# mattise



nicholas w. mattise | mechanical option

# senior





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penn state | ae 482

# thesis

# mattise senior thesis



advisor Dr. Laura Miller

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# 201 Rouse The Navy Yard Philadelphia PA, 19112

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about 201 rouse location building statistics existing systems performance

### thesis proposal

mechanical depth

electrical breadth

### conclusion

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84,500 square feet

4 stories

high end office space

Franklin Square Capital Partners

September 2013 to Q1 2015

\$19.4 million



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## architecture

zinc clad exterior facade

glass walled ground floor pedestal

floor to ceiling windows

premium materials

solar shading fins



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# 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

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Airflow (M Packaged Unit [SCF		lax/Min) M]	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	Prim Inlet Dia. (in)		Prima	ry Air (Max/Min) (CFM)	Electric Reheat Coil Capacity (BTU/hr)		
А	6		420/210		10239		
В	8			800/400	20478		
С	10			1400/700 34		34310	
D		12		1800/900	42663		



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# building loads

electrical plug density - 0.75 W/ft<sup>2</sup>

lighting intensity -  $1.0 \text{ W/ft}^2$ 

task lighting -  $0.75 \text{ W/ft}^2$ 

equipment density - 0.229 W/ft<sup>2</sup>

HVAC -  $0.709 \text{ W/ft}^2$ 

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# design conditions

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

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

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all electric equipment | uniform demand rate

# building performance

envelope driven performance

HVAC is 36% of annual electricity usage

\$181,191 yearly utility cost

31% EUI performance gain

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all electric equipment | uniform demand rate

# building performance

envelope driven performance

HVAC is 36% of annual electricity usage

\$181,191 yearly utility cost

31% EUI performance gain



- Space Heat Hot Water Vent. Fans
- Ext. Usage
- Misc. Equip.
- Task Lights
- Area Lights
- Other

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all electric equipment | uniform demand rate

# building performance

envelope driven performance

HVAC is 36% of annual electricity usage

\$181,191 yearly utility cost

31% EUI performance gain

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![](_page_9_Figure_15.jpeg)

about 201 rouse location building statistics existing systems performance

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#### ŀ

all electric equipment | uniform demand rate

# building performance

envelope driven performance

HVAC is 36% of annual electricity usage

\$181,191 yearly utility cost

31% EUI performance gain

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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	_

![](_page_11_Figure_0.jpeg)

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# mechanical depth

geothermal heat pumps active chilled beams dedicated outdoor air

goals

testbed of geothermal application lower annual energy use increase LEED rating

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![](_page_11_Figure_7.jpeg)

# structural breadth

### analyze roof structural support

![](_page_11_Figure_10.jpeg)

# electrical breadth

electrical equipment and wires for new HVAC equipment

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#### mechanical depth

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

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#### standing column well

![](_page_12_Figure_8.jpeg)

#### open loop

![](_page_12_Figure_11.jpeg)

#### closed loop

![](_page_12_Figure_13.jpeg)

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# ground coupled heat pump

constant thermal properties

reduced pump energy

lowest level of maintenance

maintains usable site space

expensive

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![](_page_13_Figure_15.jpeg)

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# 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

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![](_page_14_Figure_13.jpeg)

retaceous rocks, which are present in small areas of southern Montgomery County, cannot be shown at the scale of this map. repared by Bureau of Topographic and Geologic Survey. Third Edition, 1990; Fourth Printing, Slightly Revised, 2007.

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![](_page_15_Picture_7.jpeg)

#### Ingersoll and Zobel Bore Length Equations

Short Circuit Heat Loss Factor, Fsc Part Load Factor, PFLm Net annual heat transfer to ground, Qa Building Design Block Load Cooling, Qlc Building Design Block Load Heating, Qlh Effective thermal resistance of ground annual puls Effective thermal resistance of ground daily pulse Effective thermal resistance of ground monthly puls Effective thermal resistance of bore, Rb Undisturbed ground Temperature, tg Temp penalty for interference of adjacent bores Liquid temp at HP inlet, twi Liquid temp at HP outlet, two System power input at design cooling load, V System power input at design heating load, W

