PHIPPS
center for sustainable landscapes

[architectural engineering thesis . mechanical option]

by JOSH WENTZ

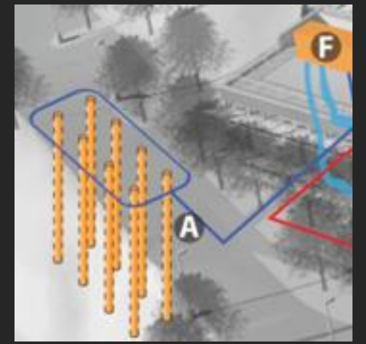
BAE Architectural Engineering
Mechanical Option

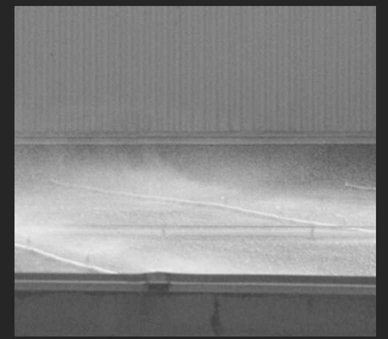
BS Information Sciences & Technology
Integration & Application Option

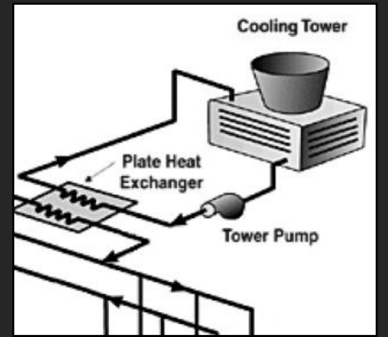
by JOSH WENTZ


PROJECT

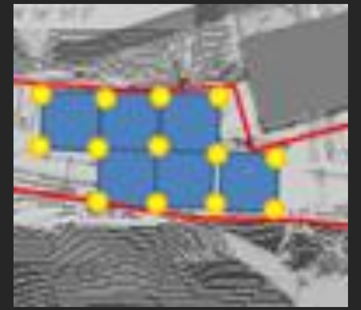
EXISTING

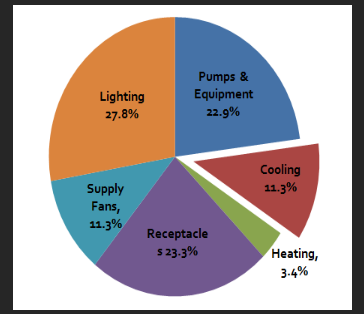

PROPOSED

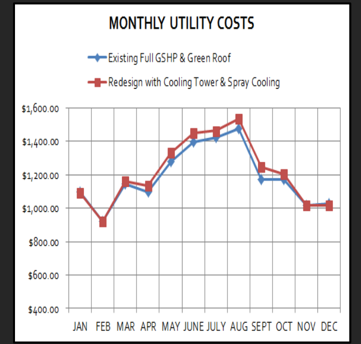

DEPTH 1



DEPTH 2


BREADTH


ENERGY

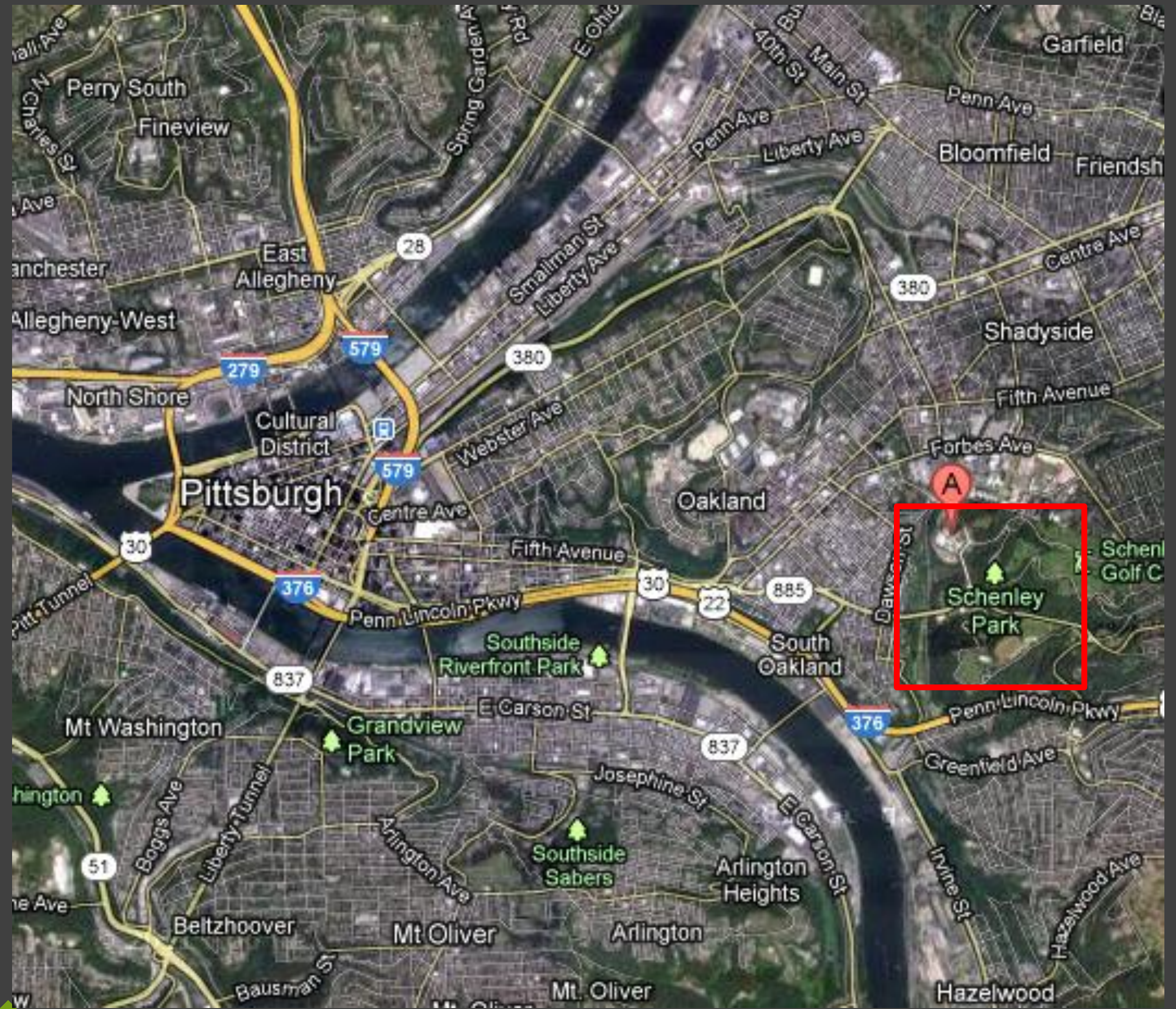


COSTS


CONCLUSION

[project]

Pittsburgh, PA



OFFICE / CLASSROOM / CONFERENCE

for

Phipps Employees / University Researchers

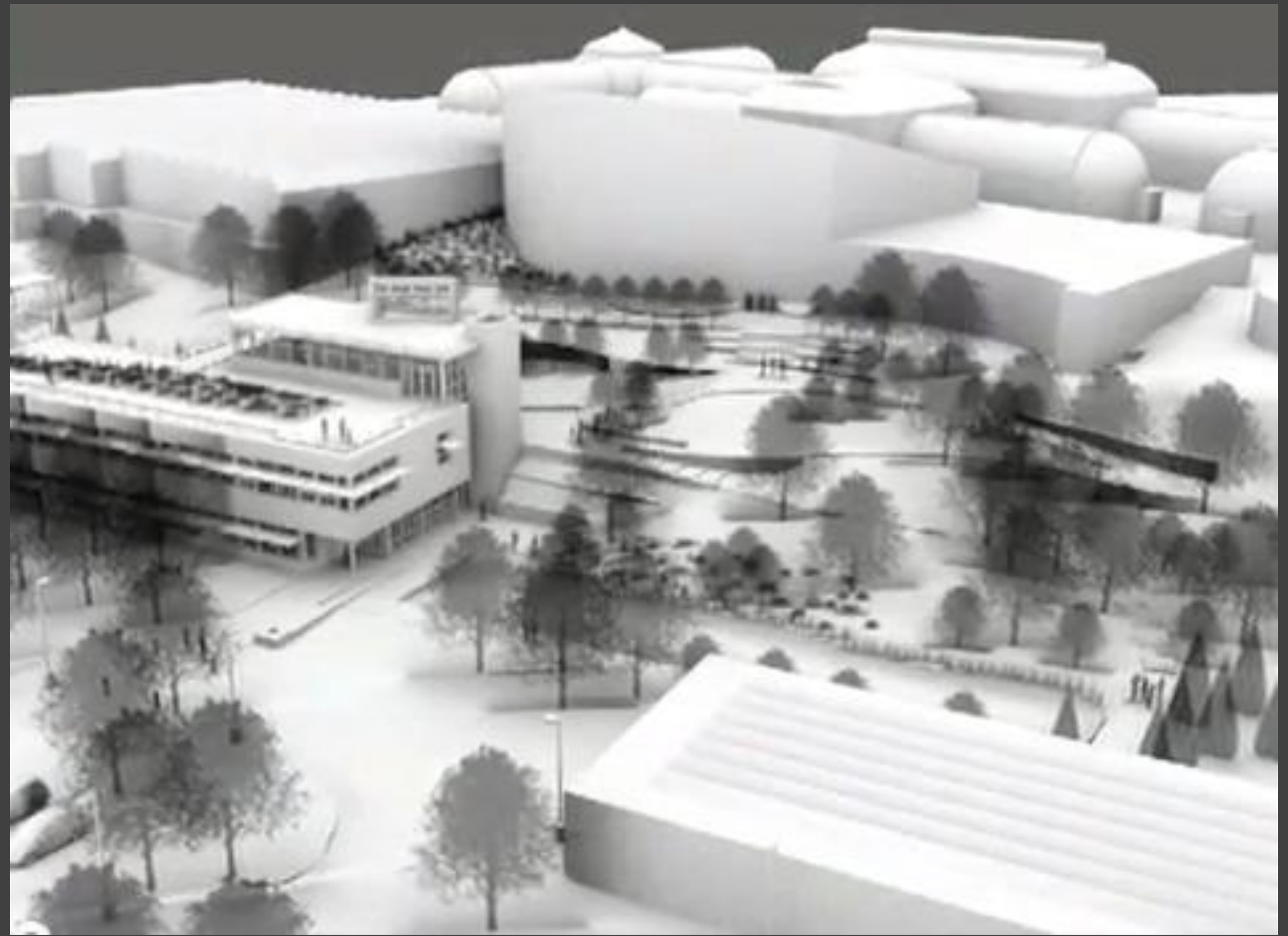
24,350 square foot

Dec. 2010 – Apr. 2012

$ **$20 million**

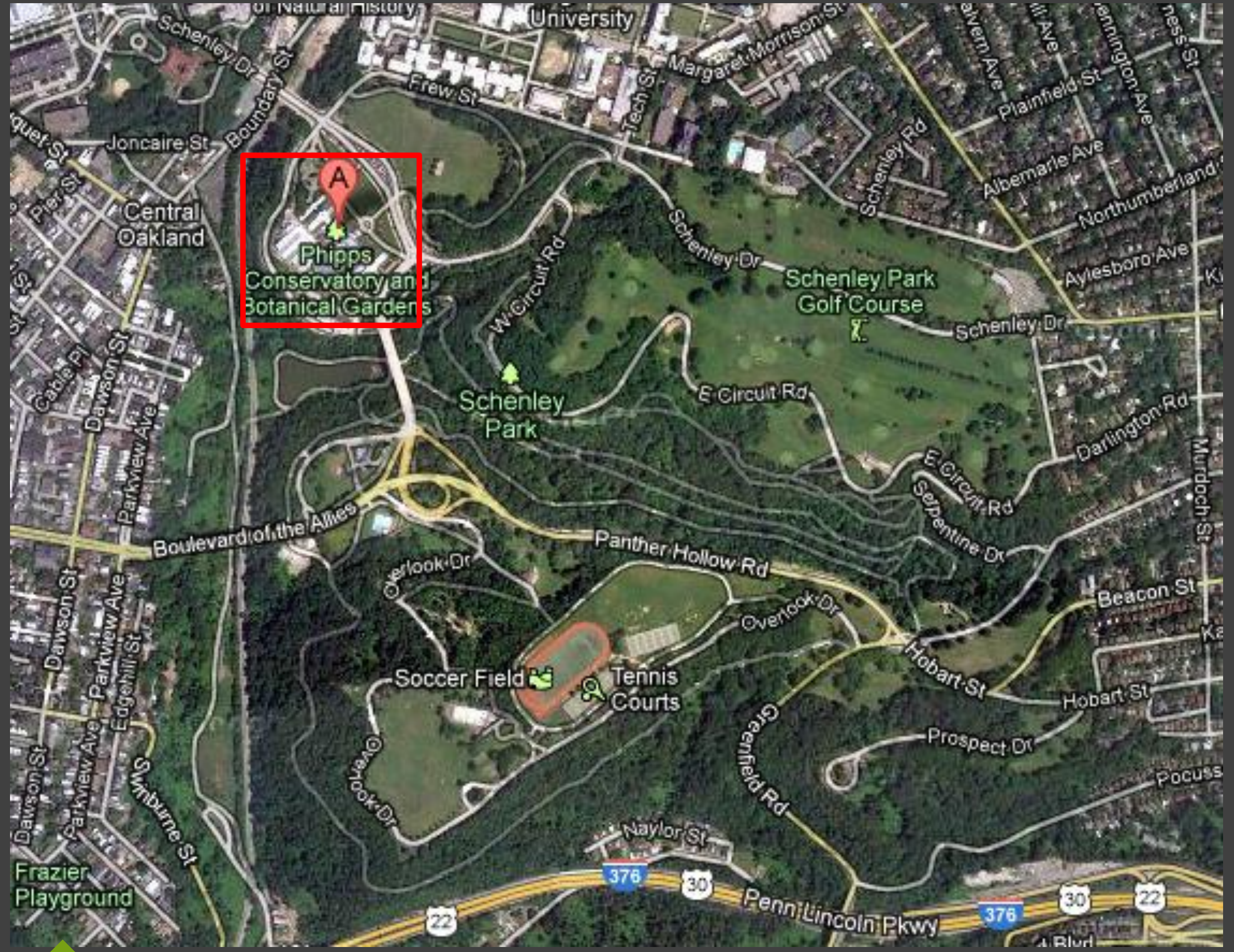
Lump Sum with Contractor

Phipps Conservatory & Botanical Gardens educates & entertains people with formal gardens & exotic plants



