse
location
building statistics
existing systems
performance

thesis proposal

mechanical depth

electrical breadth

conclusion

201 Rouse

84,500 square feet

4 stories

high end office space

Franklin Square Capital Partners

September 2013 to Q1 2015

$19.4 million

architecture

zinc clad exterior facade

glass walled ground floor pedestal

floor to ceiling windows

premium materials

solar shading fins

mechanical system

dual 125 ton packaged AHUs

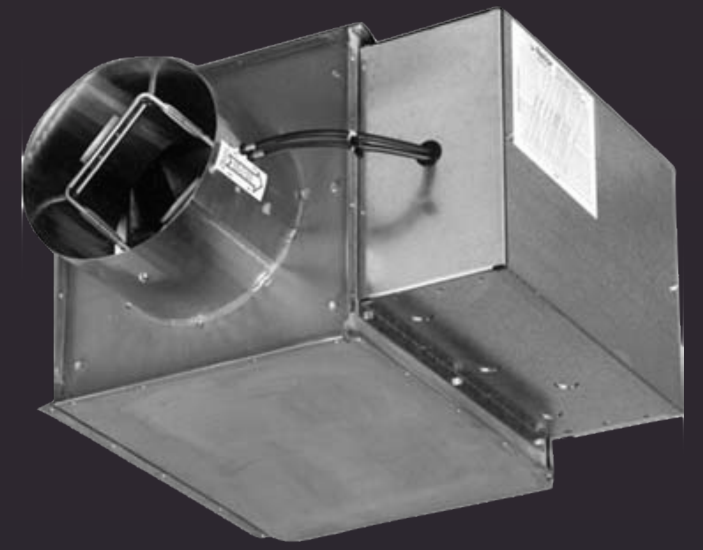
67,200 CFM | 24% min OA

DX coil cooling | electric heating

two vertical risers for supply & return

4 sizes of VAV with reheat terminals

separate HVAC for restrooms and core



Packaged Unit	Airflow (Max/Min) [SCFM]	Cooling Capacity (MBH)	Heating Capacity (MBH)	Unit Specified
1 & 2	33,600/8,230	1501.5	748.5	McQuay RPS130D
3	1,600/165	48.6	65.5	McQuay MHSH04B

Unit	Inlet Dia. (in)	Primary Air (Max/Min) (CFM)	Electric Reheat Coil Capacity (BTU/hr)
A	6	420/210	10239
B	8	800/400	20478
C	10	1400/700	34310
D	12	1800/900	42663

building loads

electrical plug density - 0.75 W/ft^2

lighting intensity - 1.0 W/ft^2

task lighting - 0.75 W/ft^2

equipment density - 0.229 W/ft^2

HVAC - 0.709 W/ft^2

design conditions

outdoor
summer - 90.6°F dry bulb
summer - 74.3 °F wet bulb
winter - 16.9°F

indoor
cooling - 75°F
heating - 70°F
54% relative humidity

building performance

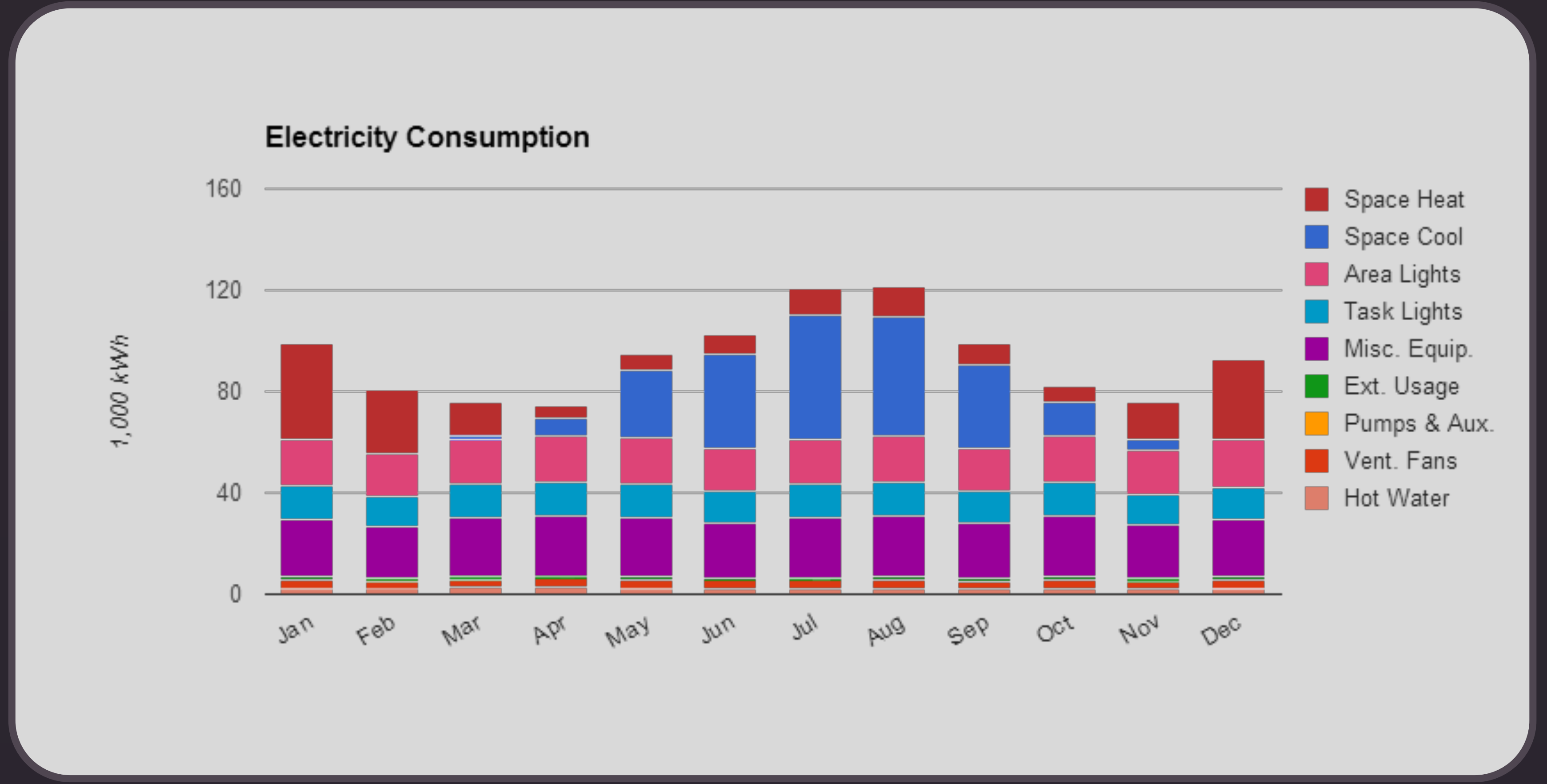
envelope driven performance

HVAC is 36% of annual electricity usage

all electric equipment | uniform demand rate

$181,191 yearly utility cost

31% EUI performance gain



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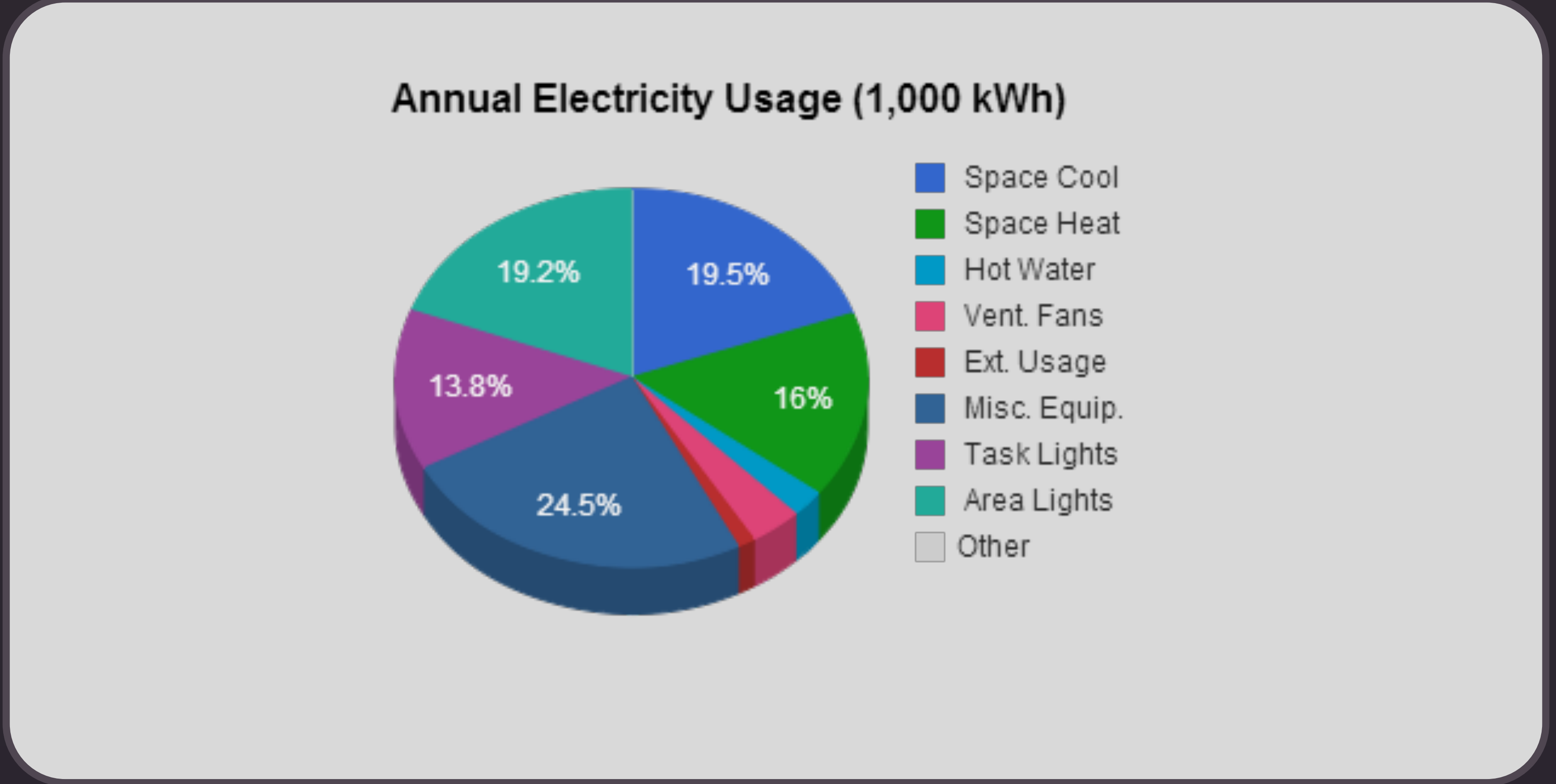