#### **Required Length**

# well sizing

bedrock mix of sand and gravel

conductivity of 1.6 Btu/hr\*ft\*<sup>o</sup>F

constant ground temperature of 55°F

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

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	Cooling	Heating	Units
	1.04	1.04	-
	1.00	1.00	-
	700,000	700,000	btu/hr
	3,000,000	-	btu/hr
	-	2,300,000	btu/hr
e, Rga	0.24	0.24	ft*hr* <sup>0</sup> F / Btu
e, Rgd	0.13	0.13	ft*hr* <sup>0</sup> F / Btu
se, Rgm	0.21	0.21	ft*hr* <sup>0</sup> F / Btu
	0.10	0.10	ft*hr* <sup>0</sup> F / Btu
	55.00	55.00	٥F
s, tp	2.00	2.00	٥F
	75.00	35.00	٥F
	85.90	30.00	٥F
lc	100,000	-	W
/h	-	100,000	W
	48,617	50,096	ft

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![](_page_16_Figure_7.jpeg)

grid of 8x16 wells

128 wells

400 foot well depth

20 ft well spacing

surface area of 51,200 ft<sup>2</sup>

reverse return piping setup

underneath 201 rouse parking lot

![](_page_16_Figure_16.jpeg)

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![](_page_17_Figure_7.jpeg)

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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

![](_page_18_Figure_14.jpeg)

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# well field pump

3 GPM/ton design flow

750 GPM pipe requirement

96 feet head loss

25 bhp pump operating at 2,700 RPM

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![](_page_19_Picture_13.jpeg)

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

![](_page_19_Figure_16.jpeg)

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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<sup>2</sup>/ton cooling

2,352 Mbtu heating | 431 ft<sup>2</sup>/ton heating

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#### heating

Source			Loa	d						
EWT (deg	F) (GP	w Hea M) Los	ad EW <sup>-</sup> ss	T Source LWT	e HC (MBtuh)	Power (kW)	HA (MBtuh)	LWT	СОР	Head Loss
35	50	) 9.9	9 110	) 30.3	180.9	18.9	116.4	117.2	2.8	7.4
coolir	cooling									
Source			Load							
EWT (°F)	Flow (GPM)	Head Loss	EWT	Source LWT (°F)	ТС (МВН)	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
penn state   ae 482										

![](_page_20_Picture_17.jpeg)

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# dedicated outdoor air system (DOAS)

handles air ventilation requirement and space latent loads

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

increases indoor air quality (IAQ)

60% relative humidity for spaces

downsizes air flow requirements for space conditioning

reduces duct size

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![](_page_21_Figure_15.jpeg)

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# dedicated outdoor air system (DOAS)

WNW

SE (d

To

sized based upon ACBs and peak wet bulb

12,500 CFM

73 tons cooling | chilled water from GCHP

#### hot water sensible heating

ace	# of Typical	Latent Load
(office)	4	7.45 kBtu/hr
office)	4	11.4 kBtu/hr
tal	8	75,400 Btu/hr

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![](_page_22_Picture_18.jpeg)

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![](_page_23_Picture_10.jpeg)

# 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

![](_page_23_Figure_16.jpeg)

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	a
I	
	re
Selected ACB	V
8 ft DID632 Z	
NOZZIE	50 CFM

# active chilled beams (ACB)

selected Trox 8ft active chilled beam

covers an area of 300 ft<sup>2</sup>

equires 60 per floor to condition space

• — —						_
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V	Qcw	Qh	GPM	Head Loss
CFM	4,305 Btu/hr	7,803 Btu/hr	1	5.8 ft H20
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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

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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

# energy modeling complexities

ended up using eQUEST

![](_page_25_Picture_13.jpeg)

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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

# geothermal model

ground source vertical well system

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# 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

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# monthly performance

#### Electricity Consumption-DOAS/Ground Loop/ACBs

![](_page_27_Figure_10.jpeg)

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![](_page_27_Figure_12.jpeg)

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16.000

12,000

# monthly utility cost

#### Redesigned 201 Rouse Monthly Utility Bills

![](_page_28_Figure_12.jpeg)

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![](_page_28_Figure_14.jpeg)

# Pumps & Aux.

# saves 270,000 kWh

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Building201 Rouse Initial201 Rouse Thesis<br/>Revised

Difference

### cost comparison

Mechanical Systems Cost	Total Building Cost	Mechanical %
\$1,513,000	\$19,402,000	7.80%
\$2,193,132	\$20,082,132	10.92%
-	\$680,132	3.12%