center for sustainable landscapes

Schenley Park



OFFICE / CLASSROOM / CONFERENCE

for

Phipps Employees / University Researchers

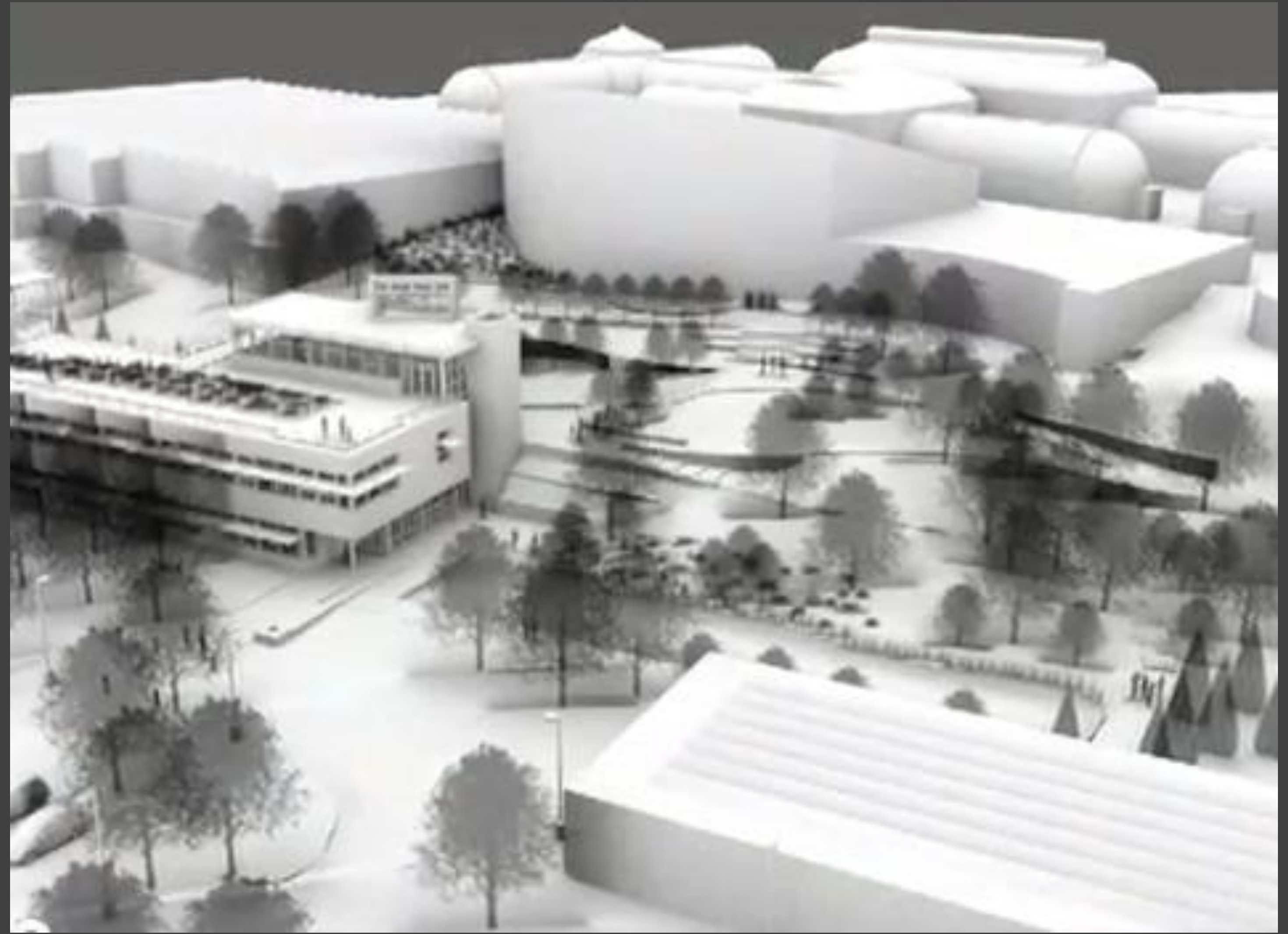
24,350 square foot

Dec. 2010 – Apr. 2012

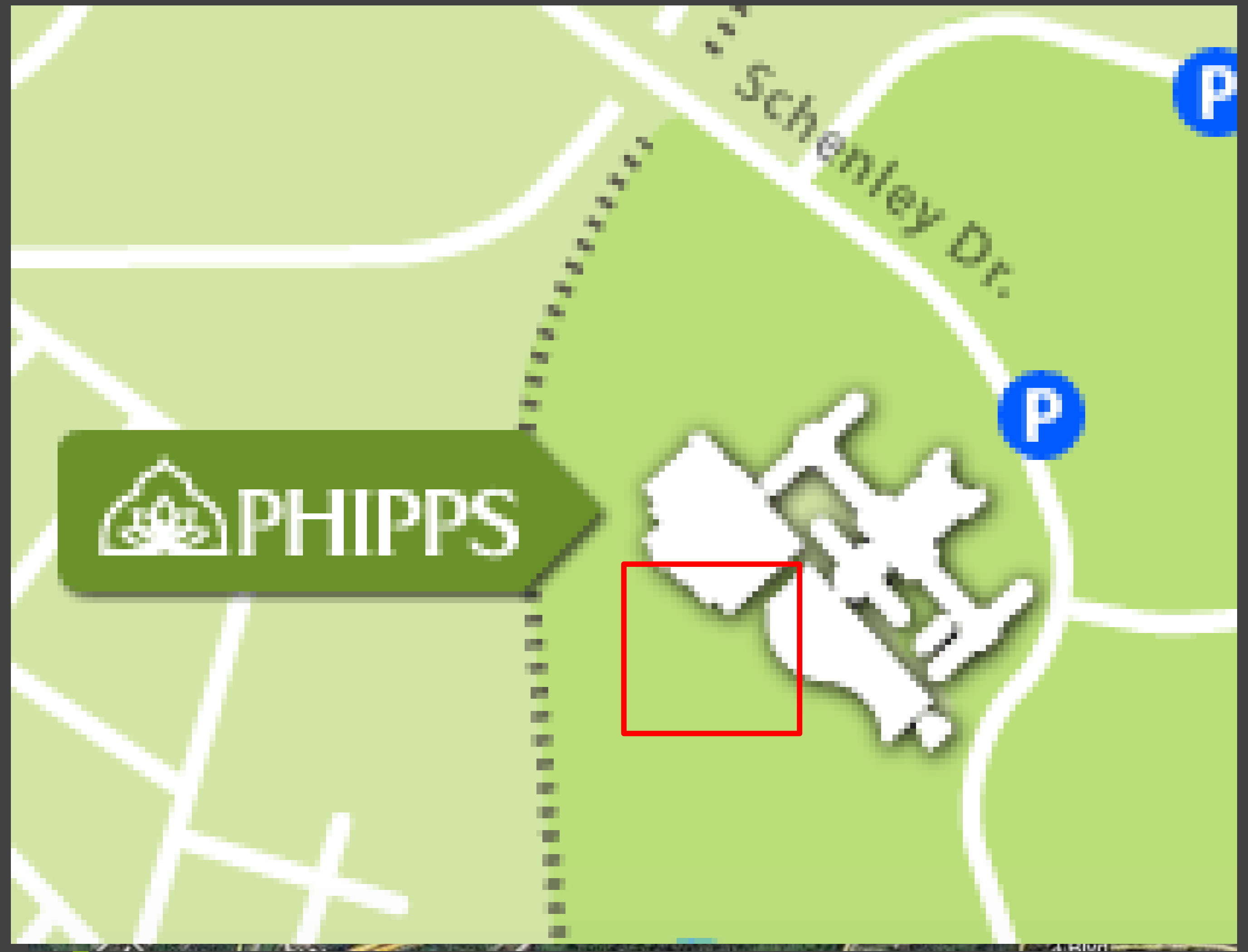
$ **$20 million**

Lump Sum with Contractor

Phipps Conservatory & Botanical Gardens educates & entertains people with formal gardens & exotic plants



Phipps Conservatory



OFFICE / CLASSROOM / CONFERENCE

for

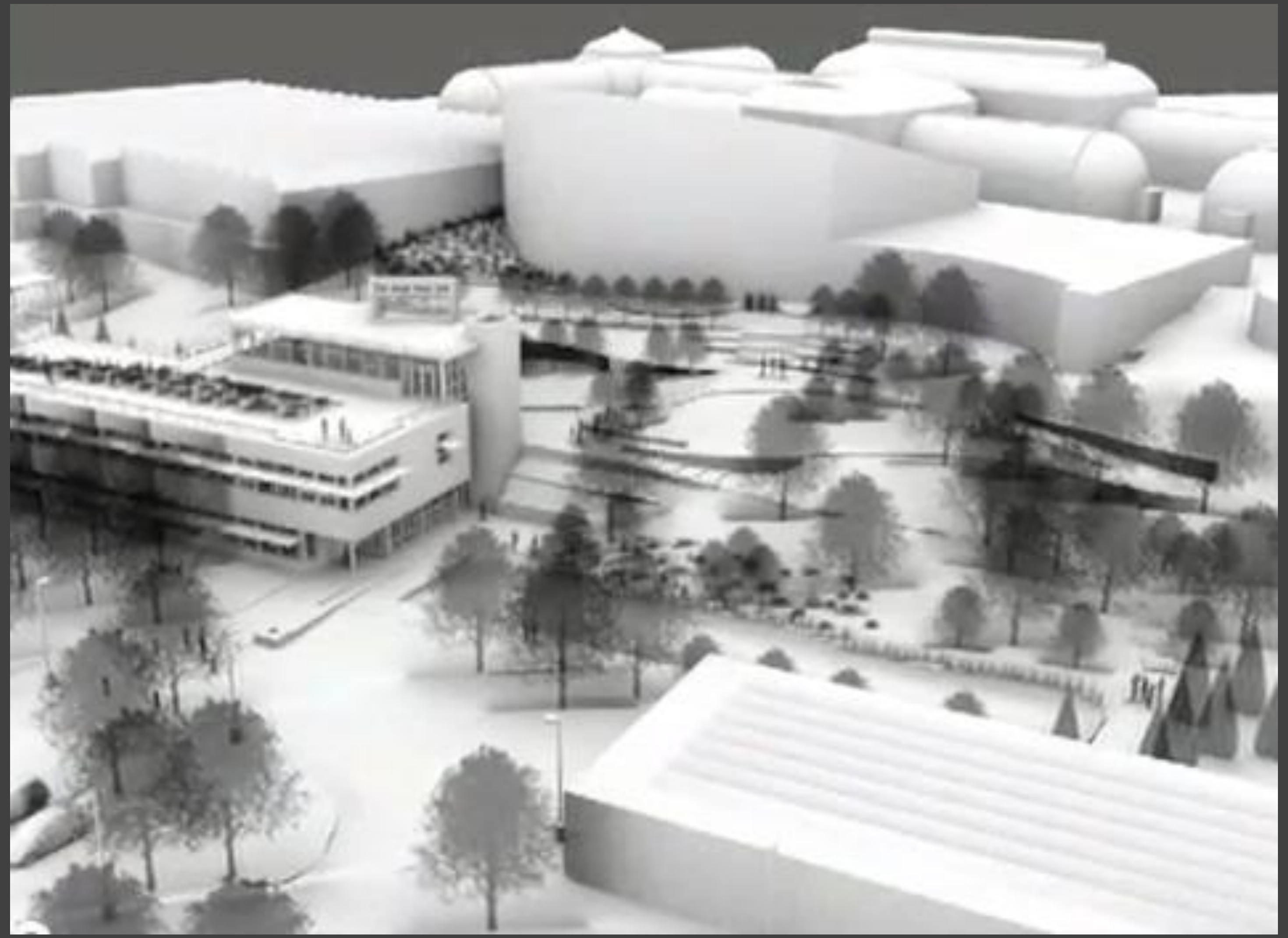
Phipps Employees / University Researchers

24,350 square foot

Dec. 2010 – Apr. 2012

$ **$20 million**

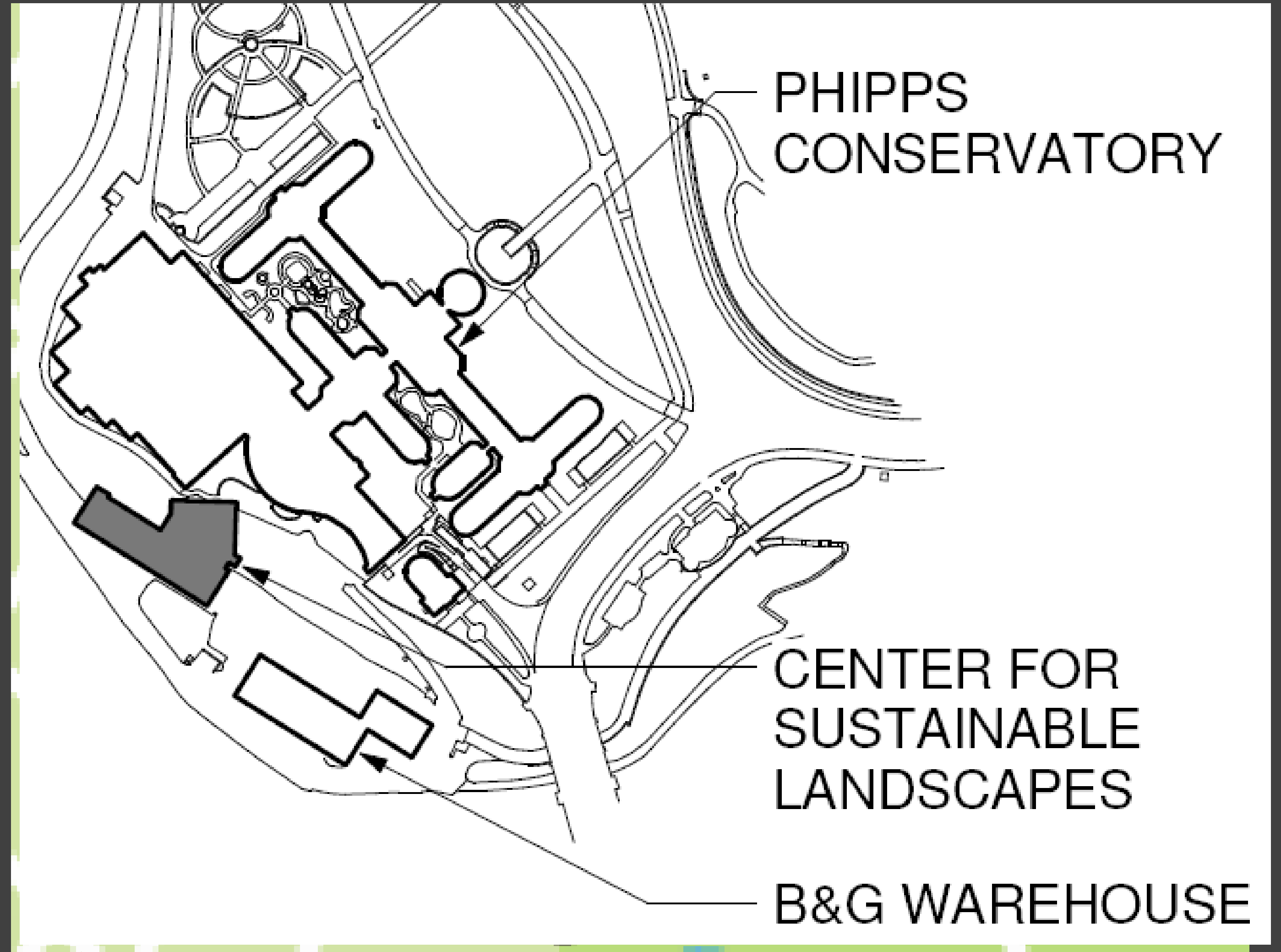
Lump Sum with Contractor



Phipps Conservatory & Botanical Gardens educates & entertains people with formal gardens & exotic plants

center for sustainable landscapes

Phipps Conservatory



OFFICE / CLASSROOM / CONFERENCE
for
Phipps Employees / University Researchers

24,350 square foot

Dec. 2010 – Apr. 2012

$ **$20 million**
Lump Sum with Contractor

Phipps Conservatory & Botanical Gardens educates & entertains people with formal gardens & exotic plants

team

OWNER

PHIPPS

ARCHITECT	LANDSCAPE	STRUCTURAL ENGINEER	MEP ENGINEER	LEED CONSULTANTS	CONSTRUCTION MANAGER
The Design Alliance	Andropogoan Associates	Atlantic Engineering Services	CJL Engineering	10+	Turner Construction

[existing]

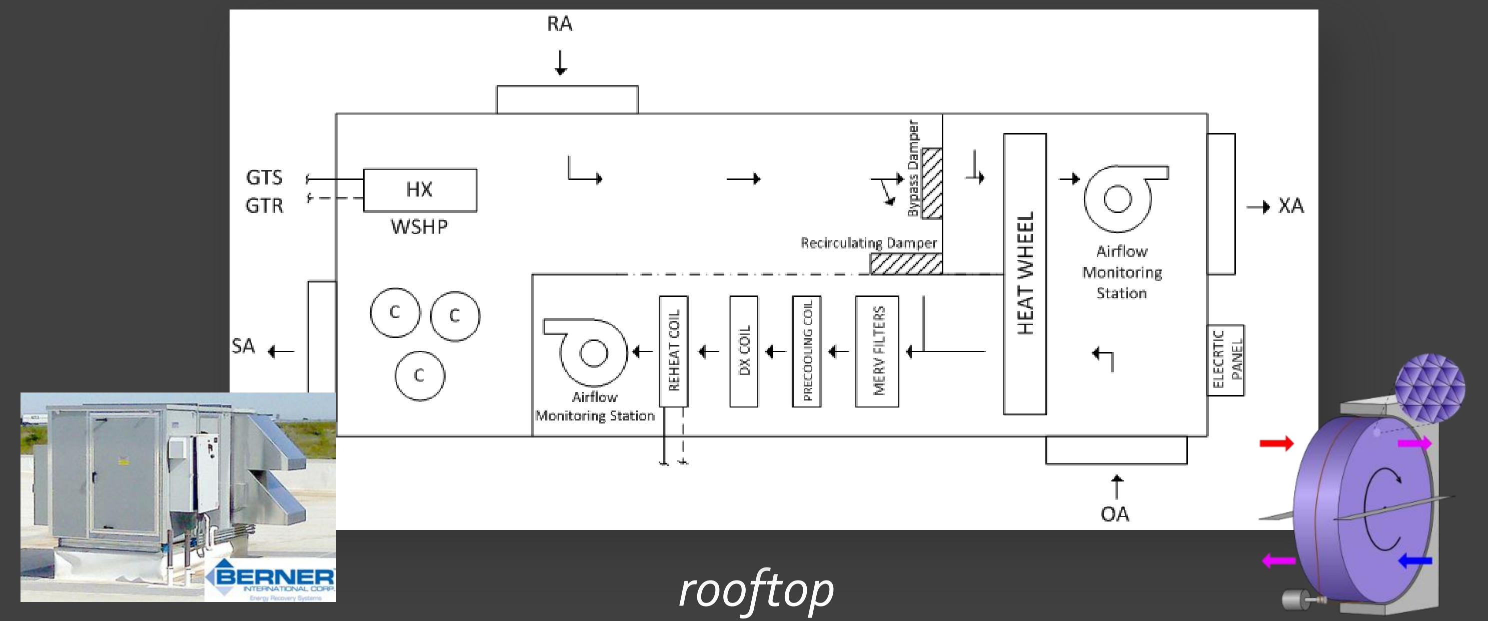
mechanical systems

GEOTHERMAL FULL GROUND SOURCE

driveway

- + Ground Source Heat Exchanger at 55 F
- + 2 pumps at 2 HP, 1750 RPM … *in mechanical room*
- + Small mechanical room

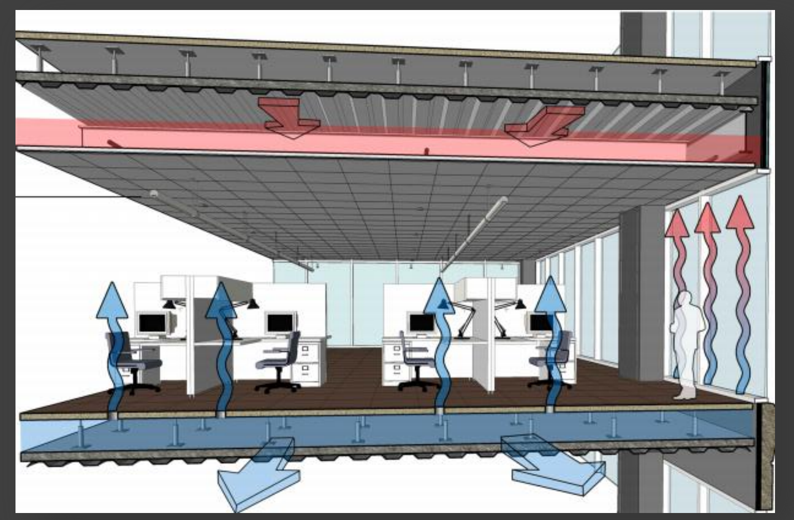
ENERGY RECOVERY UNIT



rooftop

- + 2 MODES: Energy Recovery Ventilator & DOAS
- + 12,400 cfm
- + Enthalpy Wheel Economizer Mode