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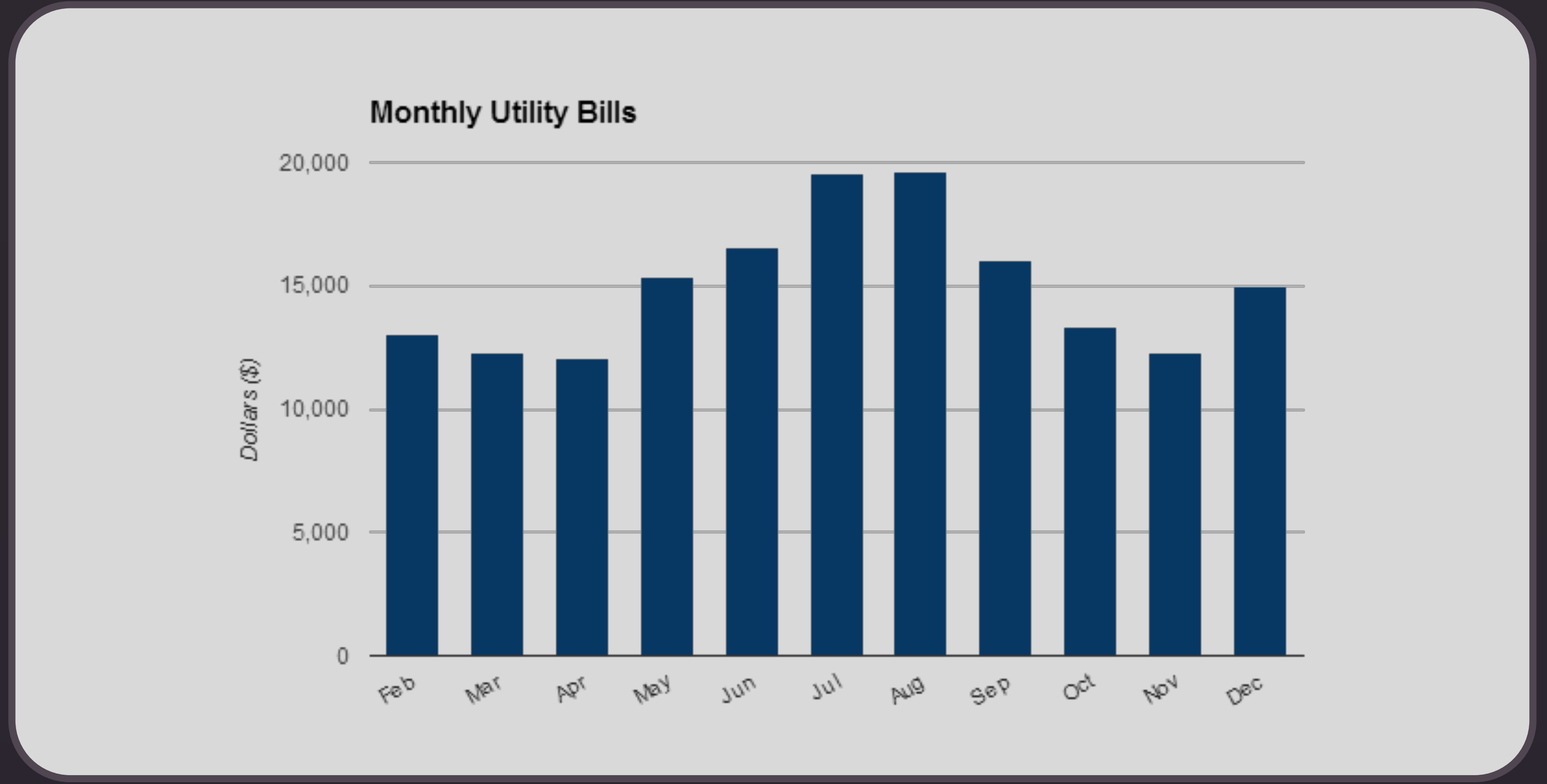


building performance

envelope driven performance

HVAC is 36% of annual electricity usage

all electric equipment | uniform demand rate

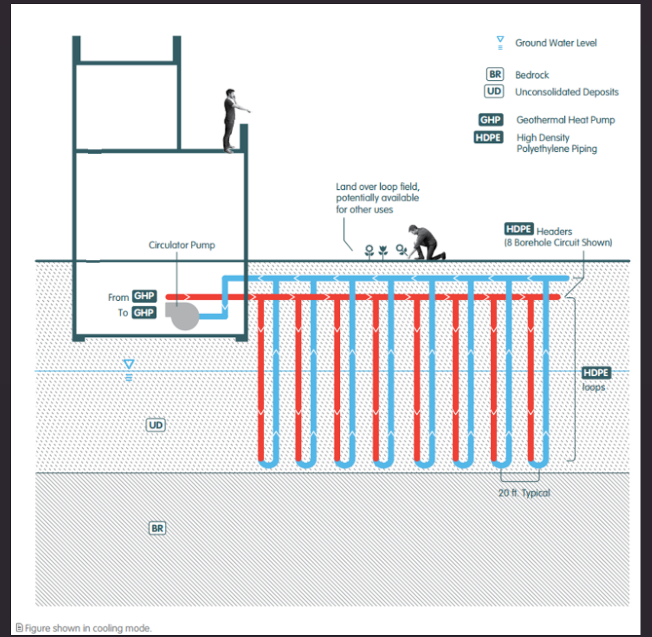
$181,191 yearly utility cost

31% EUI performance gain

Building	Site EUI (kBtu/sqft)	Source EUI (kBtu/sqft)	Performance Gain
201 Rouse	46.4	139.2	31% Site 6% Source
CBECS National Average	67.3	148.1	-