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## 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

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# 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

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## 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	-	-

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# 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

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![](_page_31_Picture_14.jpeg)

# 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

![](_page_31_Picture_24.jpeg)

![](_page_32_Figure_0.jpeg)

electrical utility via PECO and local microgrid

# existing electrical system

- 600 amp high voltage connection
- 4000 amp main distribution board (mdb)
- ~1650 FLA of existing and future HVAC equipment

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# 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

![](_page_33_Figure_0.jpeg)

Equipment	Quantity
Well Field Pump	2
Heat Pump	13
Hot/Chilled Water Pump	4
DOAS Unit	1
Panelboard HVH1	1

# new electrical wiring

7	Amps	Wire Type	Wires	Wire Size	Ground Size	Conduit
	23.3	THHW	3 Current 1 Neutral 1 Ground	10 AWG	14 AWG	1" EMT
	22.73	THHW	3 Current 1 Neutral 1 Ground	10 AWG	14 AWG	(3) 1 1/2" EMT
	4.04	THHW	1 Current 1 Neutral 1 Ground	14 AWG	14 AWG	1" EMT
	37.8	THHW	3 Current 1 Neutral 1 Ground	8 AWG	12 AWG	3/4" EMT
	350	THHW	3 Current 1 Neutral 1 Ground	(2) 2/0 AWG	4 AWG	2" EMT

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# 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

![](_page_34_Figure_0.jpeg)

owner choice between electrical panel savings or additional future capacity

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# 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