UNDERFLOOR AIR DISTRIBUTION



open offices, classrooms

- + Decreases duct runs
- + Perimeter diffusers
- + Convective heat created from people, computers

water side

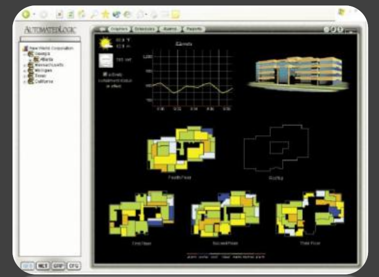
air side

desiccant dehumidification

demand controlled ventilation

minimally conditioned atrium

natural ventilation



building management system

passive solar design

[1] LEED Platinum

[2] Living Building Challenge

[3] SITES Certification for Landscapes

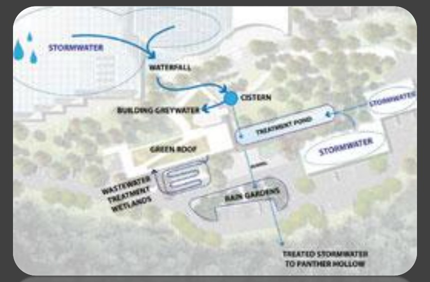
10+ Consultants

32/32 LEED pts for mechanical systems

green roof

solar photovoltaics

wind turbine



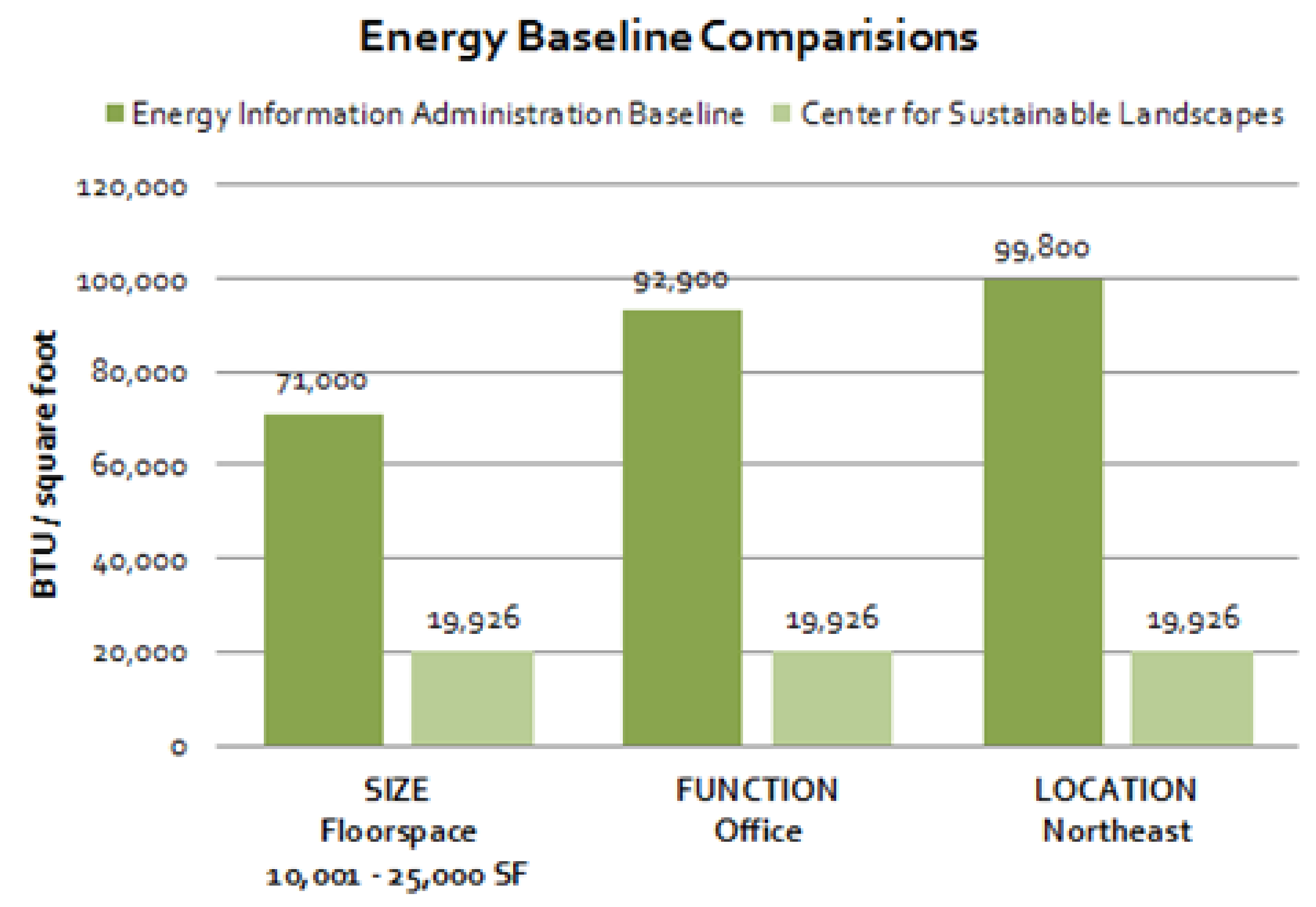
rainwater harvesting

constructed wetland

lagoon system

evaluation

CRITERIA	GRADE
Space	A
Comfort	B
Health & Indoor Air Quality	A
Controls & Maintainability	D
Energy	A
Costs	C
Sustainability	A



75%

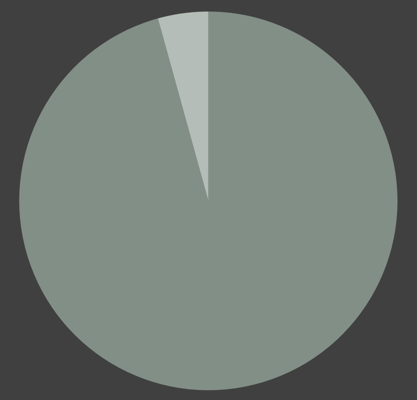
Less Energy

[www.eia.gov/state/state-energy-profiles-data.cfm?sid=PA#Prices]

$856,000

$20 million

total costs



4.3%

building costs due to mechanical systems

= $35.15 per SF

[proposed]

depths

goals

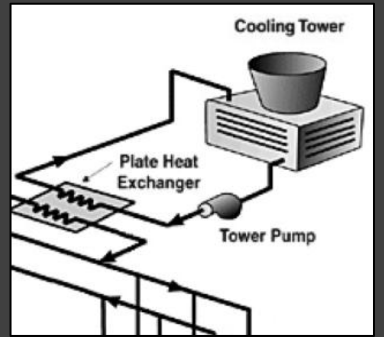
breadths

MECHANICAL

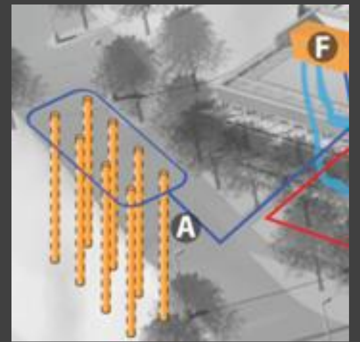
1

Green Roof
Spray Cooled Roof

2



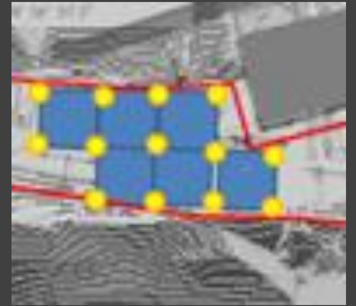
Full Geothermal
Hybrid Geothermal



DECREASE Initial Costs

Similar Energy Performance

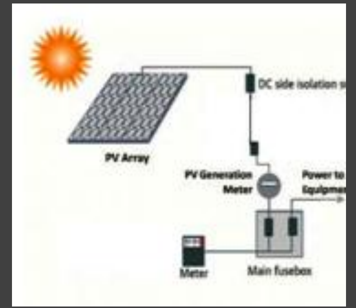
1



CONSTRUCTION
Bore Hole Optimization

2

ELECTRICAL
Direct Current Distribution

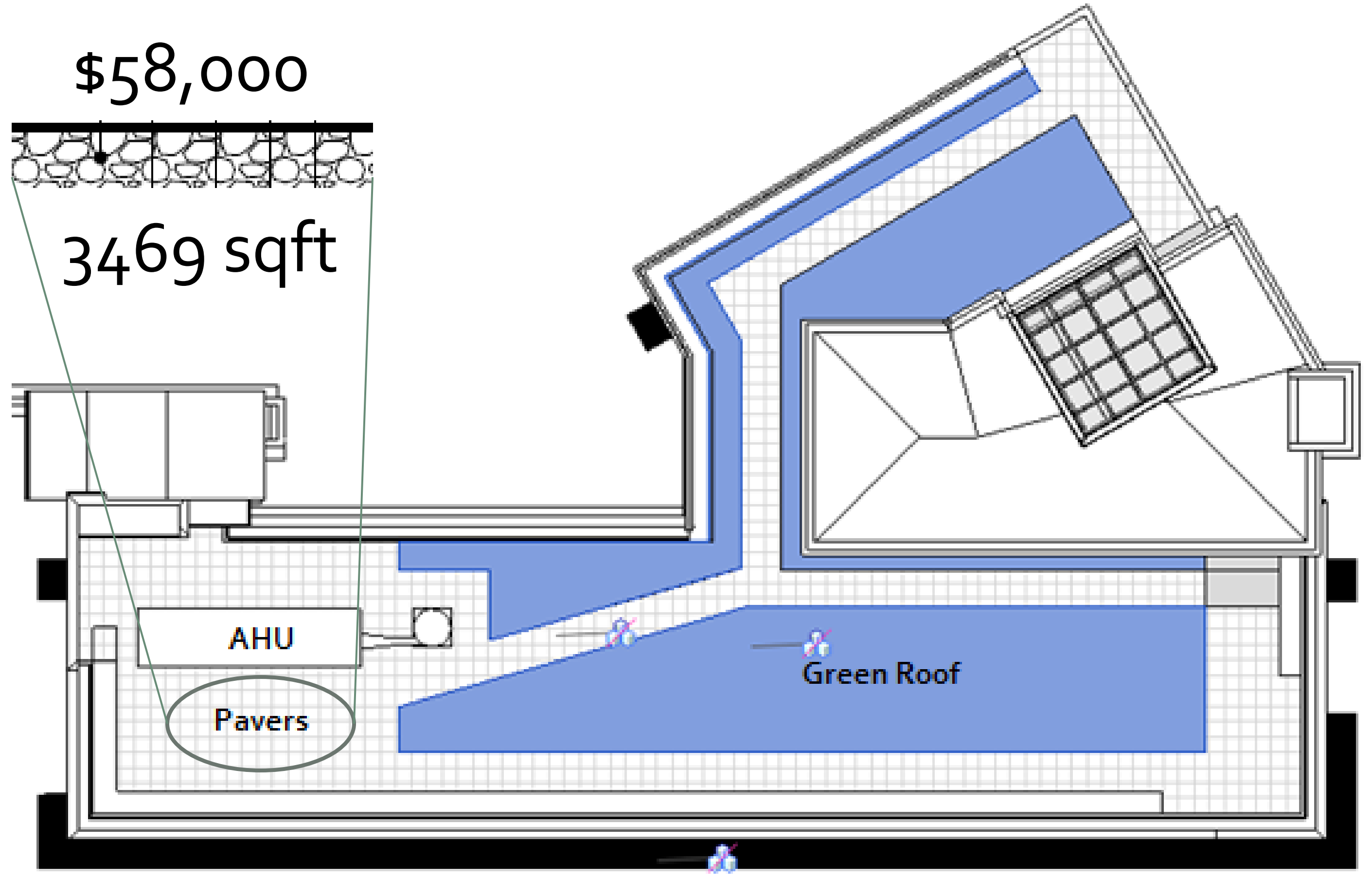


[depth 1]

spray cooled roof

green roof

$141,000



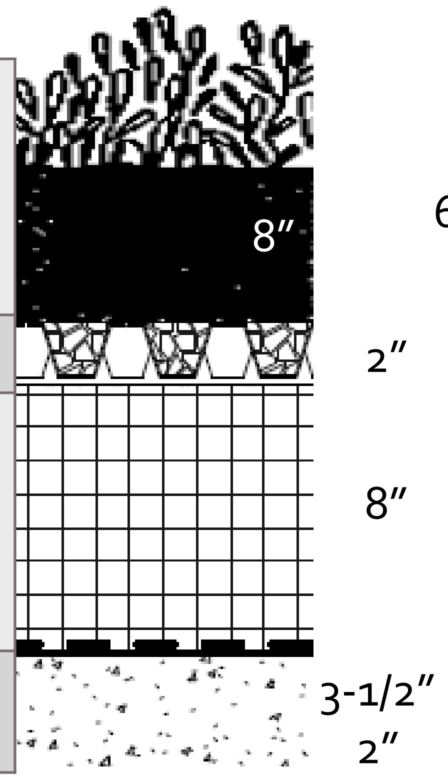
3216 sqft

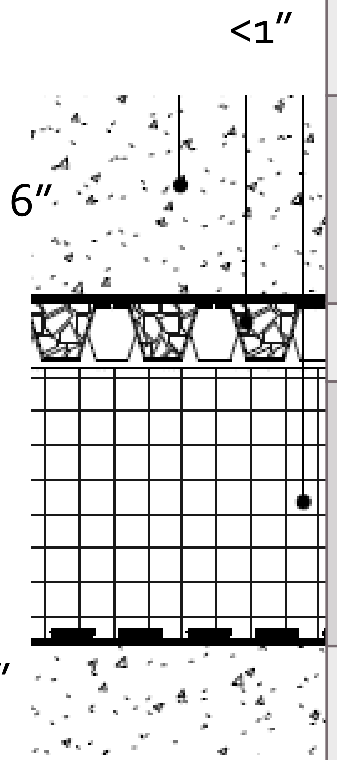
48% total

insulation

$83,000 or $26 / sqft

R-7	Growing Medium	
R-0	Drainage Course	
R-40	Rigid Insulation (extruded polystyrene)	
R-1.5 R-0	Concrete Slab Composite Steel Deck	





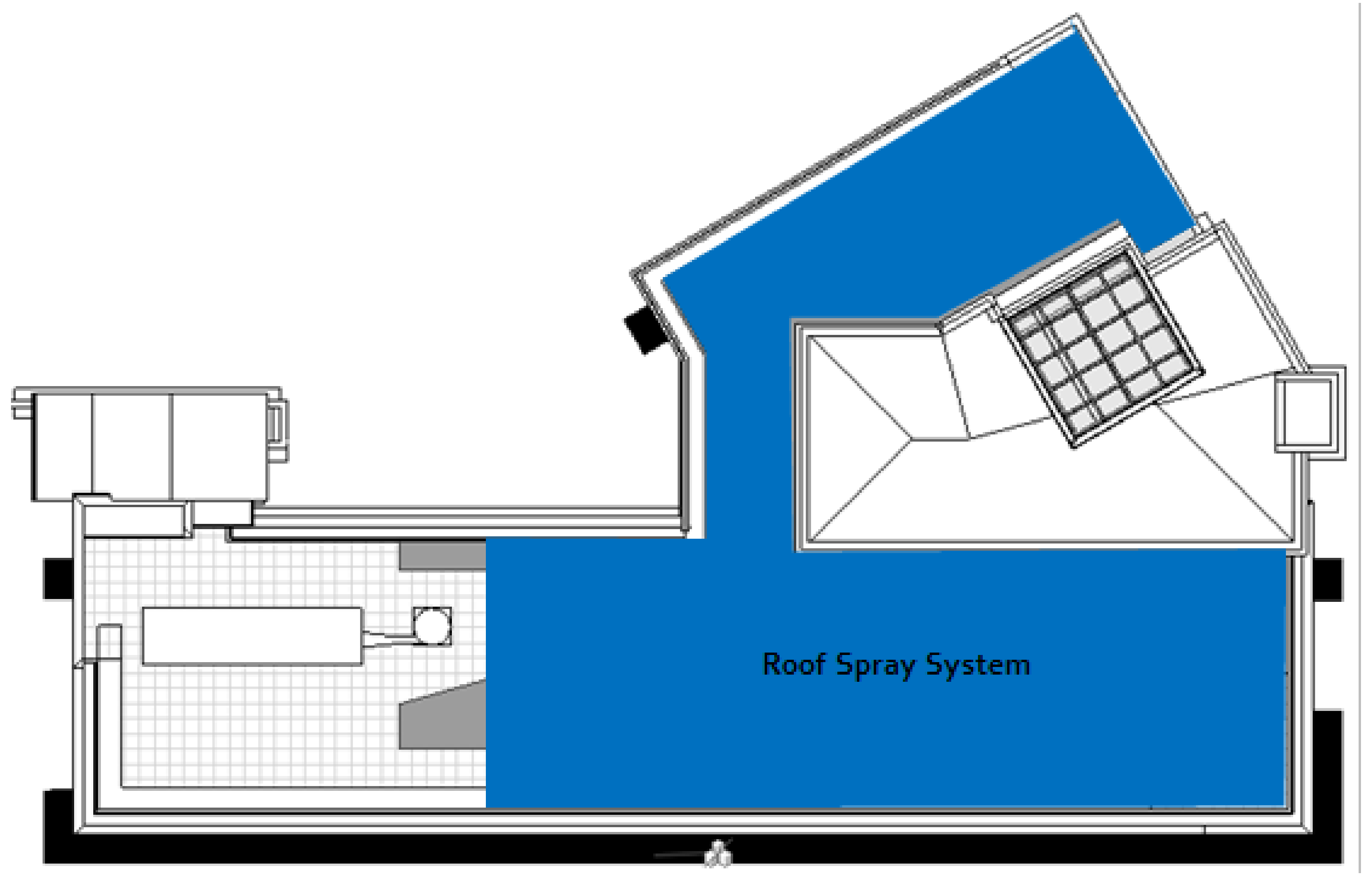
Layer of Misted Water in Summer	R~100 day R=0 night
Cast-in-Place Concrete	R-1.8
Drainage Course	R-0
Rigid Insulation (extruded polystyrene) $44,000	R-40
Concrete Slab Composite Steel Deck	R-1.5 R-0

R-48.5

R-43-143

spray cooled roof

$ TBD

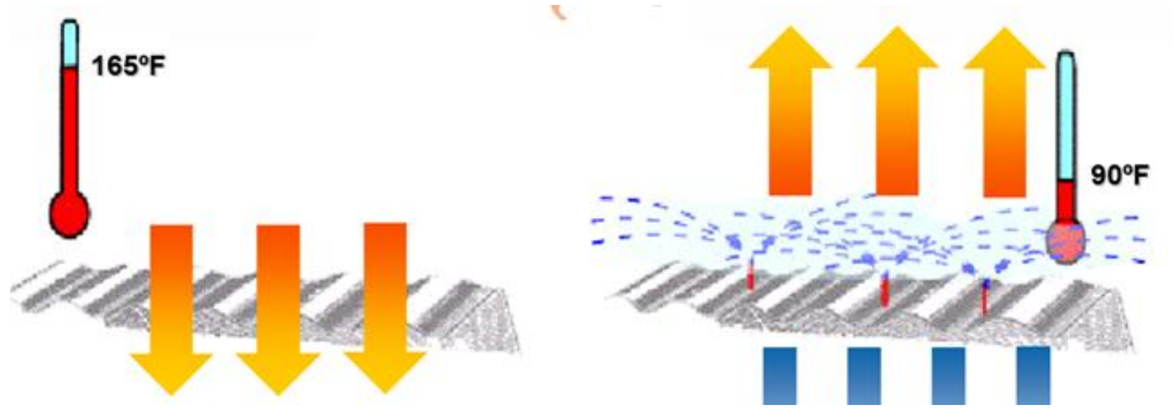


5645 sqft

85% total

vendor

SPRINKOOL SYSTEM INTERNATIONAL

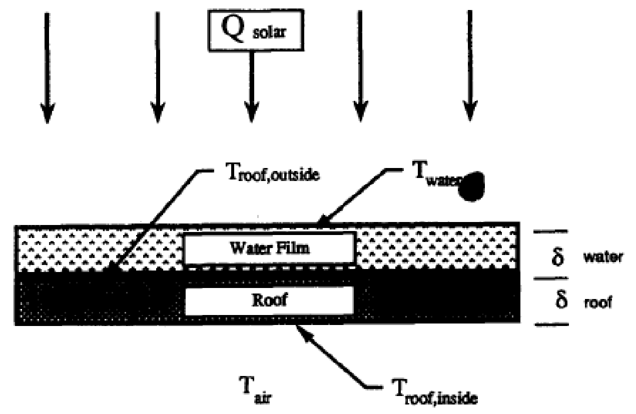


1 gal H20 absorbs 8,265 BTUs in evaporation

modeling

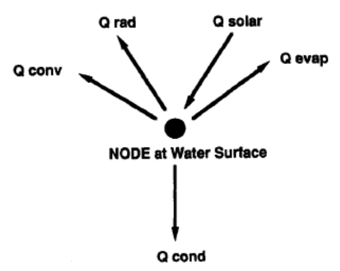
PHYSICS

Evaporative Heat Transfer Coeff = 5.678 W/m2



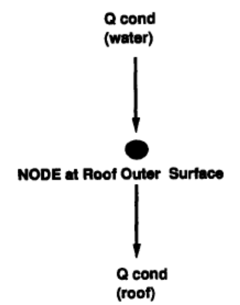
1-D Heat Flow Quasi-steady state

WATER SURFACE



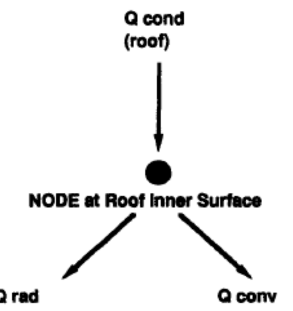
$$q_{solar} = q_{evqp} + q_{rad} + q_{conv} + q_{\ cond}$$