mechanical depth

geothermal heat pumps
active chilled beams
dedicated outdoor air

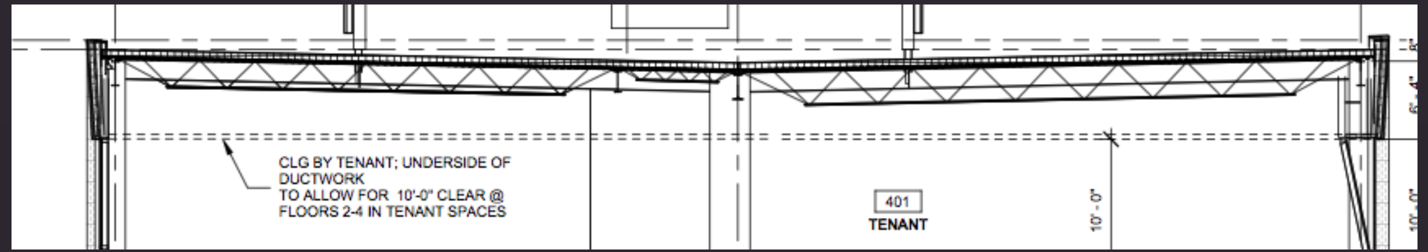


goals

testbed of geothermal application
lower annual energy use
increase LEED rating

structural breadth

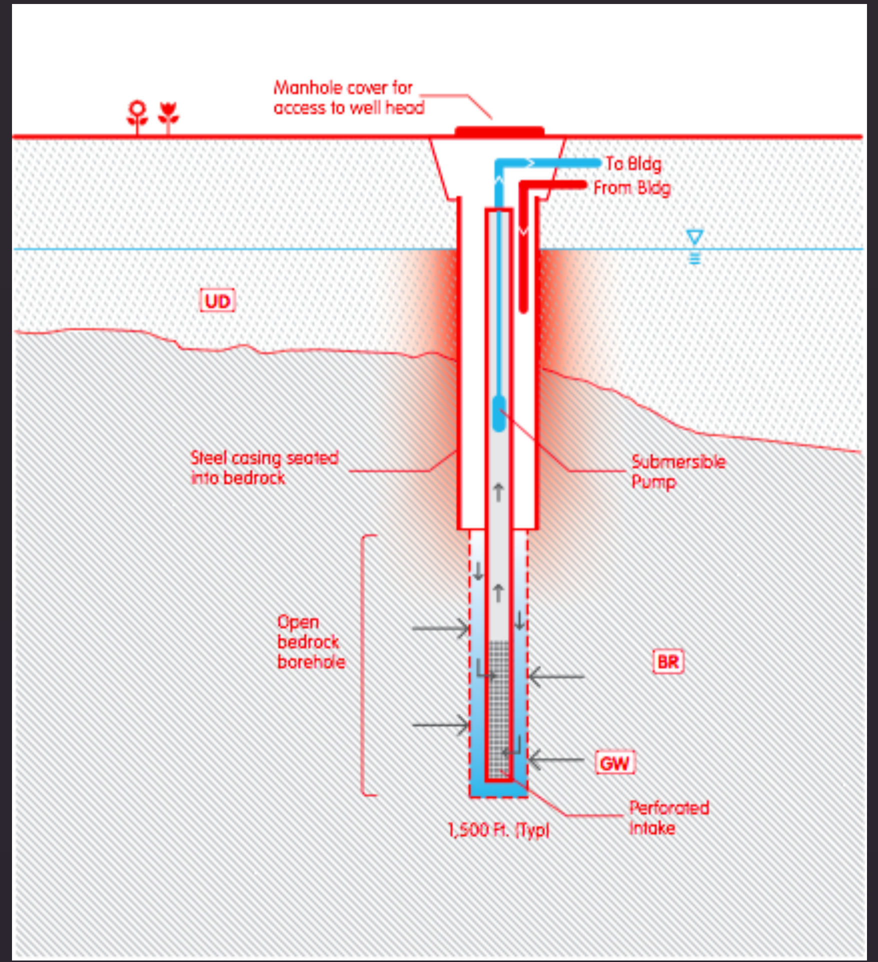
analyze roof structural support



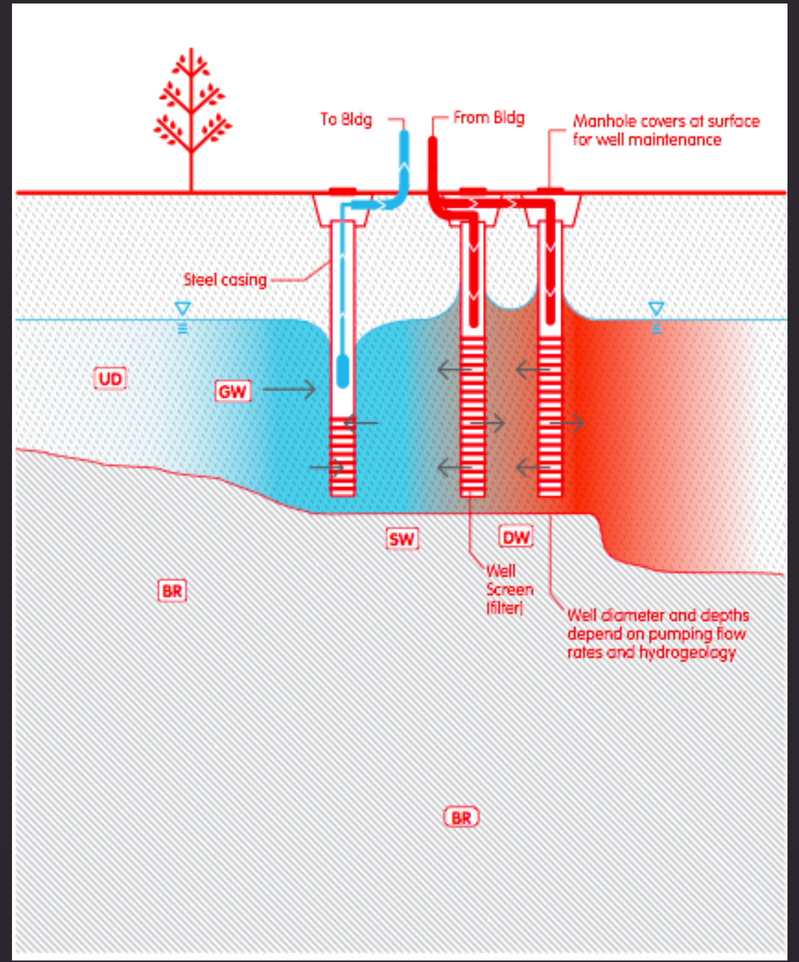
electrical breadth

electrical equipment and wires for new HVAC equipment

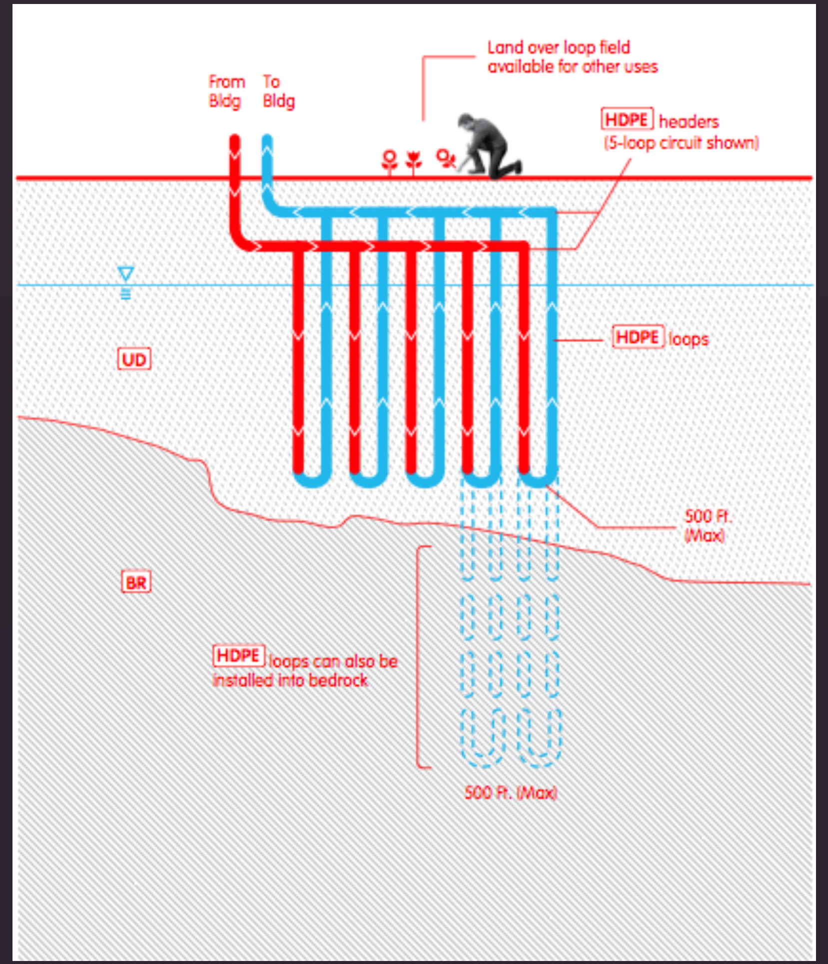
standing column well



open loop



closed loop



ground coupled heat pump

constant thermal properties

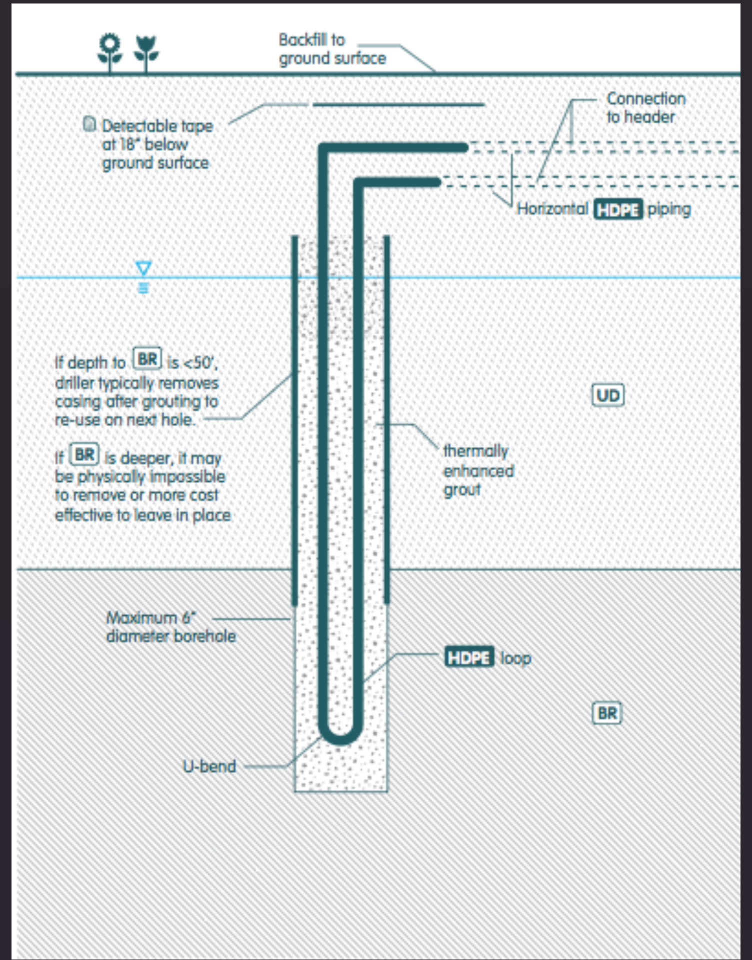
reduced pump energy

lowest level of maintenance

maintains usable site space

expensive

closed loop



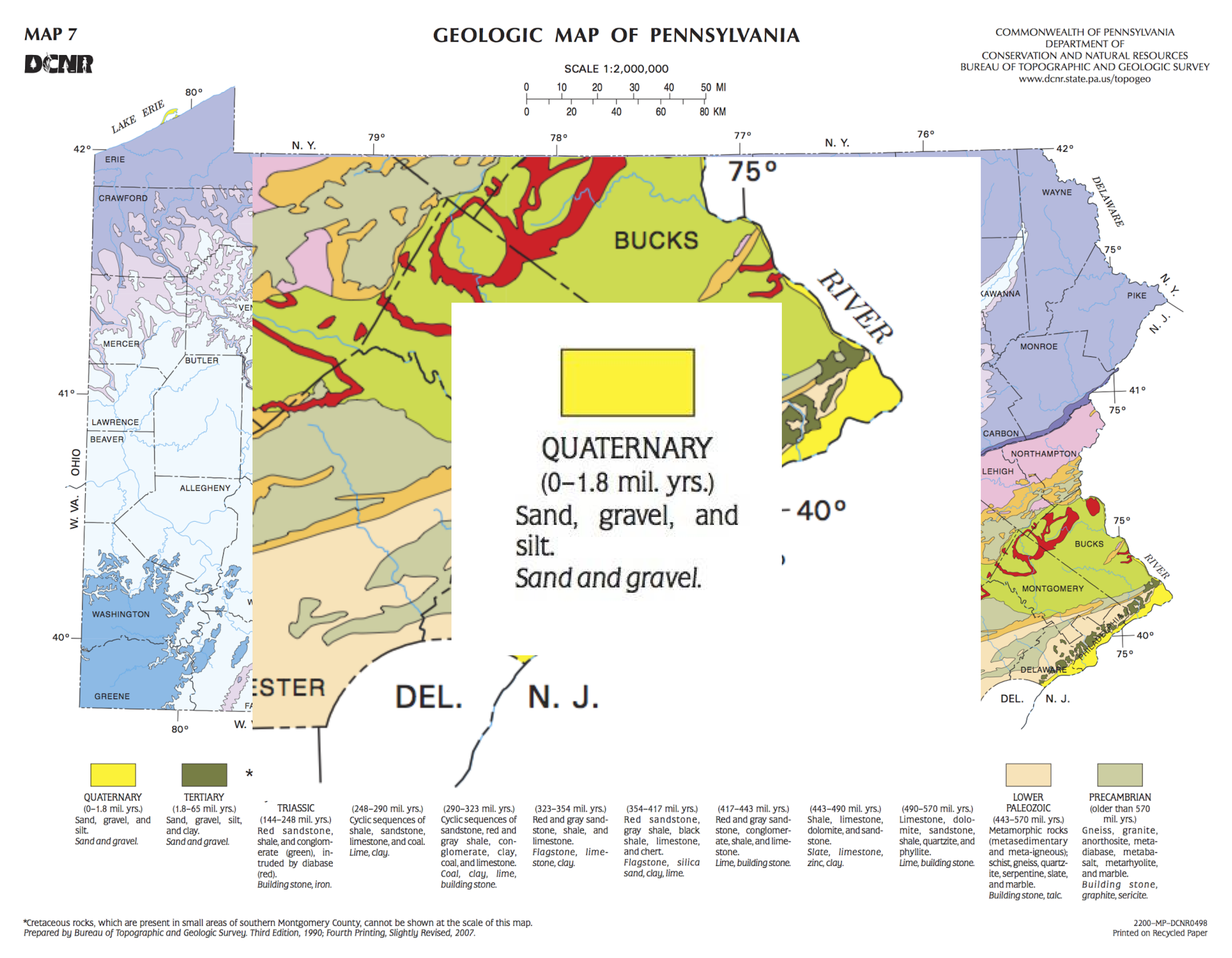
site characteristics

bedrock mix of sand and gravel

conductivity of 1.6 Btu/hr*ft*°F

constant ground temperature of 55°F

long term thermal performance with diffusivity and Potomac-Raritan-Magothy aquifer penetration



well sizing

bedrock mix of sand and gravel

conductivity of 1.6 Btu/hr*ft*°F

constant ground temperature of 55°F

long term thermal performance with diffusivity and Potomac-Raritan-Magothy aquifer penetration