# new panelboard

FOR:     COMMON HVAC AND PUMPS     PHASE:     3 PH-4W       LOCATION:     MAIN ELECTRICAL ROOM     MAIN:     225 AULO       AC:     25,000 A     MOUNTING:     SURFACE       DESCRIPTION     LTG. VA     EQUIP. VA     HVAC VA     BREAKER AMPS     BUS     SREAKER     MOUNTING:     SURFACE       #EF-1 EXHAUST FAN     3,980     15     1     A     2     25     5.010     #CH-LO LINT HEATER       #FTU-8 TERMINAL UNIT     10,180     20     9     B     10     15     1,120     #TTU-AS FAN TERMINAL UNIT       #HTU-B TERMINAL UNIT     10,180     20     9     B     10     15     1,120     CHWP 1       11     C     12     20     3,000     #TTU-AS FAN TERMINAL UNIT     #TU-AS FAN TERMINAL     SPARE       #UH-A2 UNIT HEATER     5,000     15     13     A     14     P     SPARE       #UH-A2 UNIT HEATER     5,000     15     21     B     22     SPARE     SPARE       HW PUMP 1     1,120     15				PANEL:	HH1			VOLTAGE:	277/480	]			
LOCATION:     MAIN ELECTRICAL ROOM     MAIN:     228 A MLO       AIC:     25,000 A     MOUNTING:     SURFACE       DESCRIPTION     LTG. VA     EQUIP. VA     HVAC VA     BREAKER     HVAC VA     EQUIP.     LTG. VA     EQUIP. VA     HVAC VA     BREAKER     HVAC VA     EQUIP.     LTG. VA     DESCRIPTION     LTG. VA     DESCRIPTION     LTG. VA     DESCRIPTION     LTG. VA     DESCRIPTION     A     2     25     5010     HVAC VA     EQUIP. VA     HAT     VA     EQUIP. LTG. VA     EQUIP. LTG. VA     PARETAIL       #FT-L-B TEXHAUST FAN     3,980     15     1     A     14     15     1,180     #FTU-AS FAN TERMINAL UNIT       #UH-A1 UNIT HEATER     5,000     15     15     8     16     20     3,000     #CH-CUNIT HEATER       #UH-A2 UNIT HEATER     5,000     15     15     8     2     3,000     #CH-CUNIT HEATER     SPARE       #UH-A2				FOR:	COMMON HVAC AND PUMPS			PHASE:	3 PH-4W	1			
AIC:     25,000 A     MOUNTING:     SURFACE       DESCRIPTION     LTG. VA     EQUIP. VA     HVAC VA     BREAKER AMPS     BUS     BREAKER     HVAC VA     EQUIP. VA     ITG. VA     EQUIP. VA     HVAC VA     BREAKER AMPS     BUS     BREAKER     HVAC VA     EQUIP. VA     HVAC VA     DESCRIPTION       #EF-1 EXHAUST FAN     EQUIP. VA     HVAC VA     BREAKER AMPS     BREAKER     HVAC VA     EQUIP. VA     HVAC VA     EQUIP. VA     HTU-STATTERNIAL       #FTU-B TERMINAL UNIT     10,180     20     9     8     10     15     1,180     #FTU-ATATTERNINAL       #UH-A1 UNIT HEATER     0     0     1 <td></td> <td></td> <td></td> <td>LOCATION:</td> <td colspan="2">MAIN ELECTRICAL ROOM</td> <td>MAIN:</td> <td>225 A MLO</td> <td>1</td> <td></td> <td></td>				LOCATION:	MAIN ELECTRICAL ROOM		MAIN:	225 A MLO	1				
DESCRIPTION     LTG. VA     EQUIP. VA     HVAC VA     BREAKER AMPS     BUE     BREAKER     PAC VA     EQUIP. VA     LTG. VA     EQUIP. VA     VAC VA     BREAKER AMPS       #EF-1 EXHAUST FAN     3,980     15     3     8     4     15     1,180     #FTU-AT FAN TERMINAL UNIT HEATER       #FTU-B TERMINAL UNIT     10,180     29     8     10     15     1,180     #FTU-AT FAN TERMINAL UNIT HEATER       #UH-A1 UNIT HEATER     10,180     20     9     8     10     15     1,120     CHW PUMP 1       #UH-A1 UNIT HEATER     5,000     15     16     20     3,000     #FUL-AS FAN TERMINAL UNIT HEATER       #UH-A2 UNIT HEATER     5,000     15     16     20     3,000     #GUH-C UNIT HEATER       #UH-A2 UNIT HEATER     5,000     15     12     8     20     3,000     #GUH-C UNIT HEATER       #UH-A2 UNIT HEATER     5,000     15     18     8     20     3,000     #GUH-C UNIT HEATER       #UH-A2 UNIT HEATER     5,000     15     21     8 <t< td=""><td></td><td></td><td></td><td>AIC:</td><td>25,0</td><td>A 00</td><td></td><td></td><td>MOUNTING:</td><td>SURFACE</td><td>1</td><td></td><td></td></t<>				AIC:	25,0	A 00			MOUNTING:	SURFACE	1		