ROOF OUTER SURFACE



$$q_{cond(water)} = q_{cond(roof)}$$

ROOF INNER SURFACE



$$q_{cond(roof)} = q_{rad(inside)} + q_{conv(inside)}$$

ASHRAE CLTD

q = UA (CLTD) corrected
U = 0.023BTU/hr*ft2F
A = 5645.5 SF
CLTD ADJUSTED FOR latitude-month, exterior surface color, indoor & outdoor design temp, solar radiation, insulation

1. **Hourly Temperature Variation**
   - Design Month = AUG, 10 Hour Avg = 81.55 F
2. **Hourly Cooling Load Temperature Differential**
   - CLTD(c) = [(CLTD(unc)) + LM) * K + (78 F – Tr) + (To – 85 F)] *f
3. **Monthly Cooling Load Temperature Differential**
   - Used for Usage Reduction in Energy Analysis
4. **Peak Monthly Cooling Load Temperature Differential**

modeling

1. Hourly Temperature Variation

Solar Time [hrs]	1-9	9	10	11	12	13	14	15	16	17	18	19-24	10 hr. Avg.
Daily Range Ratio	0	0.7	0.6	0.4	0.2	0.1	0	0	0	0.1	0.2	0	
Dry Bulb [F]	0	87	87	87	87	87	87	87	87	87	87	0	
Daily Range	0	23	23	23	23	23	23	23	23	23	23	0	
To=Dry Bulb - Range*Ratio	0	71	74	78	82	84	86	87	86	85	82	0	81.55

10 hr. Avg. Daily Range 81.6 F

2. Hourly Cooling Load Temperature Differential

Solar Time [hrs]	1-8	9	10	11	12	13	14	15	16	17	18	19-24	10 hr. Avg.
CLTD (uncorrected) @1400 hours	0	34	49	61	71	78	79	77	70	59	45	0	62.3
LM (Latitude/Month correction) JUNE	0	2	2	2	2	2	2	2	2	2	2	0	
CLTD & LM	0	36	51	63	73	80	81	79	72	61	47	0	
K = 1	0	1	1	1	1	1	1	1	1	1	1	0	
(CLTD & LM)K	0	36	51	63	73	80	81	79	72	61	47	0	
78 F - Tr Tr = 78 F	0	0	0	0	0	0	0	0	0	0	0	0	
To - 85 To = 81.55 F	0	-3	-3	-3	-3	-3	-3	-3	-3	-3	-3	0	
f = 1	0	1	1	1	1	1	1	1	1	1	1	0	
CLTD (corrected)	0	33	48	60	70	77	78	76	69	58	44	0	61.3

10 hr. Avg. CLTD(c) 61.3 F

3. Monthly Cooling Load Temperature Differential

MONTH	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	MO. AVG.
CLTD (uncorrected) 10 hr. average	62.3	62.3	62.3	62.3	62.3	62.3	62.3	
LM (Latitude/Month correction)	-3	1	2	1	-3	-8	-14	
CLTD & LM	59	63	64	63	59	54	48	
K = 1	1	1	1	1	1	1	1	
(CLTD & LM)K	59	63	64	63	59	54	48	
78 F - Tr Tr = 78 F	0	0	0	0	0	0	0	
To - 85 To = 81.55 F	-3	-3	-3	-3	-3	-3	-3	
f = 1	1	1	1	1	1	1	1	
CLTD (corrected)	50	54	55	54	50	46	41	50

Mo. Avg. CLTD (c) 50 F

4. Peak Monthly Cooling Load Temperature Differential

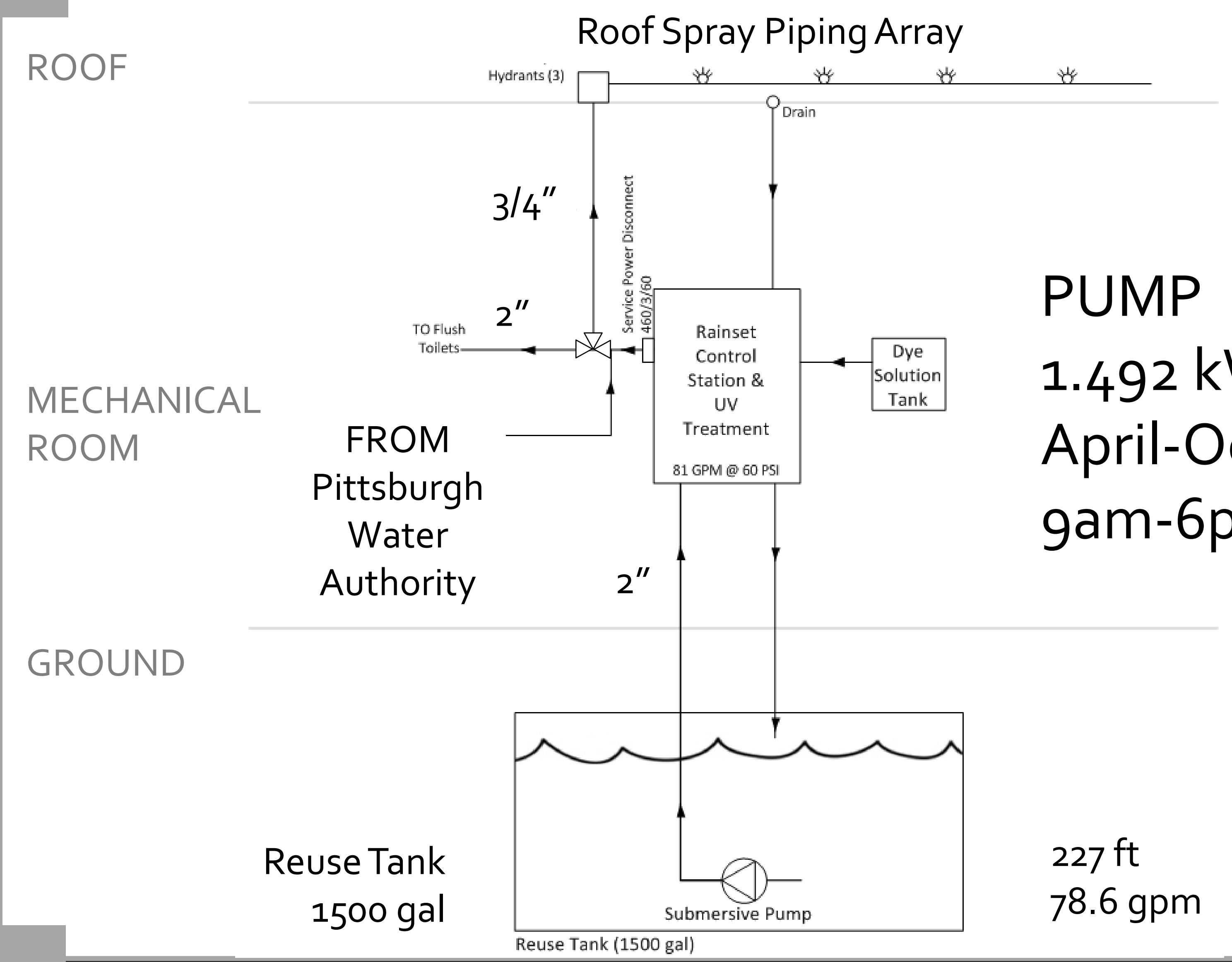
MONTH	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	MO. AVG.
CLTD (uncorrected) 10 hr. average				79	79	79	79	79	79	79			
LM (Latitude/Month correction)	-19	-14	-8	-3	1	2	1	-3	-8	-14	-19	-21	
CLTD & LM				76	80	81	80	76	71	65			
K = 1				1	1	1	1	1	1	1			
(CLTD & LM)K				76	80	81	80	76	71	65			
78 F - Tr Tr = 78 F				0	0	0	0	0	0	0			
To - 85 To = 81.55 F				-3	-3	-3	-3	-3	-3	-3			
f = 1				1	1	1	1	1	1	1			
CLTD (corrected)				66	69	70	69	66	61	56			65

Mo. Avg. CLTD (c) 65 F

GREEN ROOF CALCULATOR

by Portland State University, added to EnergyPlus

schematic



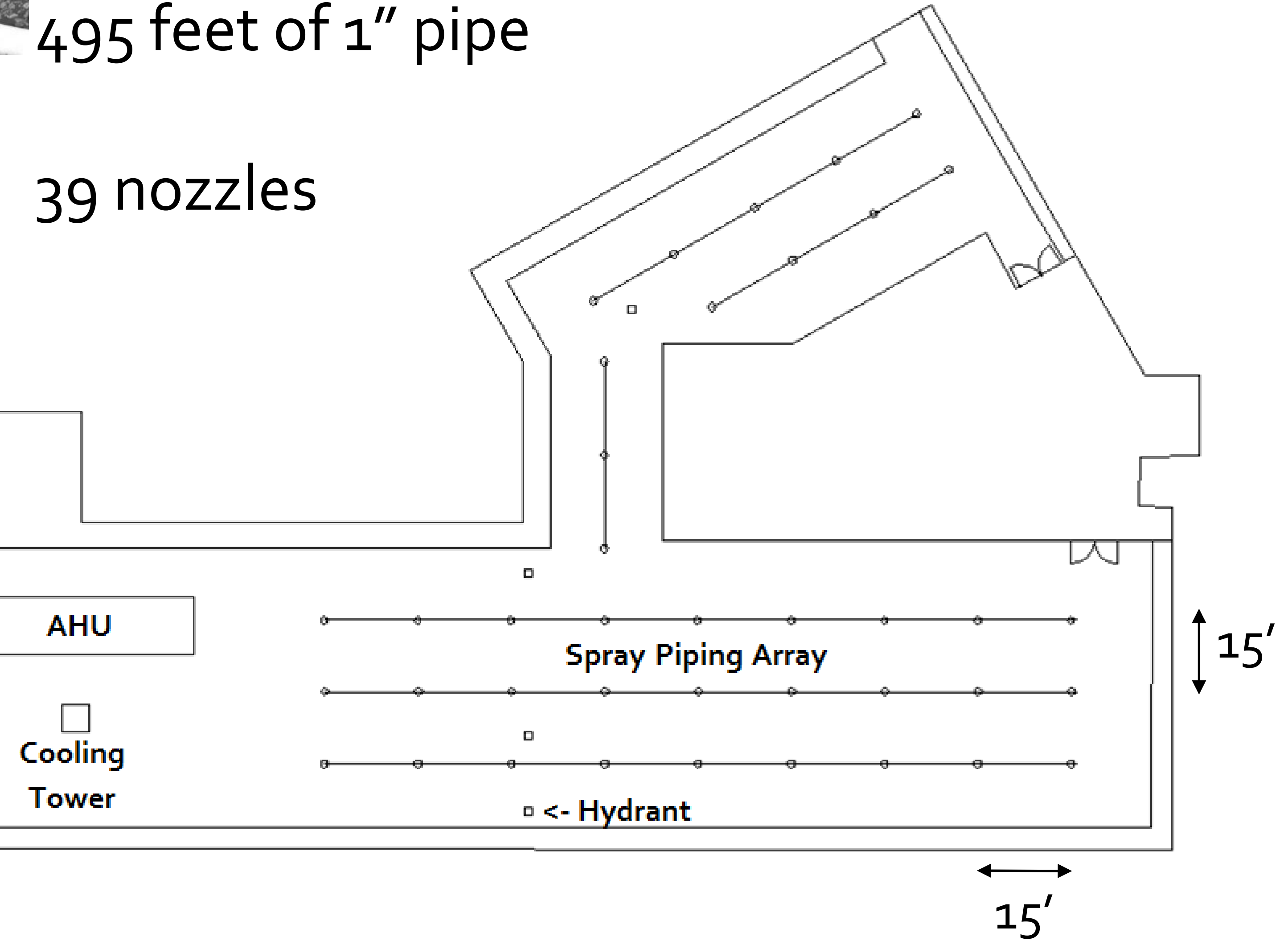
PUMP
1.492 kWh
April-October
9am-6pm

227 ft
78.6 gpm

layout

495 feet of 1" pipe

39 nozzles



water usage

SHORT misting time
QUICK frequency rate
based on room temp sensors

MONTH	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
Hrs./Day (Pittsburgh, PA)							
Solar Radiation BTU / sqft per day							
Gal / sqft per day							
Gal / sqft per hour							
Usage days per month							
Usage hours per day							
Gal / sqft per month							
H2o gal / month							
H2o $ / 1000 gal							
H2o $ / month							

580 gal/day

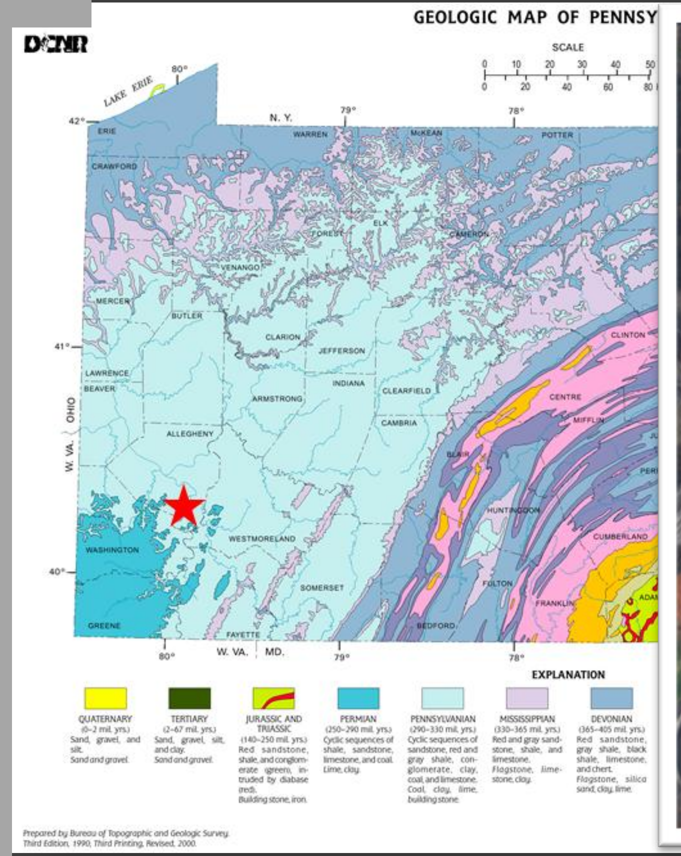
105,914 gal/month

$105.92 / month

[depth 2]

hybrid geothermal

site



< 225	brown shale & clay, red shale, dark gray shale, red & gray shale
225 – 325	gray sand shale
> 325	sand rock

downsizing

87°F	9°F

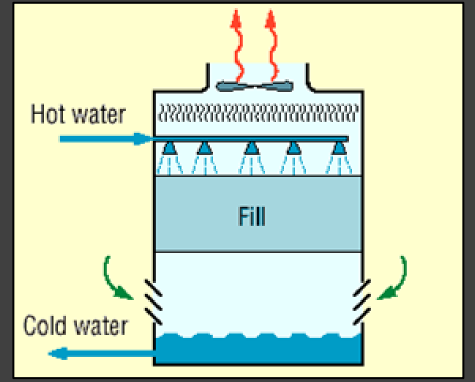
75°F

COOLING COIL PEAK	HEATING COIL PEAK
605,880 BTU/hr	397,007 BTU/hr

REDUCTION	LOAD COVERAGE BY GROUD LOOP HEAT EXCHANGER	RESULTING COOLING TOWER SIZE
0%	605,800 BTU/hr	0 tons
10%	545,400 BTU/hr	5 tons
20%	485,800 BTU/hr	10 tons
30%	425,880 BTU/hr	15 tons

cooling tower

1. **Select Maximum Wet Bulb Temperature**
   - Twb for Pittsburgh is 73 F
2. **Set Cooling Range**
   - T entering – T leaving = 95 F – 85 F = 10 F
3. **Set Approach Temperature**
   - T water exit – T wb air = 85 F – 73 F = 12 F
4. **Adjust Fluid Flow**
   - $\dot{m}_{H20} = \frac{\dot{q}}{Cp * \Delta T_{cooling\ range}}$
5. **Choose Cooling Tower Selection Factor**