Ingersoll and Zobel Bore Length Equations

	Cooling	Heating	Units
Short Circuit Heat Loss Factor, Fsc	1.04	1.04	-
Part Load Factor , PFLm	1.00	1.00	-
Net annual heat transfer to ground, Qa	700,000	700,000	btu/hr
Building Design Block Load Cooling, Qlc	3,000,000	-	btu/hr
Building Design Block Load Heating, Qlh	-	2,300,000	btu/hr
Effective thermal resistance of ground annual pulse, Rga	0.24	0.24	ft*hr*°F / Btu
Effective thermal resistance of ground daily pulse, Rgd	0.13	0.13	ft*hr*°F / Btu
Effective thermal resistance of ground monthly pulse, Rgm	0.21	0.21	ft*hr*°F / Btu
Effective thermal resistance of bore, Rb	0.10	0.10	ft*hr*°F / Btu
Undisturbed ground Temperature, tg	55.00	55.00	°F
Temp penalty for interference of adjacent bores, tp	2.00	2.00	°F
Liquid temp at HP inlet, twi	75.00	35.00	°F
Liquid temp at HP outlet, two	85.90	30.00	°F
System power input at design cooling load, Wc	100,000	-	W
System power input at design heating load, Wh	-	100,000	W
Required Length	**48,617**	**50,096**	**ft**

well layout

grid of 8x16 wells

128 wells

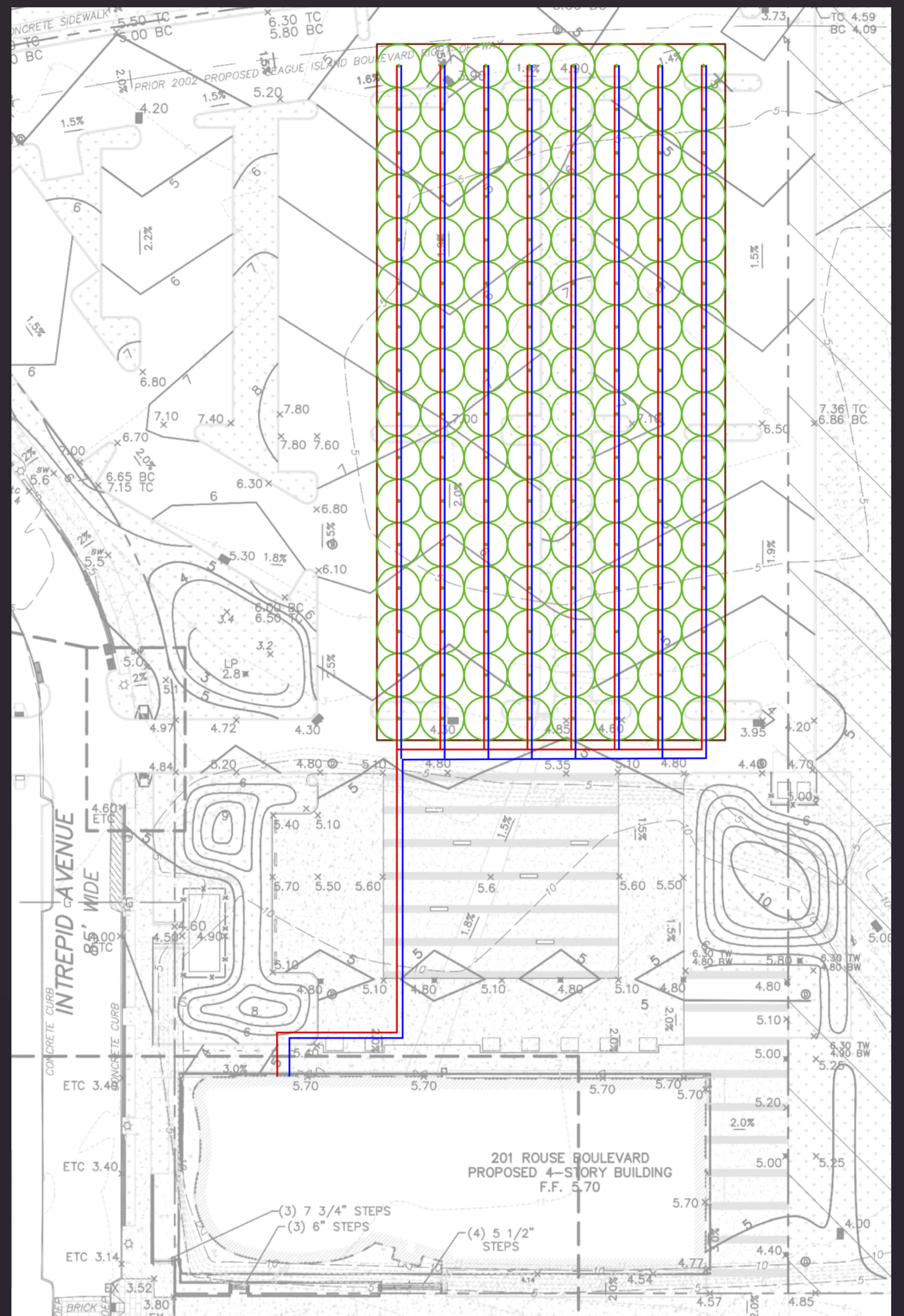
400 foot well depth

20 ft well spacing

surface area of 51,200 ft^2

reverse return piping setup

underneath 201 rouse parking lot



about 201 rouse

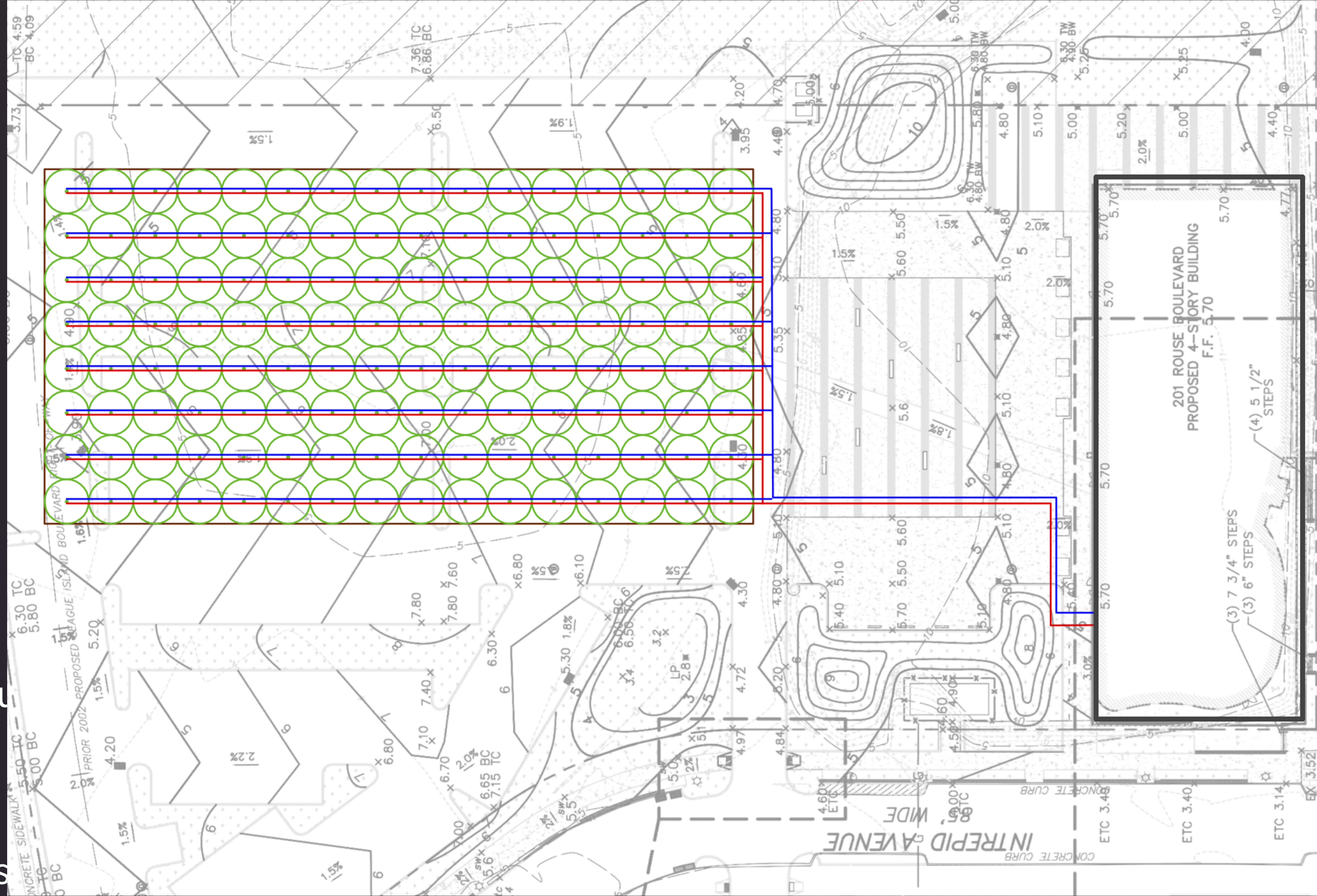
thesis proposal

mechanical depth

- selection
- geothermal calculations
- **well layout**
- equipment
- dedicated outdoor air system
- active chilled beams
- performance