DESCRIPTION     LTG. VA     EQUIP. VA     HVAC VA     BREAKER AMPS     BUS     BREAKER     HVAC VA     EQUIP.     LTG. VA     DESCRIPTION       #EF-1 EXHAUST FAN     3,980     15     3     8     4     15     1,180     #fTU-4: FAN TERMINAL       #FTU-B TERMINAL UNIT     10,180     20     9     8     10     15     1,180     #fTU-4: FAN TERMINAL       #FTU-B TERMINAL UNIT     10,180     20     9     8     10     15     1,180     #fTU-4: FAN TERMINAL       #UH-A1 UNIT HEATER     10,180     20     9     8     10     15     1,120     CHW PUMP 1       #UH-A2 UNIT HEATER     5,000     15     15     8     16     20     3,000     #fUH-CUNIT HEATER       #UH-A2 UNIT HEATER     5,000     15     1     8     20     3,000     #fUH-CUNIT HEATER       #UH-A2 UNIT HEATER     5,000     15     27     8     20     3,000     #fUH-CUNIT HEATER       #UH-A2 UNIT HEATER     5,000     15     27     8											1		
#EF-1 EXHAUST FAN     3,980     15     1     A     2     25     5.010     #CUH-C UNIT HEATER       #FTU-B TERMINAL UNIT     10,180     20     6     15     1,180     #FTU-A3 FAN TERMINAL INTO     #FTU-A3 FAN TERMINAL UNIT       #FTU-B TERMINAL UNIT     10,180     20     9     B     10     15     1,180     #FTU-A3 FAN TERMINAL INTO       #UH-A1 UNIT HEATER     5,000     11     C     12     20     3,000     #CUH-C UNIT HEATER       #UH-A2 UNIT HEATER     5,000     15     15     B     16     20     3,000     #CUH-C UNIT HEATER       #UH-A2 UNIT HEATER     5,000     15     15     B     16     20     3,000     #CUH-C UNIT HEATER       #UH-A2 UNIT HEATER     5,000     15     18     B     20     3,000     #CUH-C UNIT HEATER       #UH-A2 UNIT HEATER     5,000     15     21     B     22     SPARE     SPARE       HW PUMP 1     1,120     15     27     B     28     SPARE     SPARE	DESCRIPTION	LTG. VA	EQUIP. VA	HVAC VA	BREAKER AMPS		BUS		BREAKER	HVAC VA	EQUIP.	LTG. VA	DESCRIPTION
#EF-1 EXHAUST FAN     3,980     15     3     8     4     15     1,180     #FTU-AT FAN TERMINAL WELL FIELD PUMP 2       #FTU-B TERMINAL UNIT     10,180     20     9     8     15     1,180     #FTU-AZ FAN TERMINAL WELL FIELD PUMP 2       #UH-A1 UNIT HEATER     5,000     15     11     C     12     20     3,000     #CUH-C UNIT HEATER       #UH-A1 UNIT HEATER     5,000     15     15     B     16     20     3,000     #CUH-C UNIT HEATER       #UH-A2 UNIT HEATER     5,000     15     15     B     20     3,000     #CUH-C UNIT HEATER       #UH-A2 UNIT HEATER     5,000     15     21     B     20     3,000     #CUH-C UNIT HEATER       #UH-A2 UNIT HEATER     5,000     15     21     B     20     3,000     #CUH-C UNIT HEATER       #UH-A2 UNIT HEATER     5,000     15     21     B     20     3,000     #CUH-C UNIT HEATER       WUM 2     1,120     15     25     A     26      SPARE       WELL FIELD						1	Α	2	25	5,010			#CUH-C UNIT HEATER
#FTU-B TERMINAL UNIT     #FTU-A2 FAN TERMINAL #FTU-A3 FAN TERMINAL UNIT     #FTU-A3 FAN TERMINAL UNIT       #FTU-B TERMINAL UNIT     10,160     20     9     8     15     1,180     #FTU-A3 FAN TERMINAL UNIT       #UH-A1 UNIT HEATER     5,000     15     12     20     3,000     #CUH-C UNIT HEATER       #UH-A1 UNIT HEATER     5,000     15     15     8     16     20     3,000     #CUH-C UNIT HEATER       #UH-A2 UNIT HEATER     5,000     15     15     8     16     20     3,000     #CUH-C UNIT HEATER       #W PUMP 1     1,120     15     27     18     20      SPARE       HW PUMP 2     1,120     15     27     8     28       SPARE       WELL FIELD PUMP 1     1,800     40     35     C     36      SPARE       WELL FIELD PUMP 2     18,600     40     35     C     36      SPARE       WELL FIELD PUMP 2     18,600     40     35     C     36 <t< td=""><td>#EF-1 EXHAUST FAN</td><td></td><td></td><td>3,980</td><td>15</td><td>3</td><td>В</td><td>4</td><td>15</td><td>1,180</td><td></td><td></td><td>#FTU-A1 FAN TERMINAL</td></t<>	#EF-1 EXHAUST FAN			3,980	15	3	В	4	15	1,180			#FTU-A1 FAN TERMINAL
#FTU-B TERMINAL UNIT						5	С	6	15	1,180			#FTU-A2 FAN TERMINAL
#FTU-B TERMINAL UNIT     10,180     20     9     B     10     15     1,120     CHW PUMP 1       #UH-A1 UNIT HEATER     5,000     15     13     A     14     SPARE     \$						7	Α	8	15	1,180			#FTU-A3 FAN TERMINAL
UNIT     Image: constraint of the constraint of	#FTU-B TERMINAL			10,180	20	9	В	10	15	1,120			CHW PUMP 1
#UH-A1 UNIT HEATER     5,000     15     13     A     14	UNIT					11	С	12	20	3,000			#CUH-C UNIT HEATER