induced draft counterflow tower with flow

boreholes

LENGTH COOLING

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

INPUTS

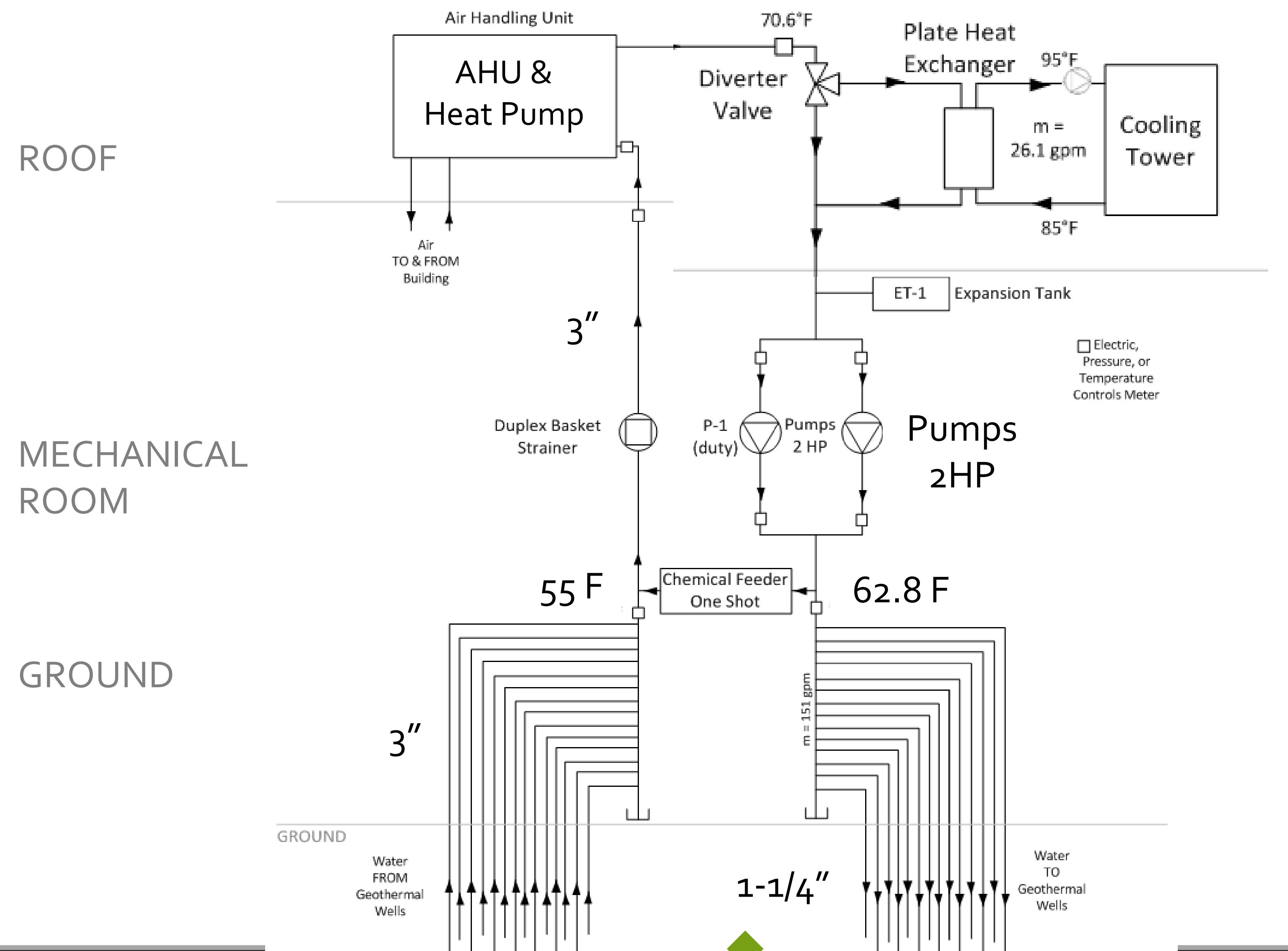
Building Area	24,350	SF
Ground Loop Load	50.49, 45.49, 40.49, 35.49	ton
Outdoor Design Temp	87	F
Indoor Design Temp	75	
Balance Temp	65	
Total Heat Pump Capacity	109.8	ton
COP cooling	6.24	
Pipe Resistance	0.048	hr-ft-F/BTU
Soil Resistance	0.25	
Mean Water Temp	70	F
Mean Earth Temp	55	

Ground Loop Sizing Spreadsheet Program based on ASHRAE

OUTPUTS

Load Coverage by Cooling Tower	0%	10%	20%	30%
Ground Loop Heat Exchanger Length [ft]	6885	5377	4055	2919

schematic



controls

$$\dot{q} = \dot{m} * C_p * \Delta T$$

Specific Heat (Cp) = 0.917 BTU/lbm-F for 20% ethylene

3 gpm/ton assumed

Cooling Tower 0%		Cooling Tower 10% (5 TON)		Cooling Tower 30% (15 TON)	
T entering	T exit	T entering	T exit	T entering	T exit
63.7 F	55 F	5 ton 62.8 F	55 F	15 ton 61.9 F	55 F
100%		90%		70%	
6885 ft		5377 ft		2919 ft	
Length Ground Loop		Length Ground Loop		Length Ground Loop	

Activate Cooling Tower if T entering	--	> 62.8 F	> 61.0 F
		10 TON > 61.9	

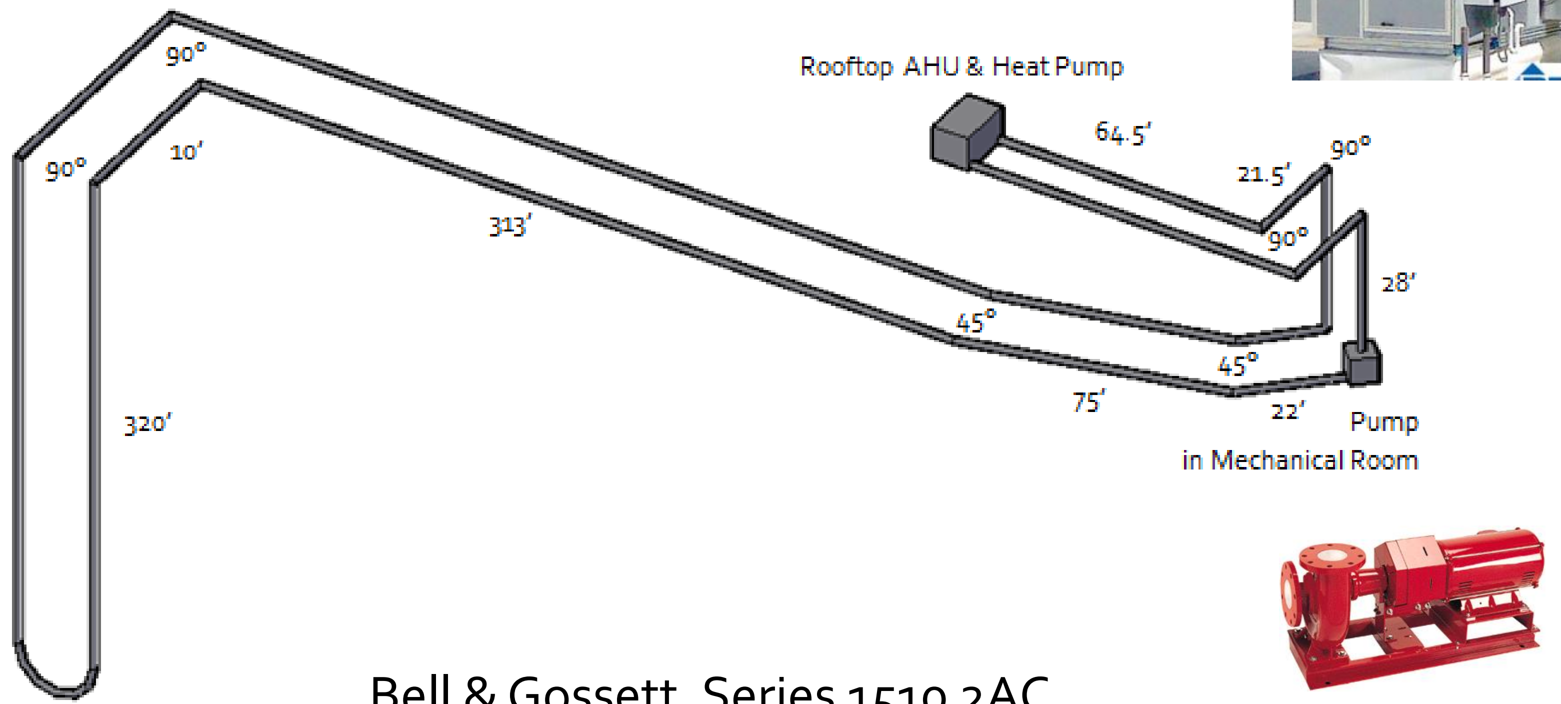
cooling tower selection

DRILL + SPACE + COST + ENERGY

	0%	20% DEC (10 ton)	SAVINGS
Borehole Length [ft]	6885	**4055**	*2830 ft*
# Boreholes	14	**13**	*1 less*
Borehole Depth [ft]	500	**320**	*180 ft*
Temperature Entering Ground Loop [F]	63.7	**61.9**	--
Annual Cooling Tower Consumption [kWh]	-	**56.5**	--
Days of Installation	30	**14**	*16 days*
Initial Cost [$]	$100,000	**$53,402**	*$46,598*
Space Needed [sqft]	3270	**3010**	*260 sqft*
$ / Square Foot Bores	$30.50	**$17.74**	*$12.76*
$ / Foot Length	$14.52	**$13.10**	*$1.42*

piping & pumps

Longest Run = 730 ft = 210 reduction

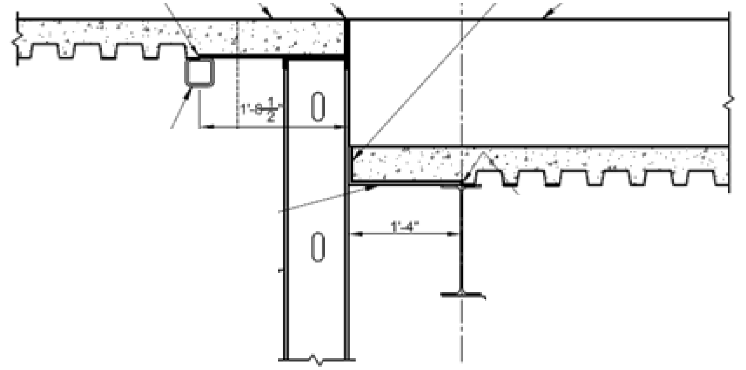


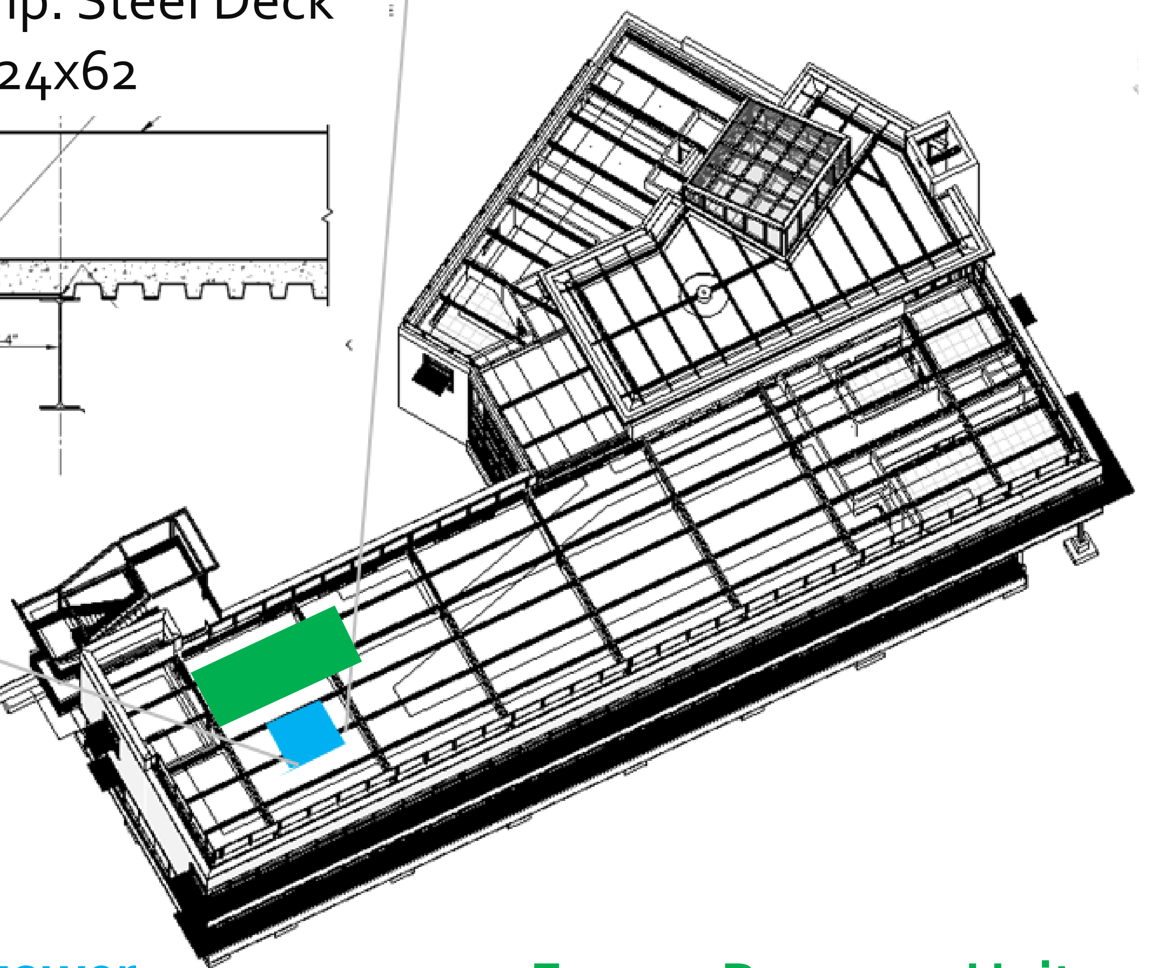
Bell & Gossett, Series 1510 2AC

FLOW RATE [GPM]	TOTAL HEAD [ft]	MOTOR POWER [HP]	PUMP SPEED [RPM]	FLA [460V]	EFFICIENCY
152	34	2	1750	4	67%

structural

Concrete Slab on Comp. Steel Deck
W12x19 & W24x62





10 ton cooling tower
442 lbs (36" diameter)

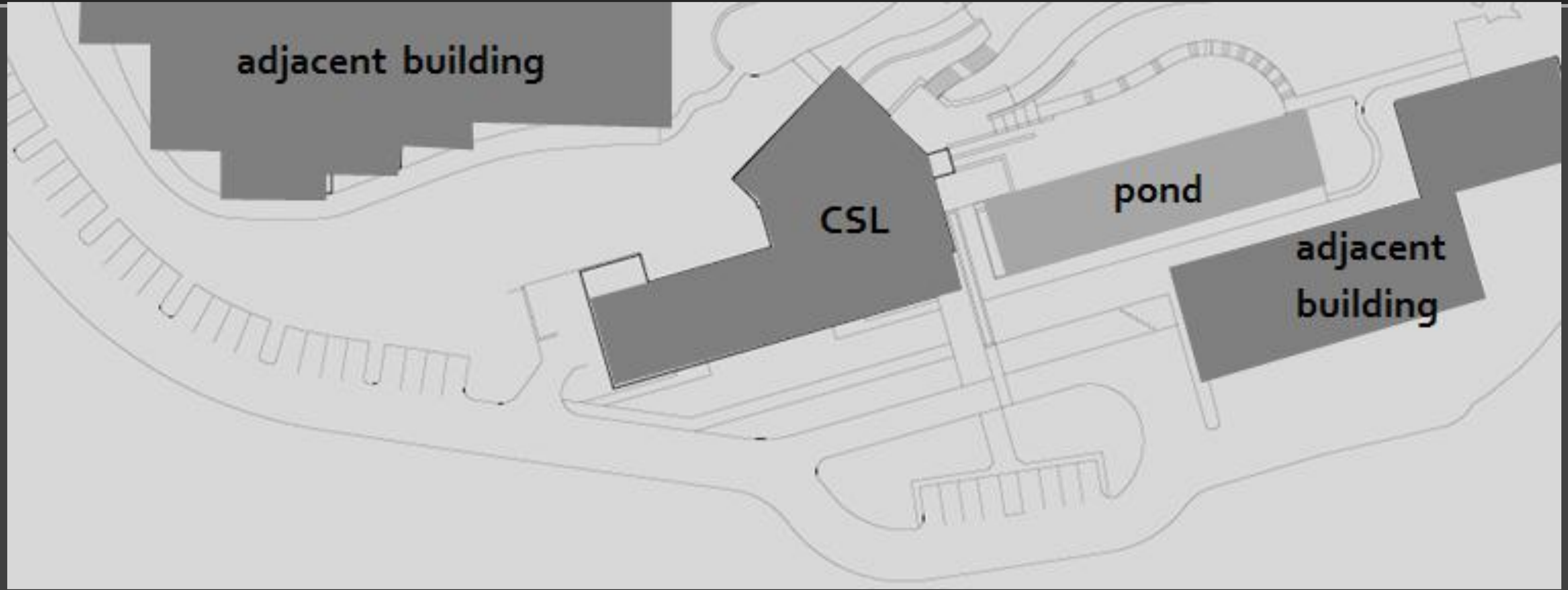
<<

Energy Recovery Unit
5,012 lbs

[breadth]