electrical breadth

conclusion



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well layout

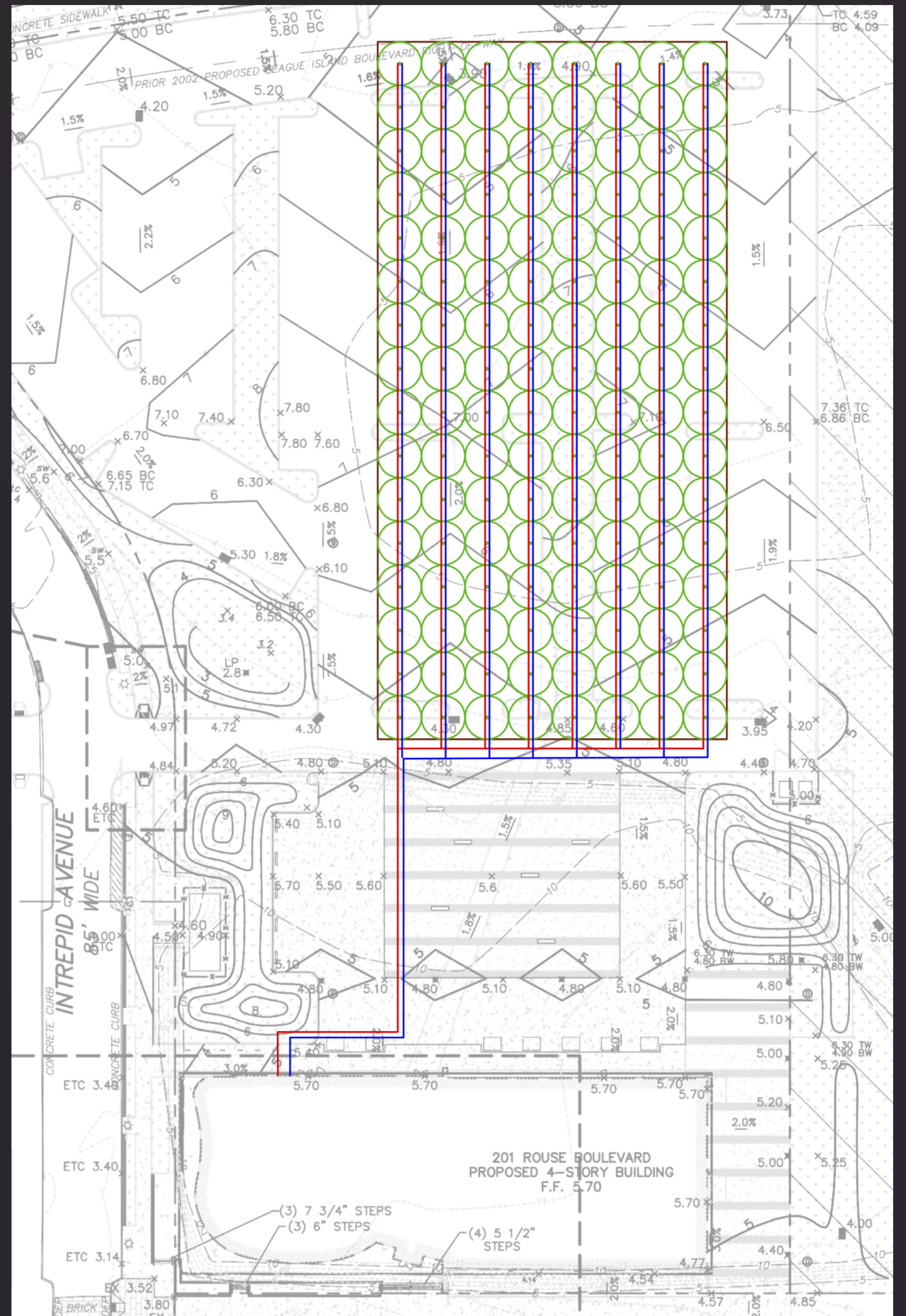
6” header pipe

2” row header pipe

1” thermally fused HDPE well piping

6” bore diameter

thermally conductive fill material



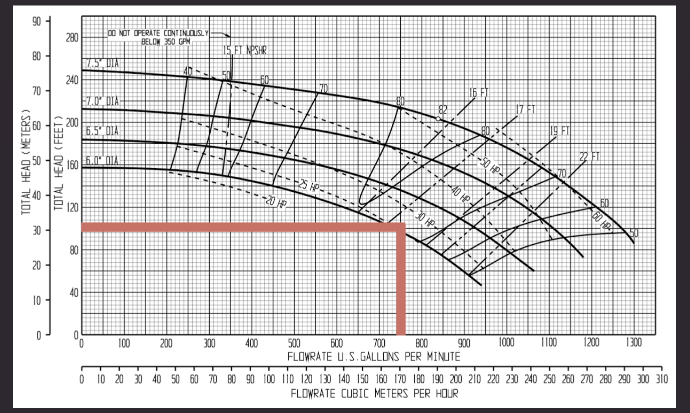
well field pump

3 GPM/ton design flow

750 GPM pipe requirement

96 feet head loss

25 bhp pump operating at 2,700 RPM



Section	Pipe Size (in)	Head Loss
Header	6.00	18.75
Bore Loop	2.00	21.51
Well	1.00	23.47
Sub Total	-	63.73
Multiplier		1.50
Total		**95.59**

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heat pump

20 ton water to water units

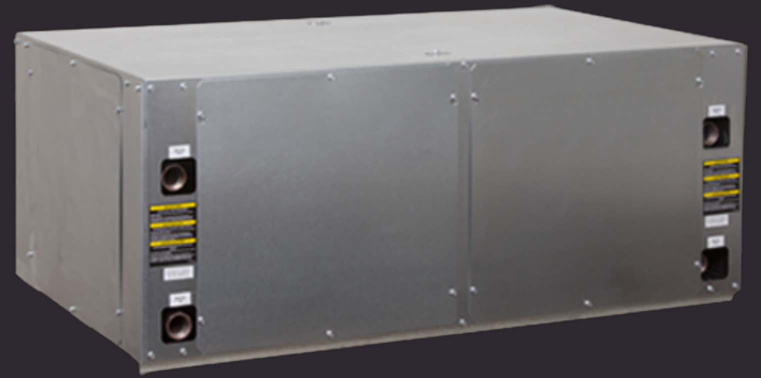
iterative design between delta T of heat pump and well requirements

13 total units

laid out on roof

247 tons cooling | 342 ft^2/ton cooling

2,352 Mbtu heating | 431 ft^2/ton heating



heating

Source	Load									
EWT (deg F)	Flow (GPM)	Head Loss	EWT	Source LWT	HC (MBtuh)	Power (kW)	HA (MBtuh)	LWT	COP	Head Loss
35	50	9.9	110	30.3	180.9	18.9	116.4	117.2	2.8	7.4

cooling

Source	Load									
EWT (°F)	Flow (GPM)	Head Loss	EWT	Source LWT (°F)	TC (MBH)	Power (kW)	HR (MBH)	LWT (°F)	EER	Head Loss
75	50	6.75	57	85.9	228.8	12.52	271.55	50.85	18.35	8.4

dedicated outdoor air system (DOAS)

handles air ventilation requirement and space latent loads

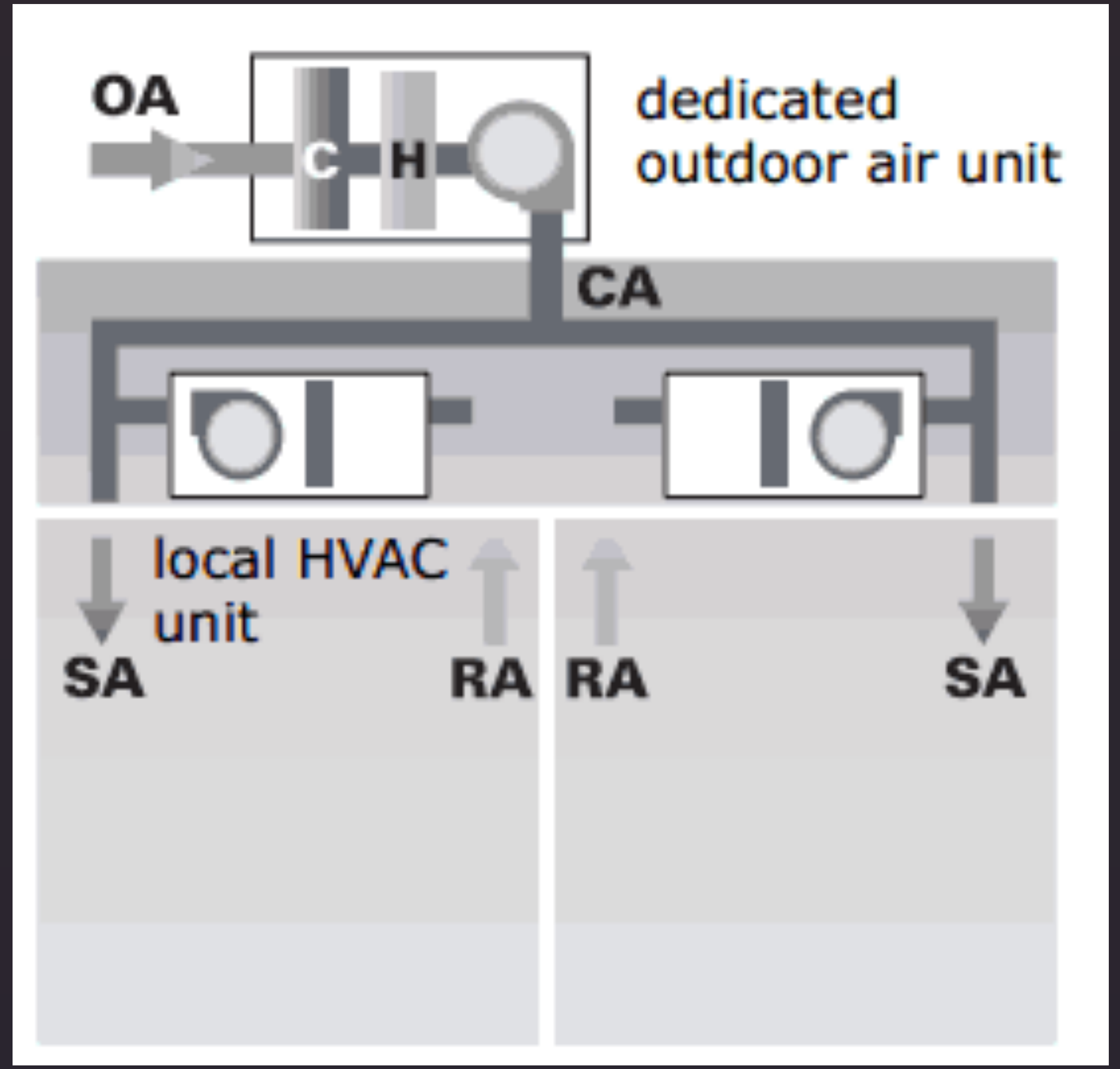
increases indoor air quality (IAQ)

60% relative humidity for spaces

downsizes air flow requirements for space conditioning

delivers conditioned "cold" air directly to the active chilled beams

reduces duct size



dedicated outdoor air system (DOAS)

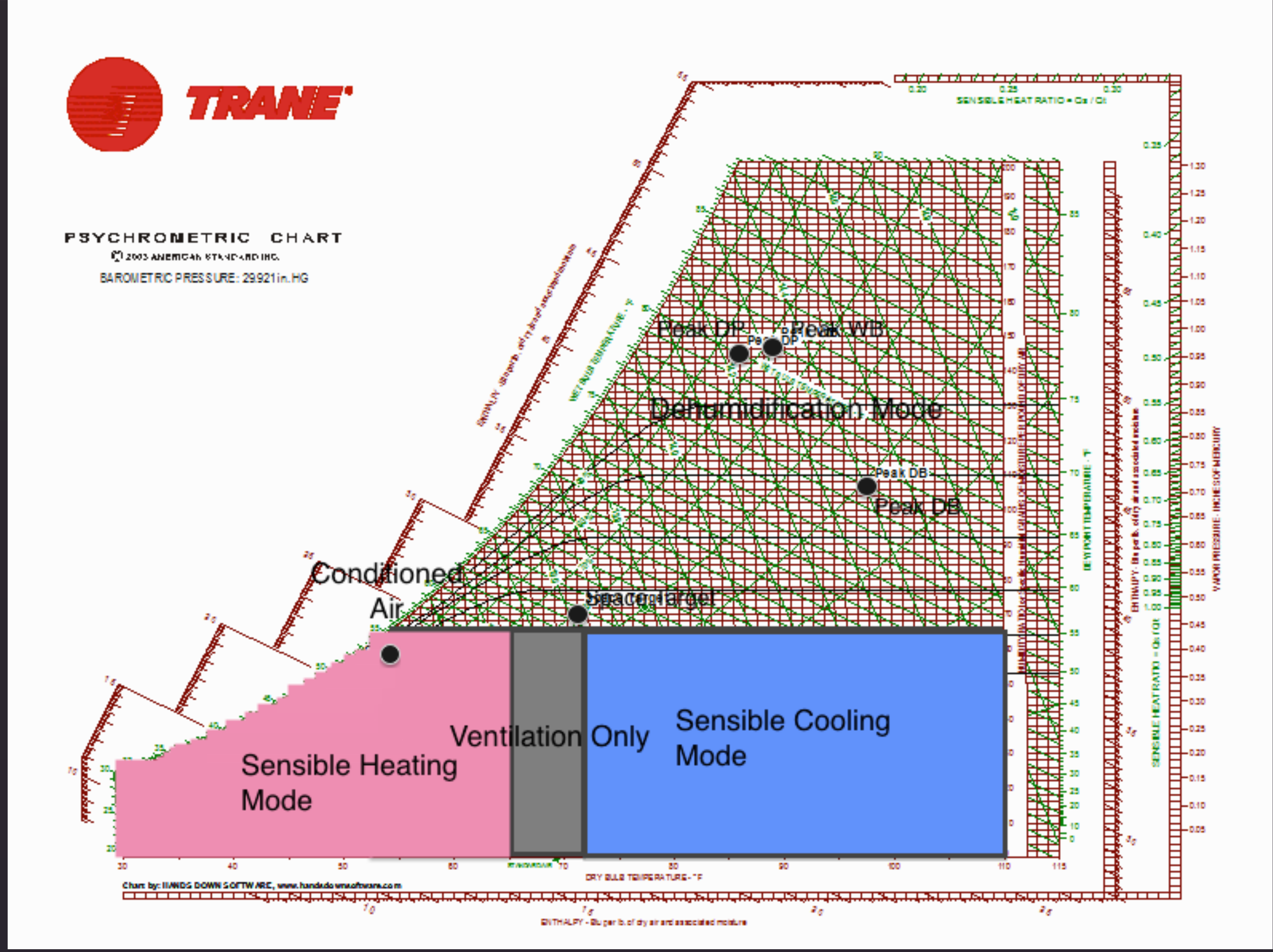
sized based upon ACBs and peak wet bulb

12,500 CFM

73 tons cooling | chilled water from GCHP

hot water sensible heating

Space	# of Typical	Latent Load
WNW (office)	4	7.45 kBtu/hr
SE (office)	4	11.4 kBtu/hr
Total	**8**	**75,400 Btu/hr**



active chilled beams (ACB)

active chilled beams are effective at cooling large spaces at low primary airflow rates

coupled with a "cold" primary air DOAS unit saves on required ACB capacity

required airflow for ACB must be sufficient to maintain latent load of space to avoid condensate