#UH-A1 UNIT HEATER   5,000   15   15   B   16   20   3,000   #CUH-C UNIT HEATER     #UH-A2 UNIT HEATER   5,000   15   16   20   3,000   #CUH-C UNIT HEATER     #UH-A2 UNIT HEATER   5,000   15   17   C   18   20   3000   #CUH-C UNIT HEATER     #WH-A2 UNIT HEATER   5,000   15   15   21   B   22    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   33   B   34     SPARE     WELL FIELD PUMP 2   18,600   40   33   B   34     SPARE     WELL FIELD PUMP 2   18,600   40   39   B   40   60   10,880   18,860   PANEL*HPI*     Totals						13	Α	14					SPARE
Image: book of the second se	#UH-A1 UNIT HEATER			5,000	15	15	В	16	20	3,000			#CUH-C UNIT HEATER
						17	С	18	20	3,000			#CUH-C UNIT HEATER
						19	Α	20					SPARE
Image: Constraint of the second sec	#UH-A2 UNIT HEATER			5,000	15	21	В	22					SPARE
HW PUMP 1   1,120   15   25   A   26   Image: Constraint of the synthesis of the synthesynthesis of the synthesis of t						23	С	24					SPARE
HW PUMP 2   1,120   15   27   B   28   Image: Constraint of the synthesis of the synthesynthesis of the synthesis of the synthesis of t	HW PUMP 1			1,120	15	25	Α	26					SPARE
CHW PUMP 2     1,120     15     29     C     30     Image: Constraint of the constraint of	HW PUMP 2			1,120	15	27	В	28					SPARE
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	CHW PUMP 2			1,120	15	29	С	30					SPARE
WELL FIELD PUMP 1     18,600     40     33     B     34     Image: Constraint of the synthesis of the synthesynthesis of the synthesis of the synthesis of the s						31	Α	32					SPARE
Image: second	WELL FIELD PUMP 1			18,600	40	33	В	34					SPARE
WELL FIELD PUMP 2     Image: Constraint of the state of the						35	С	36					SPARE
WELL FIELD PUMP 2     Image: Non-Section of Control						37	Α	38					
Image: Non-Section of the section of the se	WELL FIELD PUMP 2			18,600	40	39	В	40	60	10,880	18,860		PANEL "HP1"
Totals     0     0     64,720     29,550     18,860     0     Totals       Image: Constraint of the stress of						41	С	42	1				TRANSFORMER
Totals   0   0   64,720   Image: Normal and the stress of													
LOAD DESCRIPTION     CONN.     DEMAND VA.     PHASE VA       LIGHTING     0     0     A     37,677       GENERAL POWER     18,860     9,430     B     36,787       HVAC EQUIPMENT     94,270     94,270     C     38,667	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   Image: State of the													
LOAD DESCRIPTION     CONN.     DEMAND VA.     PHASE VA       LIGHTING     0     0     A     37,677       GENERAL POWER     18,860     9,430     B     36,787       HVAC EQUIPMENT     94,270     94,270     C     38,667													
LIGHTING     0     0     A     37,677       GENERAL POWER     18,860     9,430     B     36,787       HVAC EQUIPMENT     94,270     94,270     C     38,667       LIGHTING     Image: Comparison of the second sec	LOAD DESCRIPTION	CONN.	DEMAND VA.								PHASE VA		
GENERAL POWER     18,860     9,430     B     36,787       HVAC EQUIPMENT     94,270     94,270     C     38,667	LIGHTING	0	0								A	37,677	
HVAC EQUIPMENT     94,270     94,270     C     38,667	GENERAL POWER	18,860	9,430								В	36,787	
	HVAC EQUIPMENT	94,270	94,270								С	38,667	
TOTAL 113,130 103,700 TOTAL 113,130	TOTAL	113,130	103,700								TOTAL	113,130	
PERCENT LOADED 90.50% 82.96%	PERCENT LOADED	90.50%	82.96%										

![](_page_35_Figure_0.jpeg)

conclusion

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# 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

![](_page_35_Picture_13.jpeg)

![](_page_36_Figure_0.jpeg)

thesis proposal

mechanical depth

electrical breadth

conclusion

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# acknowledgements

Liberty Property Trust

Turner Construction

In Posse

Dr. Laura Miller

Penn State University

friends | family | co-workers

![](_page_36_Picture_16.jpeg)

![](_page_37_Figure_0.jpeg)

thesis proposal

mechanical depth

electrical breadth

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# questions

# recommendations

![](_page_37_Picture_11.jpeg)

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thesis final presentation | april 15, 2014