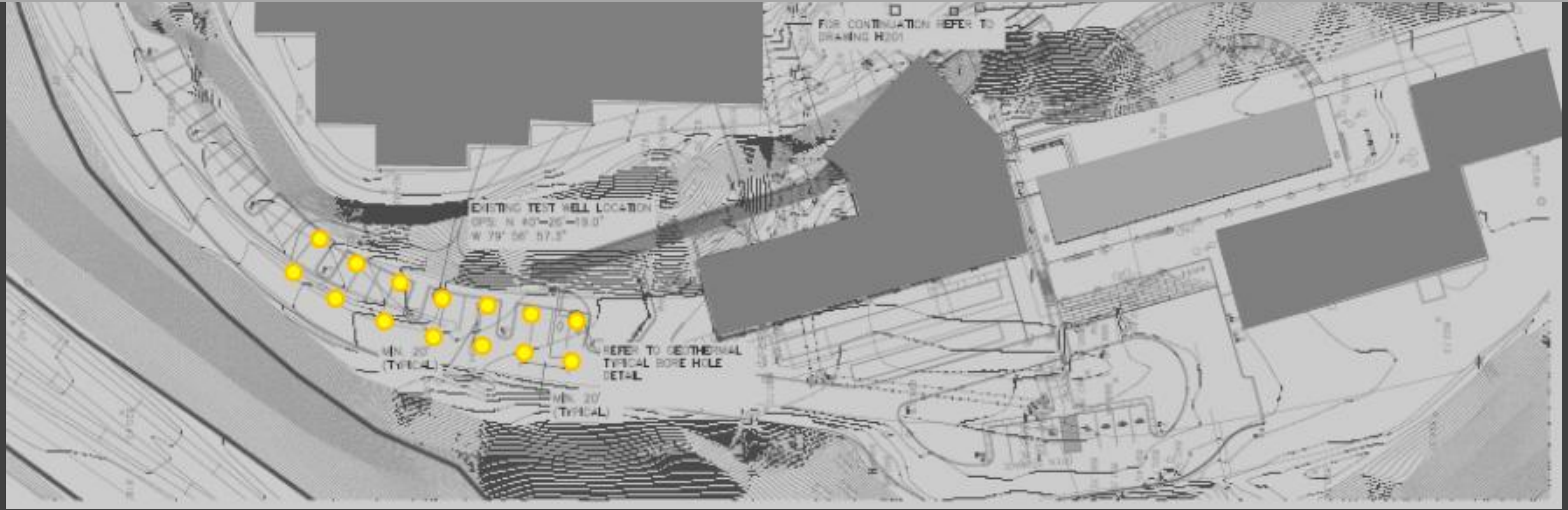
construction

borefield site layout



SITE LAYOUT

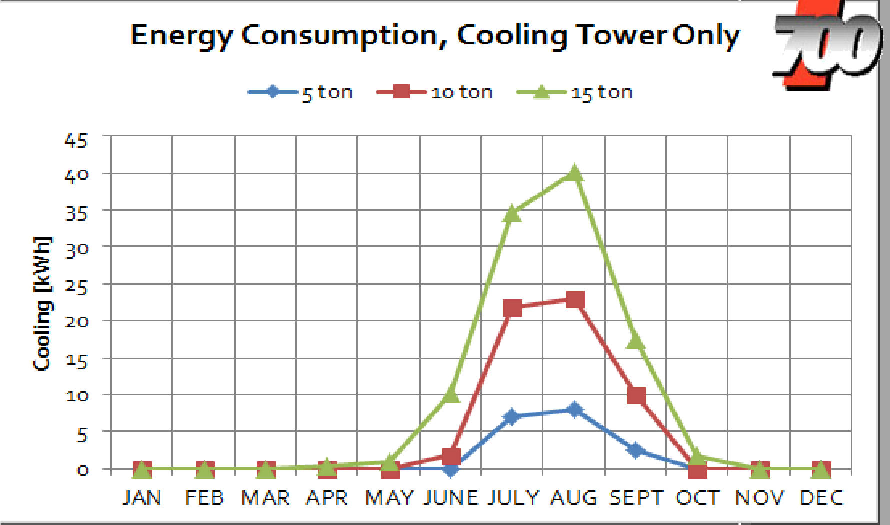
borefield site layout



SITE TERRAIN & EXISTING BOREHOLES

borehole optimization

	LENGTH	DEPTH	# BORE HOLES	AREA	TIME	COST	ENERGY
AFFECTED BY	Varying Ground Loop Capacities	*DRILL RIG* D < 225 $1737/day, 500 ft/day 225 < D < 325 $2115/day, 333 ft/day D > 325 $2417/day, 250 ft/day	←	←	← *LENGTH, DRILLING OUTPUT* Grouting $0.25/ft Piping $0.59/ft Welding $25/weld, $55/day	← *DEPTH* Labor $70hrs/day*8hrs/day*2people Cooling Tower $1185, $1562, $1856	Months of Operation
INPUT RANGES	6885, 5377, 4055, 2919 ft	140 – 500 ft	6 – 49	1,387 – 11,680 SF			
OUTPUTS					8 – 30 days	$28,541 - $119,194	5TON: July –Sept [3 months] 10 TON: June-Sept [4 months] 15 TON: May-Oct [6 months]



borefield site layout

POSSIBLE
19,000 sqft

DRIVEWAY
4,000 sqft

POSSIBLE
80 bores

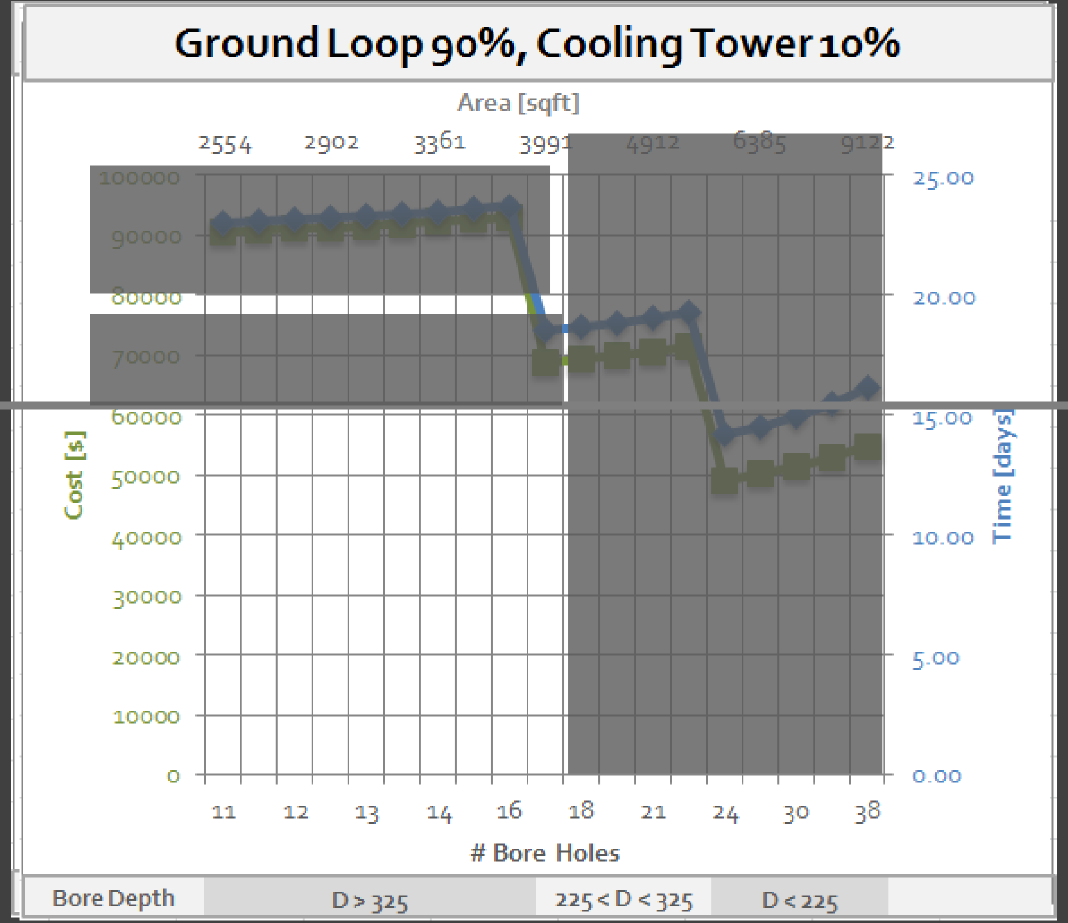
DRIVEWAY
30 bores

TOTAL MAX BOREHOLES

borehole optimization

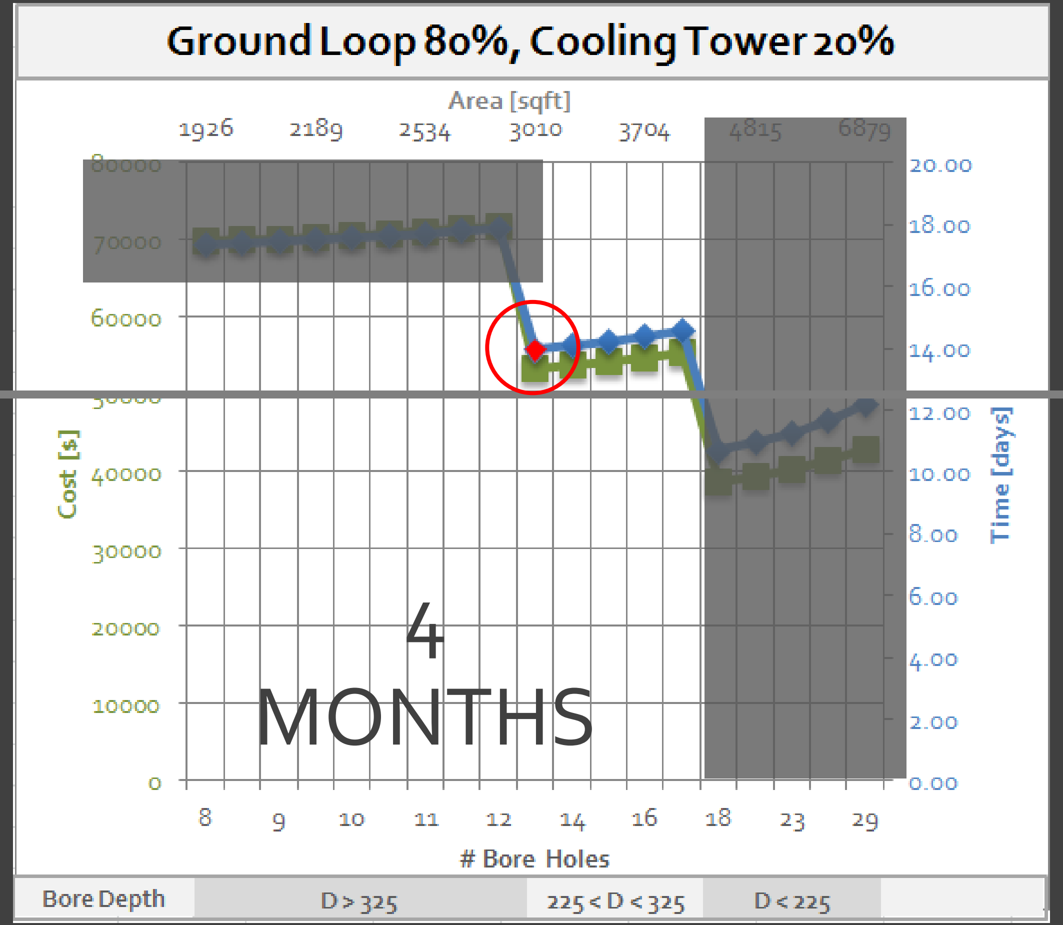
ENERGY
COST
SPACE
DRILL

5377 ft, 5 ton



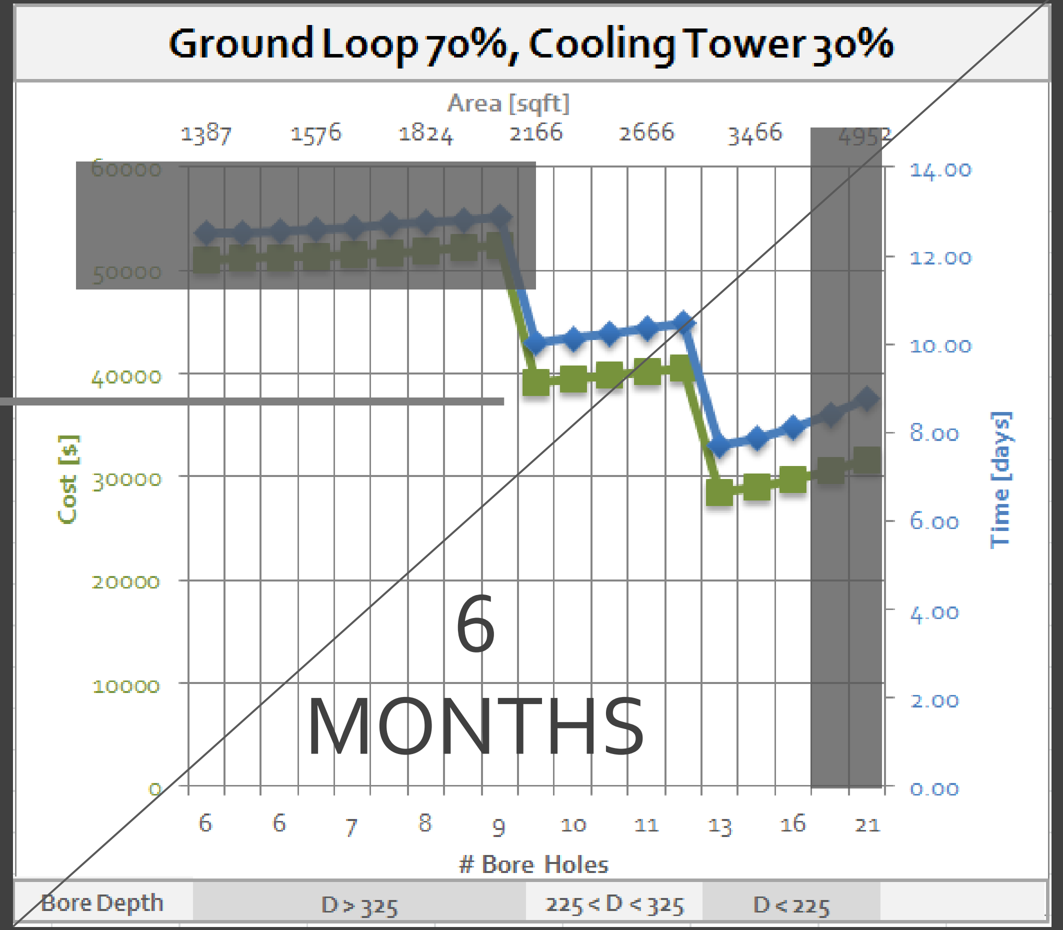
6885 ft loop . 510' depth . $100,000

4055 ft, 10 ton

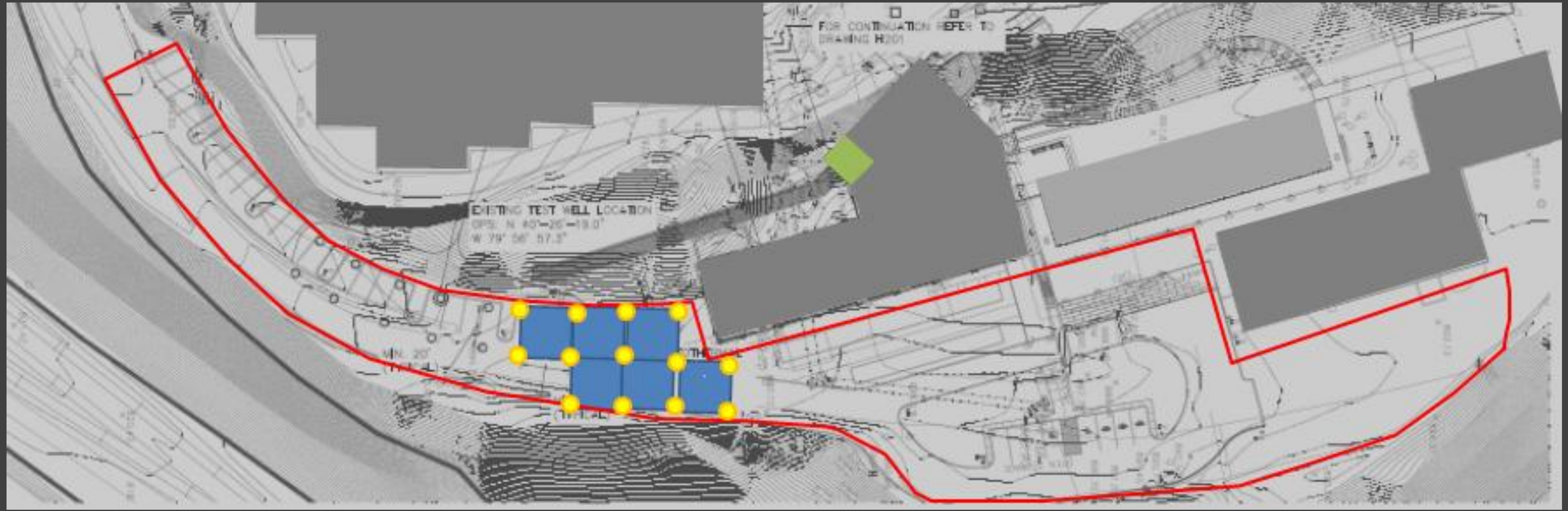


320 ft depth, 3010 sqft, $58,400

2919 ft, 15 ton



borefield site layout



HYBRID GEOTHERMAL FIELD SELECTION

borefield site layout

13 wells

320 ft depth

16 DAYS Saved

Not on Critical Path

GEOTHERMAL PIPING

$

Drilling	$	29,506.87
Piping	$	5,694.14
Grouting	$	1,013.75
Labor	$	15,625.39
Cooling Tower	$	1,561.71
TOTAL		**$53,401.86**

[energy]

spray cooled roof

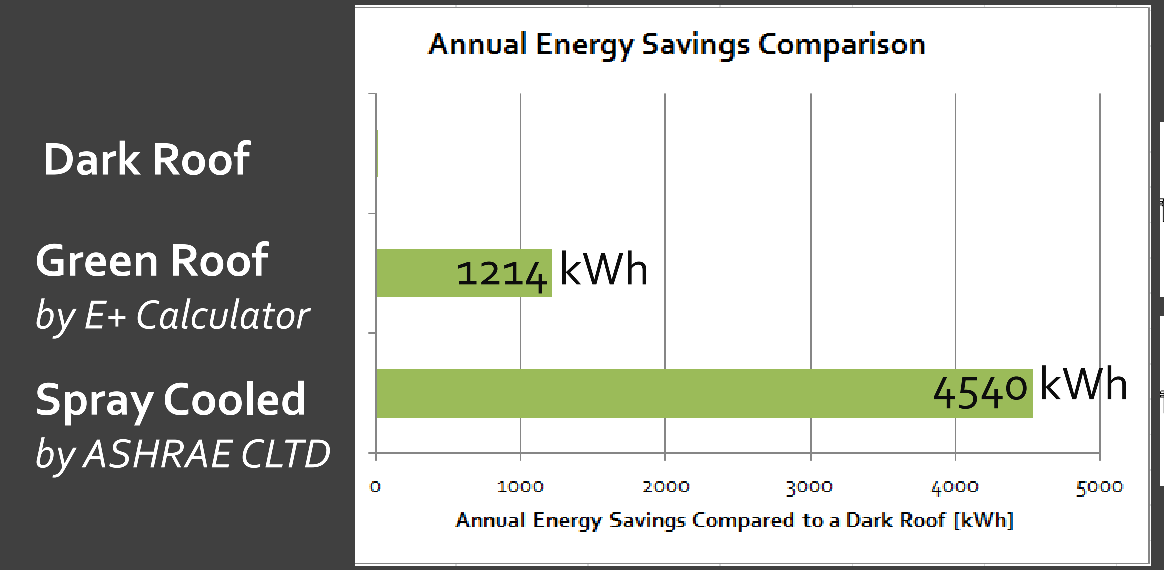
hybrid geothermal

SUMMER MONTHS SAVINGS

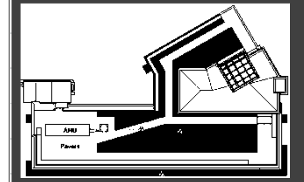
Usage Reduction (kWh/Mo)

= U*A*CLTD(c)*(Hrs/Mo.) / [EER*1000]