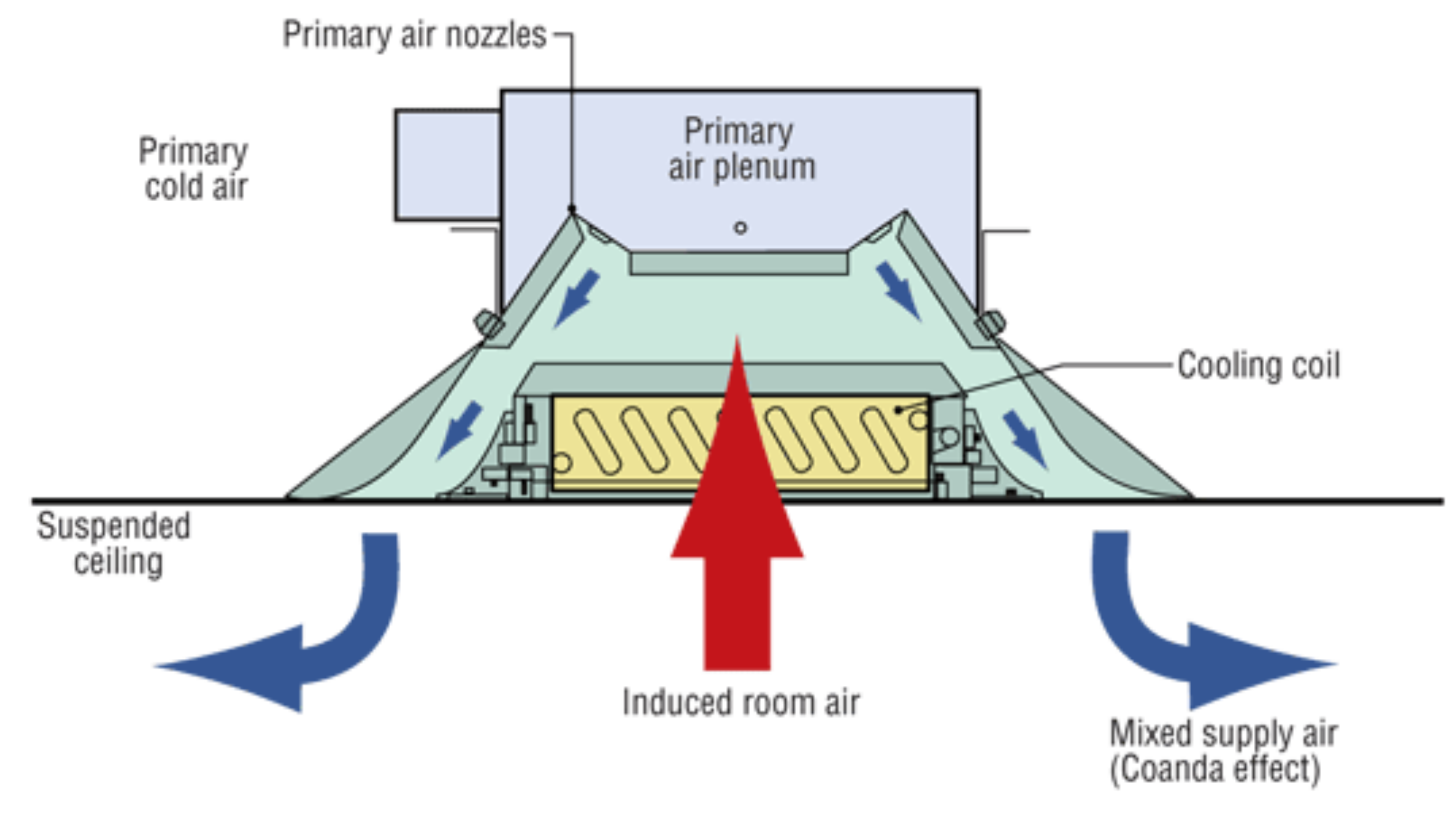


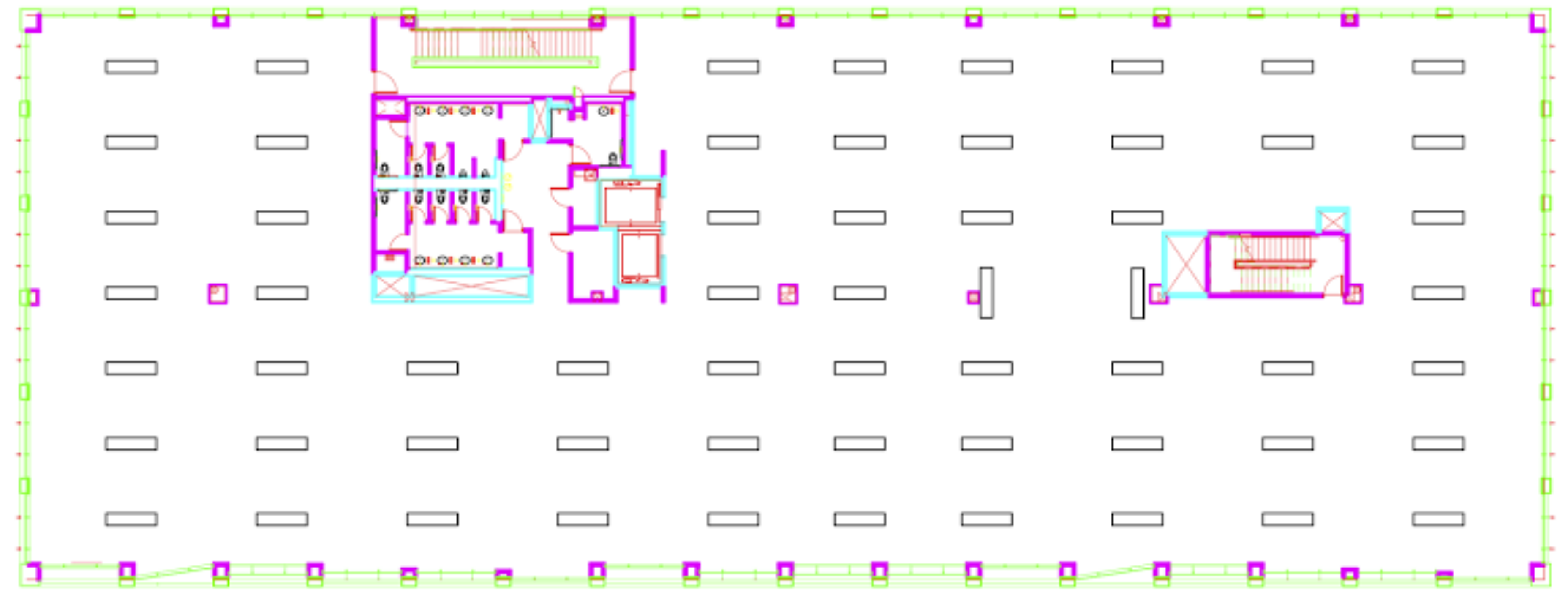
FIGURE 4. Active chilled beam—forced convection.

active chilled beams (ACB)

selected Trox 8ft active chilled beam

covers an area of 300 ft^2

requires 60 per floor to condition space



Selected ACB	V	Qcw	Qh	GPM	Head Loss
8 ft DID632 Z Nozzle	50 CFM	4,305 Btu/hr	7,803 Btu/hr	1	5.8 ft H20

Space	# ACBs	Airflow	Sensible Cooling	Heating	GPM
SE	26	1,300 CFM	112.3 kBtu/hr	202 kBtu/hr	26
WNW	34	1,700 CFM	146 kBtu/hr	265 kBtu/hr	34
Total	**60**	**2,950 CFM**	**258.3 kBtu/hr**	**467 kBtu/hr**	**60**

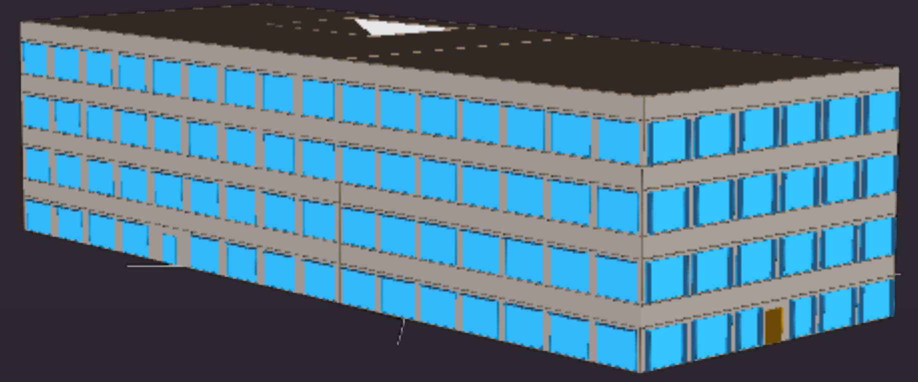
energy modeling complexities

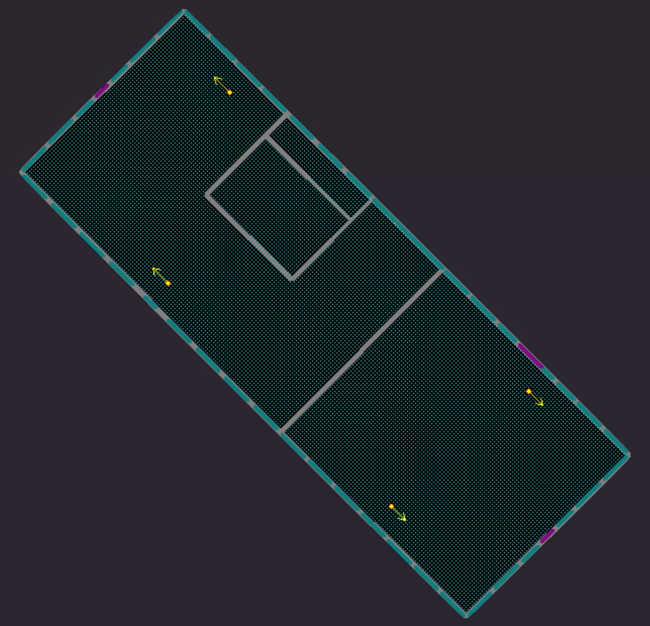
with the complexity of the designed system modeling was a hurdle

accurate modeling of advanced HVAC systems is limited by the components that different modeling programs support

many solutions do not offer all three components or they are not fully realized

ended up using eQUEST





geothermal model

ground source vertical well system

water to air heat pumps based upon water to water HP capacity

packaged fan unit based upon DOAS unit fan CFM and energy performance

yields an energy model representative of the designed system's energy use

powered induction unit model

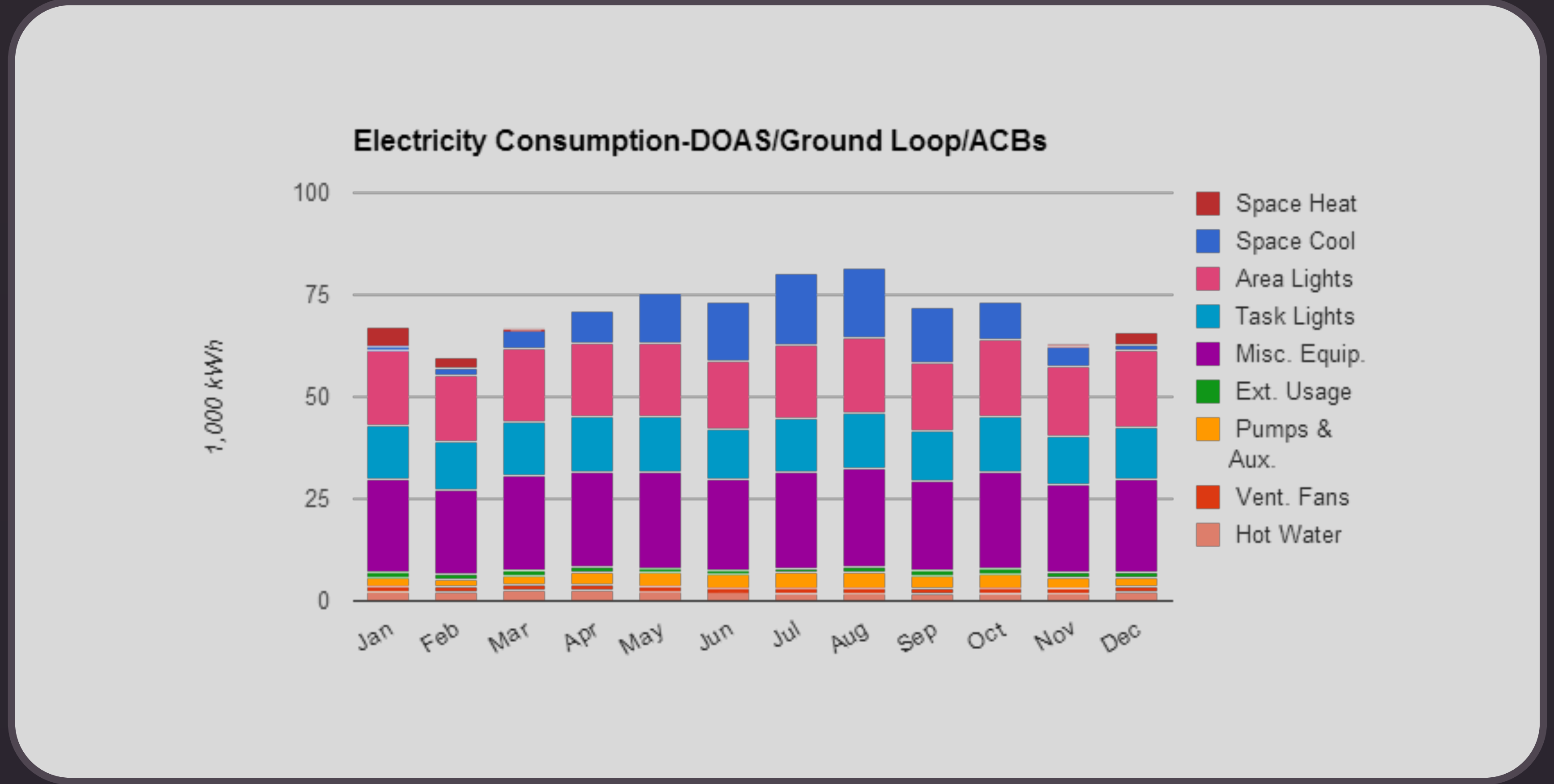
uses powered induction units

packaged fan unit sized to the DOAS unit

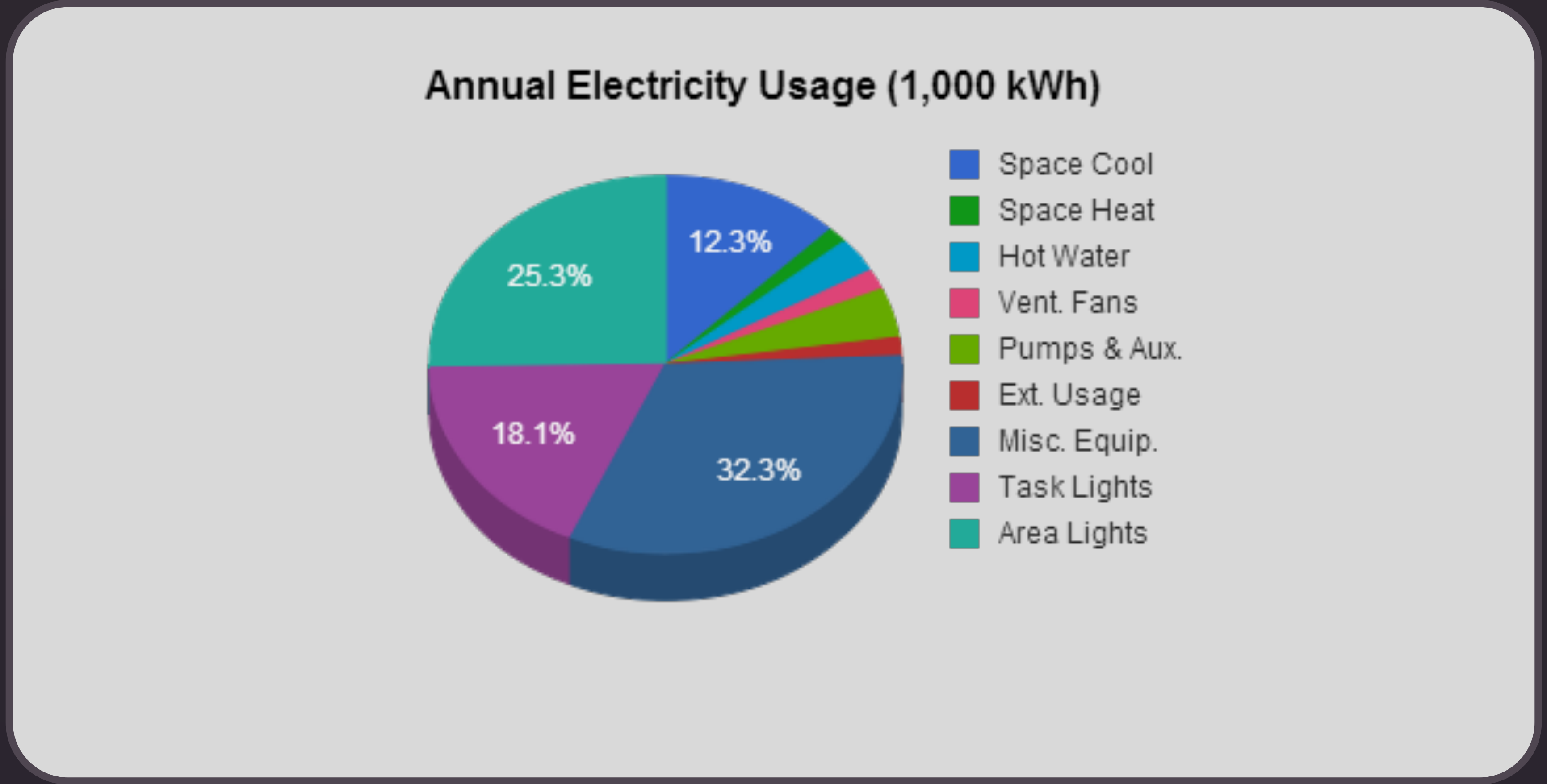
but induction units are supplied HW and CHW by boiler and cooling tower respectively