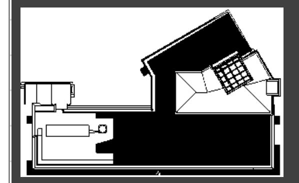
300 3.56



ROOF COVERAGE

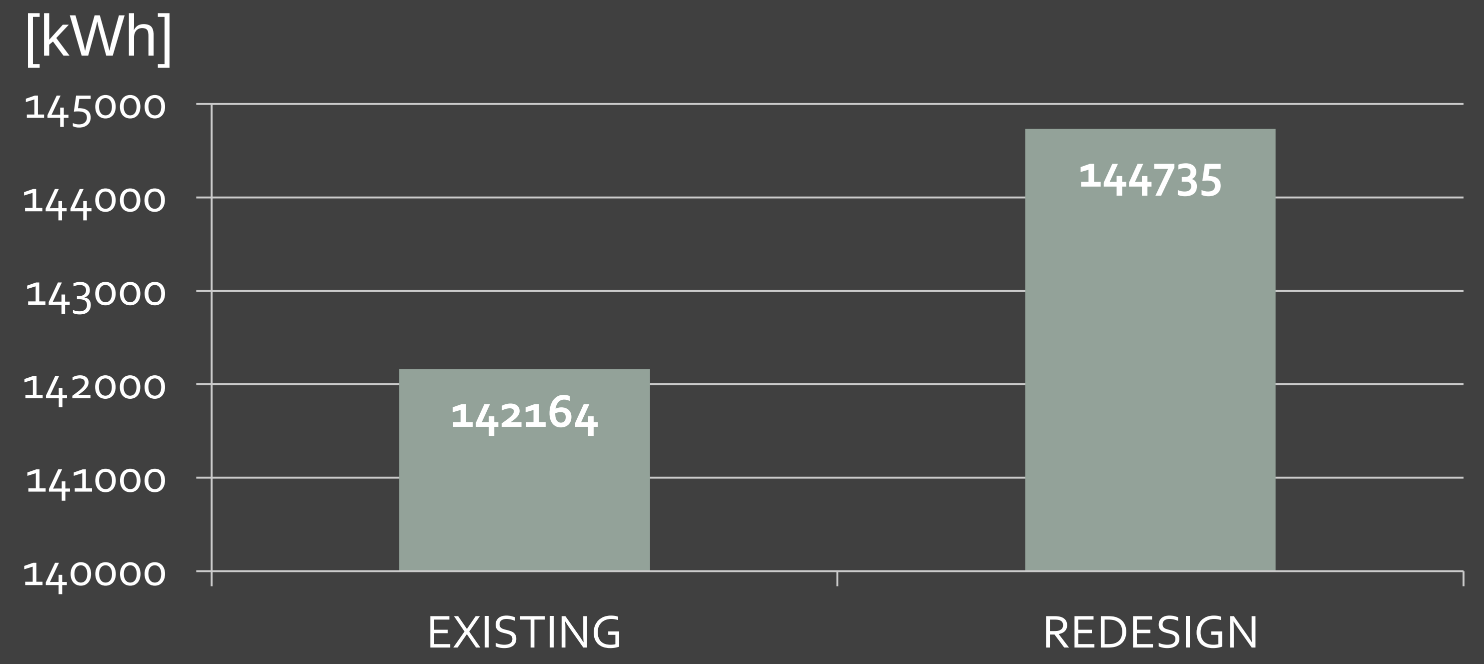


48%



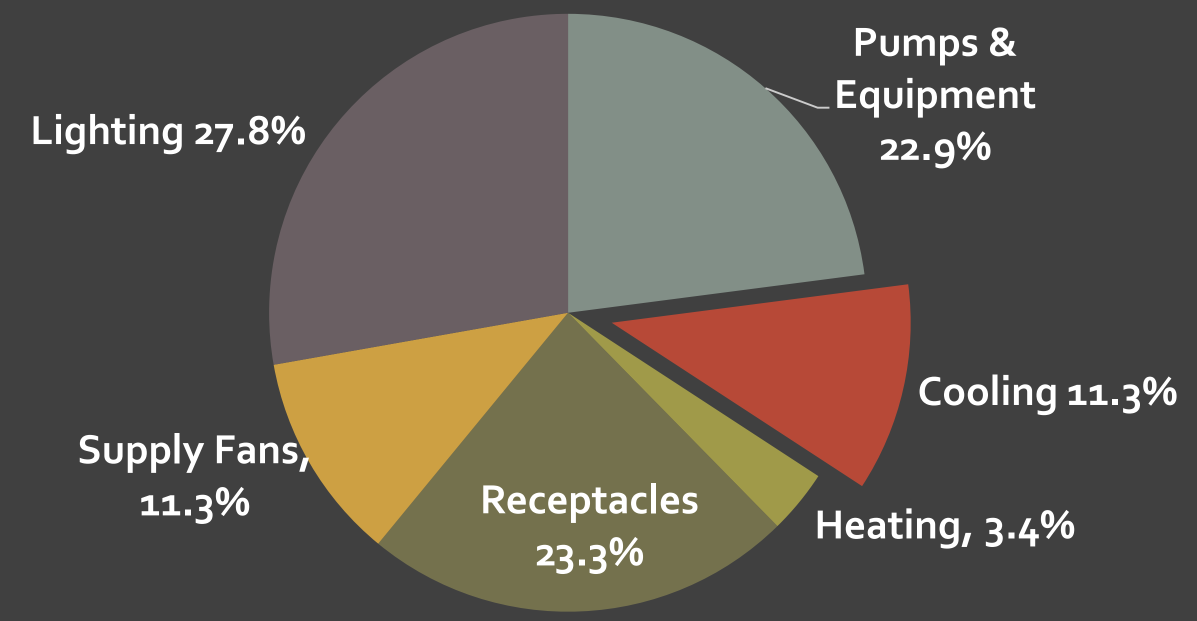
85%

ELECTRICAL CONSUMPTION



Electrical Consumption	+ 2,571 kWh
Total Building Energy	+ 7,855 kBTU/yr
Total Source Energy	+ 33,570 kBTU/yr

SUBSYSTEM



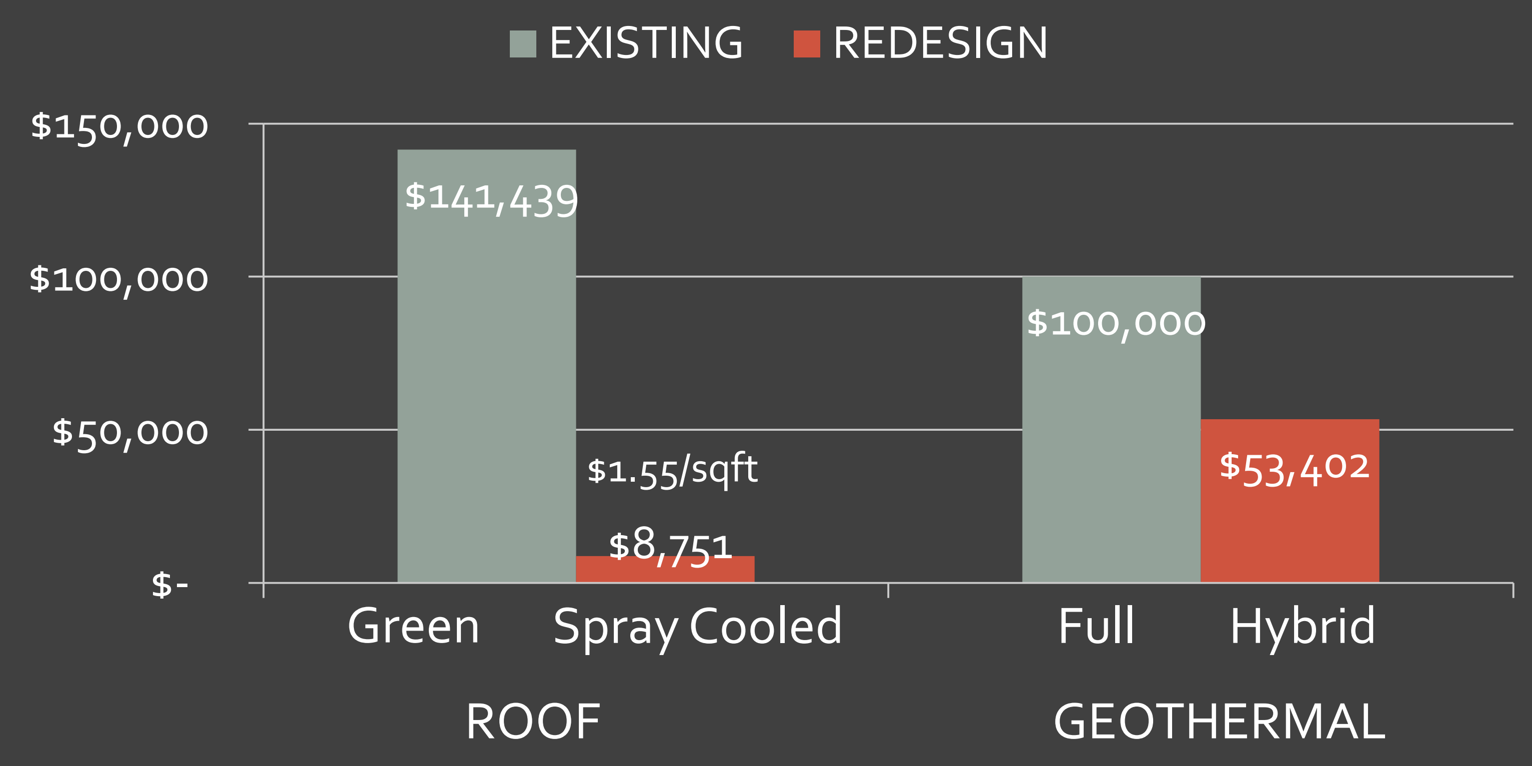
POLLUTION

242,178 lbs

+ 4,302 lbs pollutant per year

[costs]

initial



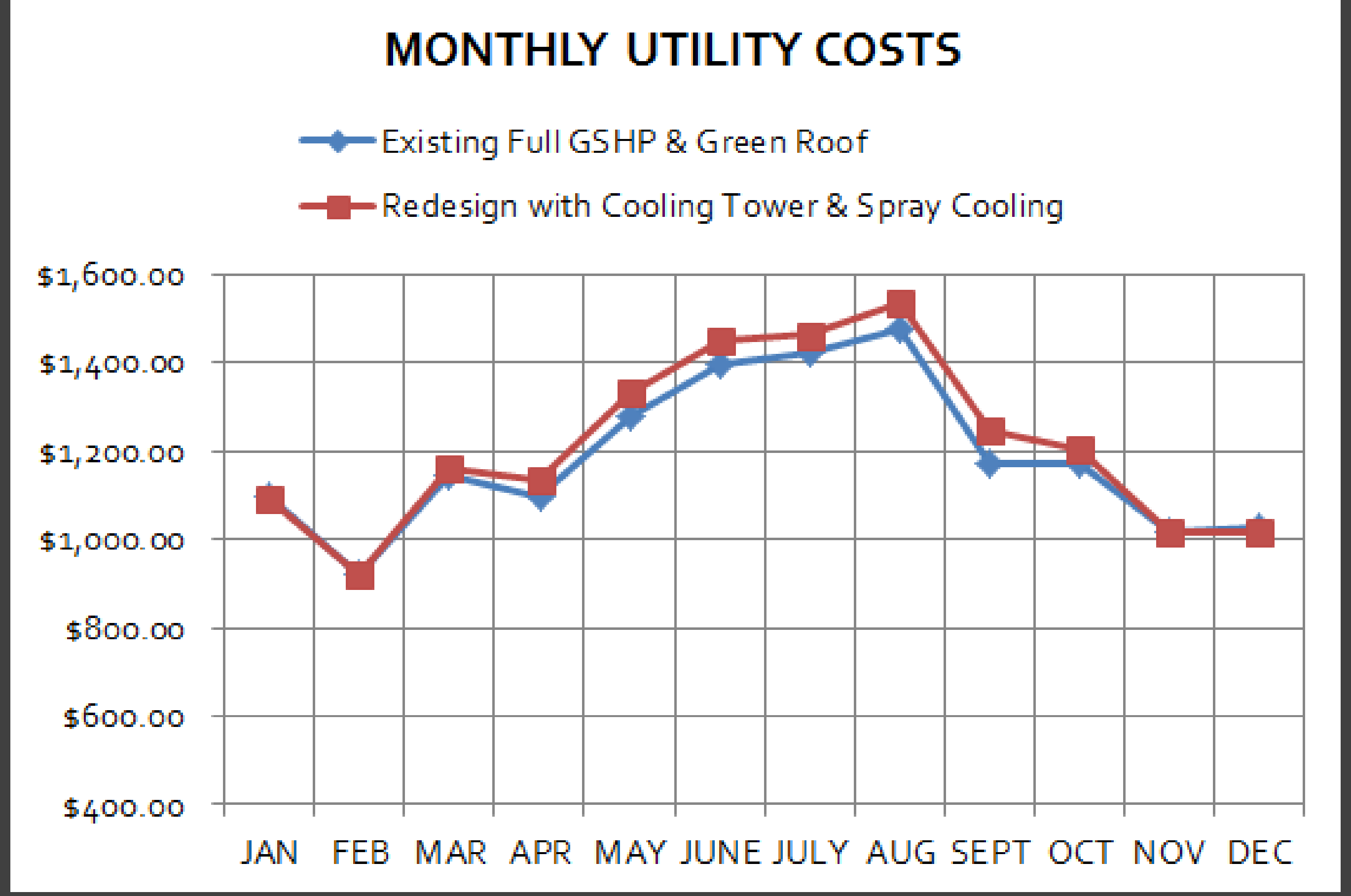
- $132,688.47

- $46,598.14

$179,286.61
decrease in initial cost

35 $/SF
to 28 $/SF

operating



TOTAL $14,580.97 DIFFERENCE + $362.97

+ 3% increase in annual utility costs

payback

SPRAY COOLED

14.6 years

[10 min. maintenance/ year]

green roof economically infeasible

[$2/sqft/year]

HYBRID GEOTHERMAL

Years for **additional energy** cost to equal **difference saved** in up-front costs

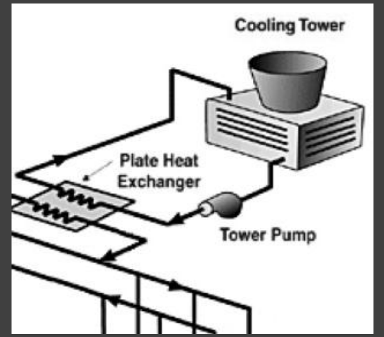
= 120

[years before hybrid not worth it]

[conclusion]

energy, costs, aesthetics

- $179,286
in initial cost

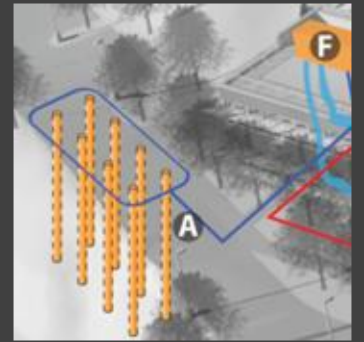


DEFINITE ADDITIONS

Hybrid Geothermal

POSSIBLE ADDITIONS

Spray Cooled Roof
for Phipps Owner & goals, +$132,000 seems worth it
for added aesthetics & occupiable space on roof



+ 3%
in annual utility costs

[credits]

ACKNOWLEGEMENTS

Family: Mom, Dad, Sister, Gram, Dedicated to Pap (APR11)

Turner Construction
- Megan Corrie
- Kristine Retetagos
- Karen Sweeney

CJL Engineering
- Craig Duda

Penn State University
- Prof. Kevin Parfitt
- Prof. Robert Holland
- Advisor: Dr. Bahnfleth
- Dr. Srebric
- AE Students from the Class of 2012
- Dr. Treado
- Prof. Ling
- Kaylee Damico
- McClure Company

OUTSIDE RESOURCES

ASHRAE, Handbook of Fundamentals, HVAC Applications
http://www.engr.psu.edu/ae/cic/bimex/index.aspo
http://www.duquesnelight.com/customerservices/CustomerGeneration/FrequentlyAskedQuestions.cfm
www.eia.gov/state/state-energy-profiles-data.cfm?sid=PA#Prices
http://www.nrel.gov/rredc/pvwatts/

IMAGES

http://phipps.conservatory.org/project-green-heart/green-heart-at-phipps/center-for-sustainable-landscapes.aspx
http://www.flickr.com/photos/phippsconservatory/?saved=1
http://www.turnerconstruction.com/experience/project/EE5/phipps-conservatory-center-for-sustainable-landscapes

thank you

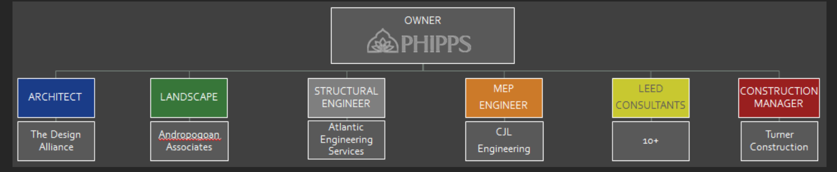
PHIPPS

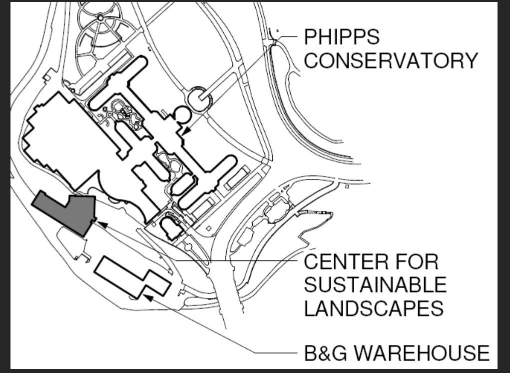
center for sustainable landscapes

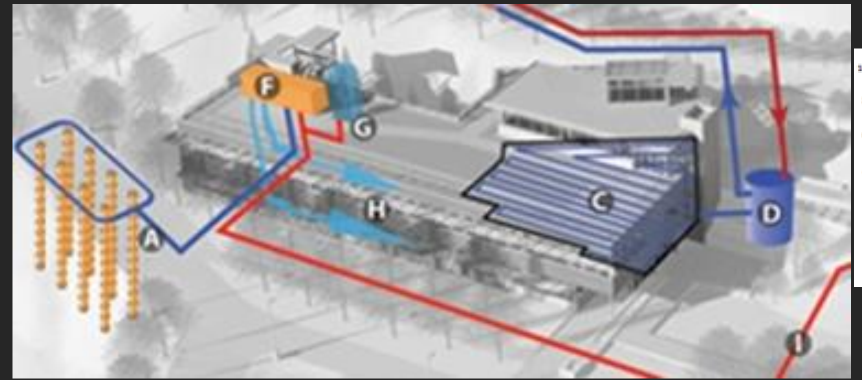
questions?