creates a representative model of building thermal performance

monthly performance



annual energy usage



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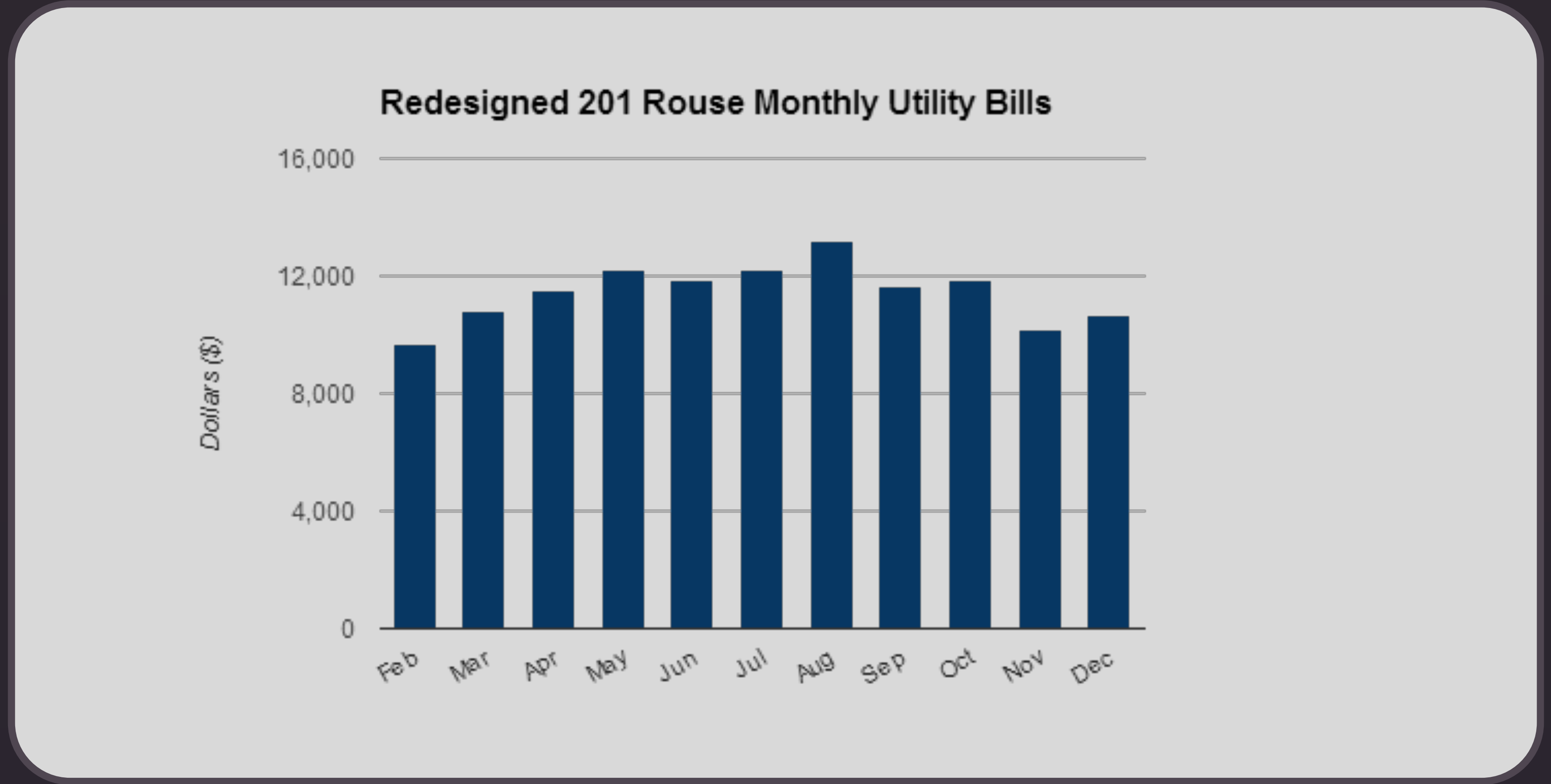
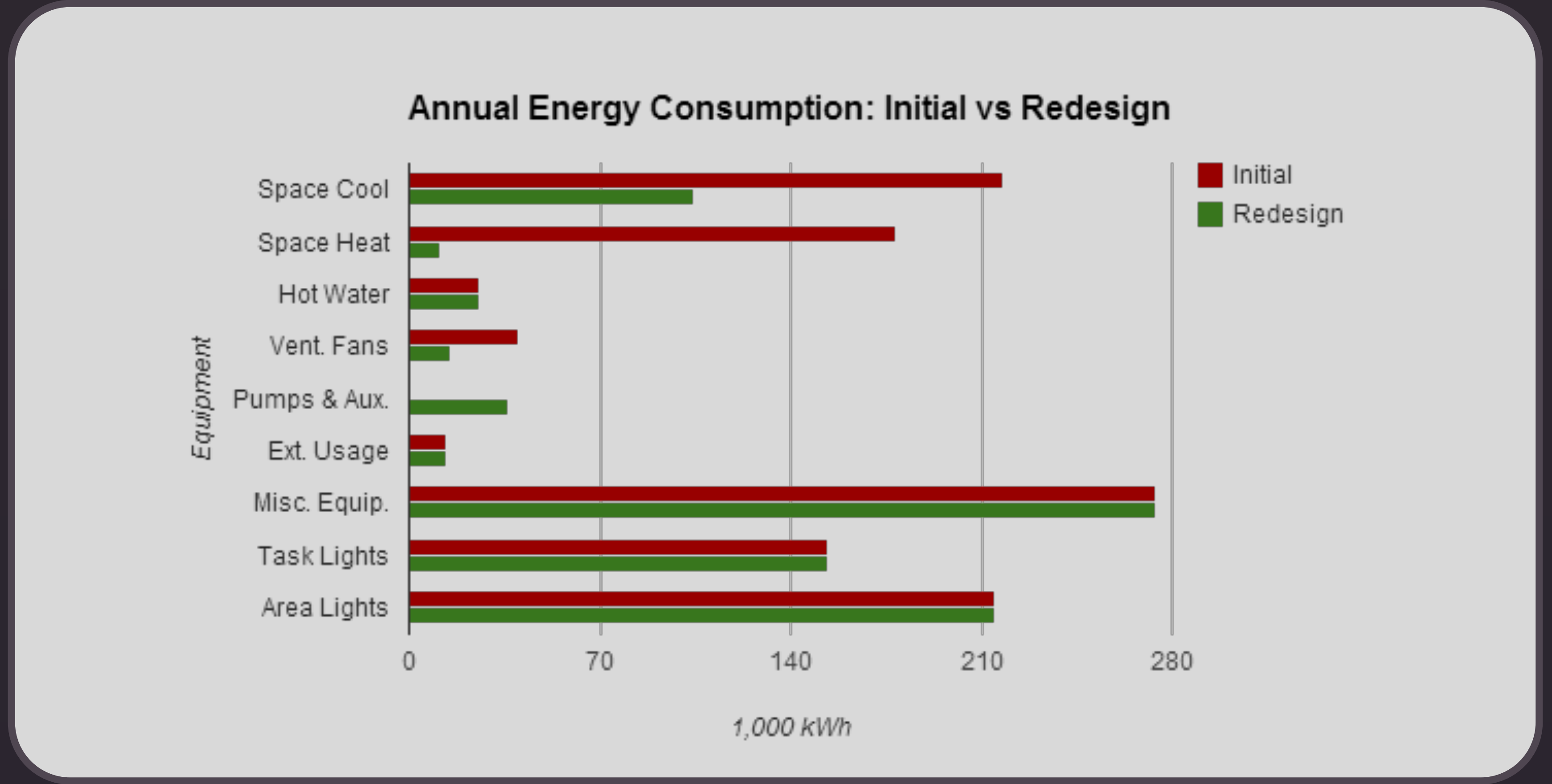
monthly utility cost



energy comparison



saves 270,000 kWh

cost comparison

Building	Mechanical Systems Cost	Total Building Cost	Mechanical %
201 Rouse Initial	$1,513,000	$19,402,000	7.80%
201 Rouse Thesis Revised	$2,193,132	$20,082,132	10.92%
Difference	-	**$680,132**	**3.12%**

new HVAC system cost

Component	Unit Cost	Unit	Units	Cost
Heat Pumps	$41,387	each	13	$538,031
Geothermal Wells and Headers	$16	per foot	51200	$819,200
DOAS	$209,958	each	1	$209,958
Ducts	$12.82	linear foot	2800	$35,896.00
Return Grills	$30.02	each	120	$3,602.40
Building Side Pumps	$10,163	each	2	$20,326
Well Field Pumps	$21,050	each	2	$42,100
Core HVAC Unit	$14.90	sqft	5312	$79,148.80
Active Chilled Beams	$1,404	each	240	$336,960
Piping	$16.35	linear foot	6600	$107,910.00
Total				**$2,193,132**

payback period

saves on average **$3,600** a month in utility bills

187 months | 15.5 years

using uniform electricity charge of $0.162 per kWh

EUI comparison

Building	Site EUI (kBtu/sqft)	Source EUI (kBtu/sqft)	Performance Gain Over Benchmark	Performance Gain over Initial
201 Rouse Initial	46.4	139.2	31% Site, 6% Source	-
201 Rouse Redesigned	35.2	105.6	48% Over Site, 28% Source	24% Site, 24% Source
CBECS National Average	67.3	148.1	-	-

initial LEED certification standing

seeking LEED new construction certification

as of October 2013 the building only qualified for 54 of the 110 LEED points

owner's goal was gold

silver is 50-59

gold threshold is 60

revised LEED certification standing

the geothermal system reaffirmed 3 points for "green power"

the DOAS added 1 LEED point for indoor air quality

the whole building energy reduction yield an additional 10 points

new LEED score | **65**

existing electrical system

electrical utility via PECO and local microgrid

600 amp high voltage connection

4000 amp main distribution board (mdb)

~1650 FLA of existing and future HVAC equipment

removed electrical loads

Equipment	Quantity	Full Load Amps	MCA	Volts	Phase	KW
Rooftop Air Handling Unit	2	369.2	400	460	3	294.2
VAV-A	8	10.83032491	15	277	1	3
VAV-B	8	21.66064982	25	277	1	6
VAV-C	8	36.10108303	40	277	1	10
VAV-D	8	45.12635379	50	277	1	12.5
Total		**1648.147292**	**1840**			**840.4**

~1650 full load amps removed from mdb

new electrical wiring

Equipment	Quantity	Amps	Wire Type	Wires	Wire Size	Ground Size	Conduit
Well Field Pump	2	23.3	THHW	3 Current 1 Neutral 1 Ground	10 AWG	14 AWG	1" EMT
Heat Pump	13	22.73	THHW	3 Current 1 Neutral 1 Ground	10 AWG	14 AWG	(3) 1 1/2" EMT
Hot/Chilled Water Pump	4	4.04	THHW	1 Current 1 Neutral 1 Ground	14 AWG	14 AWG	1" EMT
DOAS Unit	1	37.8	THHW	3 Current 1 Neutral 1 Ground	8 AWG	12 AWG	3/4" EMT
Panelboard HVH1	1	350	THHW	3 Current 1 Neutral 1 Ground	(2) 2/0 AWG	4 AWG	2" EMT

new electrical loads

Equipment	Quantity	Full Load Amps	MCA	Voltage	Phase	KW
Well Field Pump	2	23.3	30	460	1	18.6
Heat Pump	13	33.4	40	460	3	18.9
Hot/Chilled Water Pump	4	4.04	15	230	1	1.12
DOAS Unit	1	37.8	50	460	3	37.8

~540 full load amps added to mdb

electrical breadth

removal of 1,100 full load amps from main distribution

no change in panel quantity

circuit location optimized to equipment

reduction in wiring costs

owner choice between electrical panel savings or additional future capacity

new panelboard

PANEL:	HH1	VOLTAGE:	277/480
FOR:	COMMON HVAC AND PUMPS	PHASE:	3 PH-4W
LOCATION:	MAIN ELECTRICAL ROOM	MAIN:	225 A MLO
AIC:	25,000 A	MOUNTING:	SURFACE

DESCRIPTION	LTG. VA	EQUIP. VA	HVAC VA	BREAKER AMPS	BUS			BREAKER	HVAC VA	EQUIP.	LTG. VA	DESCRIPTION
#EF-1 EXHAUST FAN			3,980	15	1	A	2	25	5,010			#CUH-C UNIT HEATER
					3	B	4	15	1,180			#FTU-A1 FAN TERMINAL
					5	C	6	15	1,180			#FTU-A2 FAN TERMINAL
#FTU-B TERMINAL UNIT			10,180	20	7	A	8	15	1,180			#FTU-A3 FAN TERMINAL
					9	B	10	15	1,120			CHW PUMP 1
					11	C	12	20	3,000			#CUH-C UNIT HEATER
#UH-A1 UNIT HEATER			5,000	15	13	A	14					SPARE
					15	B	16	20	3,000			#CUH-C UNIT HEATER
					17	C	18	20	3,000			#CUH-C UNIT HEATER
#UH-A2 UNIT HEATER			5,000	15	19	A	20					SPARE
					21	B	22					SPARE
					23	C	24					SPARE
HW PUMP 1			1,120	15	25	A	26					SPARE
HW PUMP 2			1,120	15	27	B	28					SPARE
CHW PUMP 2			1,120	15	29	C	30					SPARE
WELL FIELD PUMP 1			18,600	40	31	A	32					SPARE
					33	B	34					SPARE
					35	C	36					SPARE
WELL FIELD PUMP 2			18,600	40	37	A	38	60	10,880	18,860		PANEL "HP1" TRANSFORMER
					39	B	40					
					41	C	42					
Totals	0	0	64,720						29,550	18,860	0	Totals

LOAD DESCRIPTION	CONN.	DEMAND VA.
LIGHTING	0	0
GENERAL POWER	18,860	9,430
HVAC EQUIPMENT	94,270	94,270
TOTAL	113,130	103,700
PERCENT LOADED	90.50%	82.96%

PHASE VA	
A	37,677
B	36,787
C	38,667
TOTAL	113,130

conclusion

GCHP | DOAS | ACB

costs $680,000

24% EUI reduction

$3,600 average monthly savings

15.5 year payback for HVAC system

electrical panel savings or future capacity

LEED gold

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acknowledgements

Liberty Property Trust

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In Posse

Dr. Laura Miller

Penn State University

friends | family | co-workers

questions

recommendations