APRIL 8, 2012

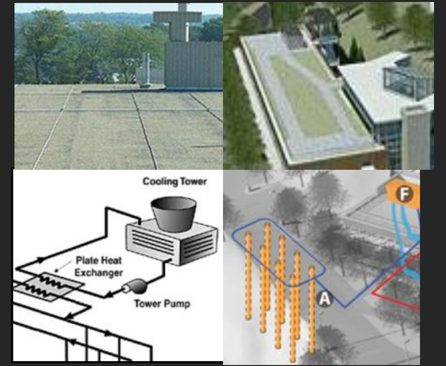
AE 482 FINAL PRESENTATION

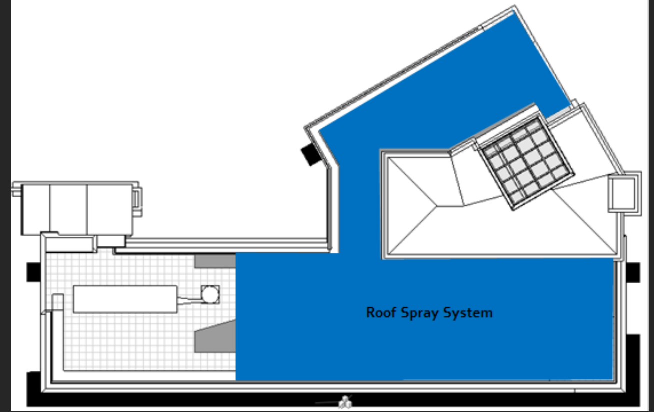


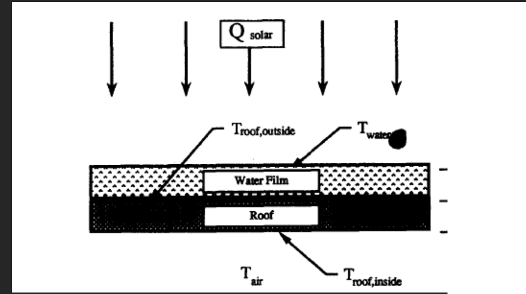


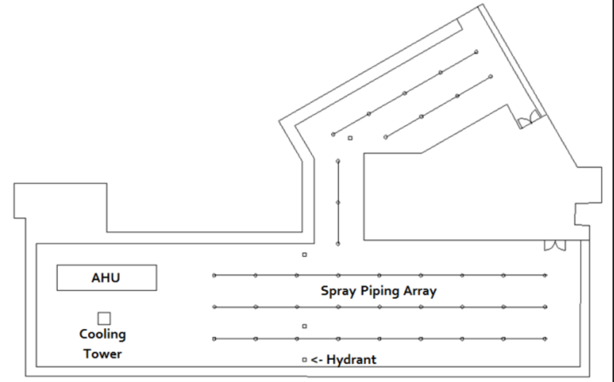


U.S. GREEN BUILDING COUNCIL
LEED PLATINUM
USGBC

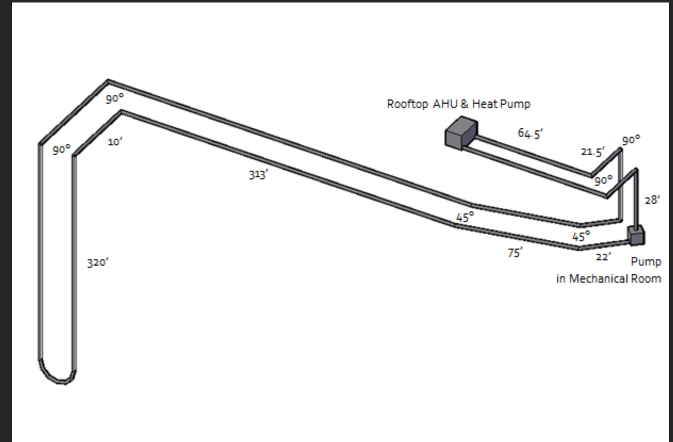


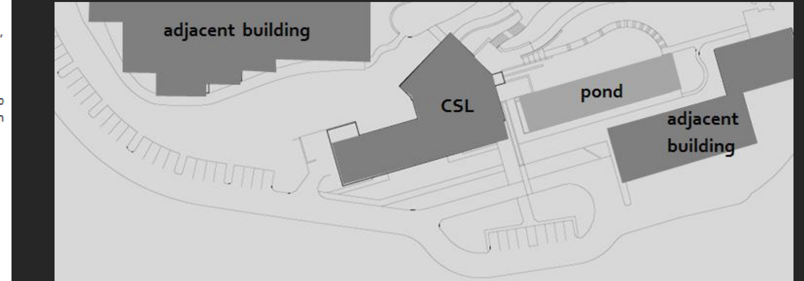




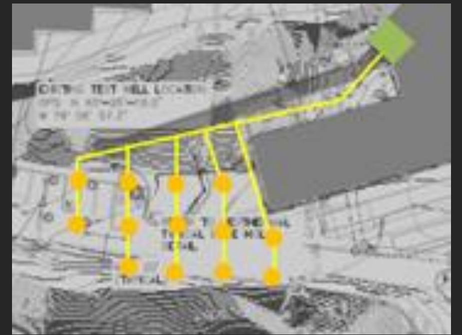


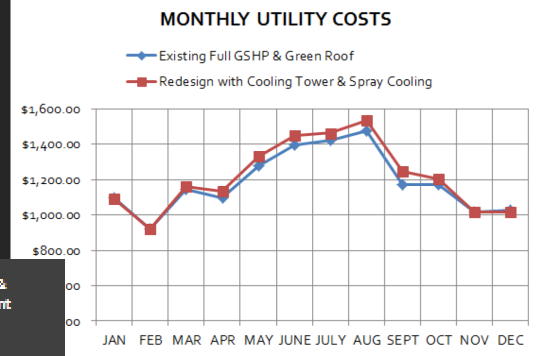
PHIPPS
center for sustainable landscapes

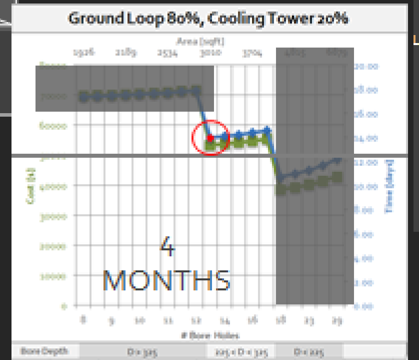


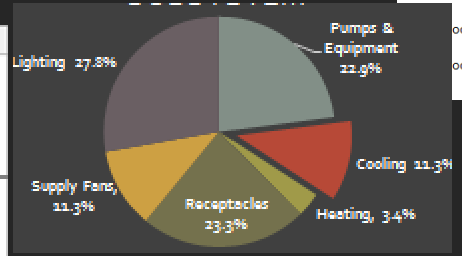


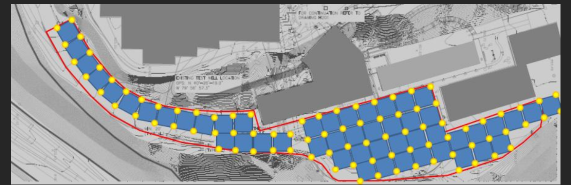
# BORE HOLES	AREA	TIME
←	←	← LENGTH, DRILLING OUTPUT Grouting $0.25/ft Piping $0.59/ft Welding $25/weld, $55/day
6 – 49	1,387 – 11,680 SF	
		8 – 30 days











PENNSTATE

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

[architectural engineering thesis . mechanical option]

by JOSHWENTZ

Table 45 Green Roof Initial Costs

ITEM	COST
Flashing FlexFlash F	1878
Flashing FlexFlash UN reinforcing	7321
Gardendrain GR30	10476
Hydrodrain 300 Panels	2337
Hydroflex 30	3559
Lite Top Soil	8956
Lite Top Aggregate	883
Lite Top Growing Media / Manufactured Growing Media	8956
Metal Edge Restraint Soil Retainer	9334
Root Stop Root Barrier	8860
Surface Conditioner for Vegetated Roof	449
Walkway Pavers & Adjustable Pedestal	34011
Holover Pavers	24300
Monolithic Membrane	6919
Adhesives Sealant	5632
System Filter	2568
Aluminum Flat Sheets	5000
TOTAL	$141,439

Table 46 Spray Cooling System Installation Costs

ITEM	COST	CSL SPECIFICS	COSTS
Sprikool Roof Spray System (Piping & Controls)	$1.55 / sqft	Installed onto 85% of the Roof (5645.5 SF)	$8,750.53
Above-Grade Storage Tank	$1500 per 1000 gallons	Unground Water Basin Already Exists	0
Connecting Pipe	$16 per lineal foot drain to coil	Connecting Pipe to Roof Already Exists due to Green Roof	0

MAINTENANCE

Green Roof: $ 1.25 - $2.00 / ft 2 (only for the first two years)

Spray Cooled: winter: drain, blow down | spring: startup

10 minutes / year

Table 49 Spray Cooled Roof Payback Analysis

Cost of Implementation	
Initial Cost of Sprinkool Roof Spray System	$8,750.53 ($1.55/sqft)
Operating Cost Per Season	
Water Usage Annually	$105.92
Net Savings per Season	
Annual Savings	$702.54
Less Annual Costs	$105.92
Net Annual Savings	$596.62
Payback	
Cost of Implementation / Net Savings per Season	14.6 seasons

Hybrid Geothermal

Compared to the full geothermal system, the hybrid geothermal costs $46,598.14 less in up-front costs. The energy simulation shows that the addition of the 10 ton cooling tower in this hybrid geothermal system (which would only operate only in June, July, August, and September) would only cost $362.97 more per year. Thus, it would take approximately 120 years for the additional energy costs of the hybrid geothermal system to equal the difference saved in up-front costs. This amount of time seems larger than expected. This may be due to an energy model simulation issue that was a result of how Trane TRACE models cooling tower.

rating

EXISTING: Green Roof	CRITERIA	REDESIGN: Spray Cooled
B For providing nominal energy savings throughout the summer, yet adding an additional layer of insulation in the winter.	Energy	**A** For saving a total of 4540 kWh throughout the summer months by maximizing cooling coverage to 85% of the roof.
D For costing $114, 439 for the complete green roof system.	Cost	**A** For only costing $8,750 to install, 94% less than the green roof.
A For creating a pleasant roof space for occupants to enjoy	Aesthetics	**C** For having a piping array in place of a green space

EXISTING: Full Geothermal	CRITERIA	REDESIGN: Hybrid Geothermal
A For only consuming $14,218 per year in electricity	Energy	**B** For causing an increase of only a few hundred dollars more annually
D For costing $100,000 in installation fees	Cost	**A** For reducing initial costs by nearly $47,000

controls

$$\dot{q} = \dot{m} * C_p * \Delta T$$

- where:
  - q = downsized ground loop capacity corresponding to the cooling tower coverage [BTU/hr]
  - m = fluid flow [gpm]
    - 3 gpm/ton assumed based on ASHRAE recommendation
    - max cooling load for CSL = 50.49 ton (calculated via Trane TRACE)
  - Cp = specific heat for 20% ethylene glycol solution [0.917 BTU/lbm-F] (using this solution in the pipes is recommended by ASHRAE due to its lower freezing temperature)
  - ΔT = T in – Tout of the ground loop heat exchanger
    - Tout during cooling months assumed to be 55 F based on the ground temperature and required temperature needed by the heat pump
- Example Calculation at Full Load:
  - 605880 BTU/hr = (3 gpm/ton * 50.49 ton * 60 min/hr * 8.33lbm/gal) * 0.917 BTU/lbm-F *(Tin – 55)
  - Tin = 63.7 F for existing full geothermal system (this is the temperature that the entering water temperature must be in order for it to exit at 55 F)

green roof calculator

Table 14 Green Roof Energy Calculator Inputs	
State	Pennsylvania
City	Pittsburgh
Type	New Office Building
Total Roof Area	6685.98 sqft
Green Roof Area	3216.28 sqft
Percentage	48.1%
Rest of Roof	Dark (0.15 albedo) Concrete Pavers
Growing Media Depth	8 inches
Leaf Area Index	2
Roof Irrigated?	Yes

Table 15 Annual Energy Savings Compared to Dark Roof	
Electrical Savings	1213.7 kWh
Total Cost Savings	$181.18

Table 16 Average Sensible Heat Flux to the Environment		
	DARK ROOF	48% GREEN ROOF
Summer Average [W/m2]	51.1	37.4
Summer Daily Peak Average [W/m2]	297.4	190.3

Green Roof Energy Calculator allows engineers to compare the annual energy performance of a building of a white roof and dark roof with a vegetative green roof. This physically based energy balance was developed by researchers at Portland State University and the University of Toronto.

- long and short wave radiation exchange within the canopy (multiple reflections, shading)
- effect of canopy on sensible heat exchange among the ambient air, leaf, and soil surfaces
- thermal and moisture transport in the growing media with moisture inputs from precipitation (and irrigation if desired)
- evaporation from the soil surface and transpiration from the vegetation canopy

The growing media characteristics for were set as follows: thermal conductivity 0.35 W/mK; density 1100 kg/m3; specific heat 1200 J/kgK; saturation volumetric moisture 0.3; residual volumetric moisture 0.01; initial volumetric moisture 0.1.

borehole sizing computer program

GEOTHERMAL VERTICAL GROUND LOOP DESIGN

Project: Phipps Center for Sustainable Landscapes
Job Number:
Date: 02/25/12
User: Wentz

INPUT DATA

Total Building Load (Ton)=	50.49	Bldg Area	24000 Sq Ft
Outdoor Design Temp. (°F)=	90	Sq. Ft / Ton	558
Indoor Design Temp. (°F)=	75		
Balance Temp. (°F)=	65		
Total Heat Pump Capacity (Ton)=	33		
$COP_{COOLING}$=	3		
Pipe Resistance (Hr-Ft-°F/BTU)=	0.048		
Soil Resistance (Hr-Ft-°F/BTU)=	0.25		
Average Water Temp. (°F)=	70		
Mean Earth Temp.(°F)=	55		

BIN DATA

Design Month: July
Location: PITTSBURGH

BIN Range		Mean	Hours	WB(°F)
95	99	97	0	0.0
90	94	92	6	71.3
85	89	87	14	70.1
80	84	82	89	69.7
75	79	77	98	66.5
70	74	72	125	64.8
65	69	67	140	63.2
60	64	62	187	60.9
			659	

CALCULATIONS

BIN Range	Bldg Load Tons	Heat Pump Hours
95/100	91.73	0.00
90/95	77.40	14.07
85/90	63.07	26.76
80/85	48.73	131.43
75/80	34.40	102.16
70/75	20.07	76.01
65/70	5.73	24.32
		374.75

Run Fraction= 0.50
Ground Loop Heat Exchanger Length(Ft/Ton)= 160.11
Total Ground Loop Length= 6884.68

Bores Required: Depth (Ft)	Number
400	17
375	18
350	20
325	21
300	23
250	28
200	34
600	11
500	13.76936

borehole optimization

GSHP @ 100% Load | Cooling Tower @ 0% Load

Drill Depth	Total Length	# Boreholes	Depth Borehole	Days	Drilling $	Piping $	Grouting $	Labor $	Cooling Tower $	Total $	Area [sqft]
D > 325	6885	14	500	29.47	71224	9986	1721	33004	0.00	115935	3270
	6885	14	480	29.55	71418	9990.42	1721	33094	0.00	116223	3407
	6885	15	460	29.64	71629	9995.22	1721	33192	0.00	116537	3555
	6885	16	440	29.73	71859	10000.5	1721	33298	0.00	116879	3716
	6885	16	420	29.84	72111	10006.2	1721	33415	0.00	117254	3893
	6885	17	400	29.95	72389	10012.5	1721	33544	0.00	117666	4088
	6885	18	380	30.08	72695	10019.5	1721	33686	0.00	118122	4303
	6885	19	360	30.22	73036	10027.2	1721	33844	0.00	118628	4542
	6885	20	340	30.38	73416	10035.9	1721	34020	0.00	119194	4809
225 < D < 325	6885	22	320	23.69	50100	9668.11	1721	26530	0.00	88020	5110
	6885	23	300	23.89	50525	9679.15	1721	26755	0.00	88680	5451
	6885	25	280	24.12	51010	9691.77	1721	27012	0.00	89435	5840
	6885	26	260	24.38	51570	9706.34	1721	27309	0.00	90307	6289
	6885	29	240	24.69	52223	9723.33	1721	27655	0.00	91323	6813
D < 225	6885	31	220	18.15	31529	9363.6	1721	20330	0.00	62943	7433
	6885	34	200	18.59	32290	9387.7	1721	20820	0.00	64219	8176
	6885	38	180	19.13	33220	9417.15	1721	21420	0.00	65779	9084
	6885	43	160	19.79	34383	9453.97	1721	22170	0.00	67728	10220
	6885	49	140	20.66	35878	9501.3	1721	23134	0.00	70234	11680

GSHP @ 80% Load | Cooling Tower @ 20% Load [10 tons]

Drill Depth	Total Length	# Boreholes	Depth Borehole	Days	Drilling $	Piping $	Grouting $	Labor $	Cooling Tower $	Total $	Area [sqft]
D > 325	4055	8	500	17.36	41948	5881.37	1014	19438	1561.71	69843	1926
	4055	8	480	17.40	42062	5883.97	1014	19491	1561.71	70013	2006
	4055	9	460	17.45	42187	5886.8	1014	19549	1561.71	70198	2094
	4055	9	440	17.51	42322	5889.89	1014	19611	1561.71	70399	2189
	4055	10	420	17.57	42471	5893.27	1014	19680	1561.71	70620	2293
	4055	10	400	17.64	42634	5896.98	1014	19756	1561.71	70862	2408
	4055	11	380	17.71	42815	5901.09	1014	19840	1561.71	71131	2534
	4055	11	360	17.80	43015	5905.66	1014	19933	1561.71	71429	2675
	4055	12	340	17.89	43239	5910.76	1014	20036	1561.71	71762	2833
225 < D < 325	4055	13	320	13.95	29507	5694.14	1014	15625	1561.71	53402	3010
	4055	14	300	14.07	29757	5700.65	1014	15758	1561.71	53791	3210
	4055	14	280	14.20	30043	5708.08	1014	15909	1561.71	54236	3440
	4055	16	260	14.36	30373	5716.66	1014	16084	1561.71	54749	3704
	4055	17	240	14.54	30758	5726.67	1014	16288	1561.71	55347	4013
D < 225	4055	18	220	10.69	18569	5514.8	1014	11973	1561.71	38633	4378
	4055	20	200	10.95	19018	5528.99	1014	12262	1561.71	39384	4815
	4055	23	180	11.26	19565	5546.34	1014	12616	1561.71	40303	5350
	4055	25	160	11.66	20250	5568.02	1014	13057	1561.71	41451	6019
	4055	29	140	12.17	21131	5595.9	1014	13625	1561.71	42927	6879

GSHP @ 70% Load | Cooling Tower @ 30% Load [15 tons]

Drill Depth	Total Length	# Boreholes	Depth Borehole	Days	Drilling $	Piping $	Grouting $	Labor $	Cooling Tower $	Total $	Area [sqft]
D > 325	2919	6	500	12.49	30196	4233.72	730	13993	1,855.71	51008	1387
	2919	6	480	12.53	30279	4235.59	730	14031	1,855.71	51130	1444
	2919	6	460	12.56	30368	4237.63	730	14072	1,855.71	51263	1507
	2919	7	440	12.60	30466	4239.85	730	14117	1,855.71	51408	1576
	2919	7	420	12.65	30573	4242.28	730	14167	1,855.71	51567	1651
	2919	7	400	12.70	30690	4244.96	730	14221	1,855.71	51742	1733
	2919	8	380	12.75	30820	4247.91	730	14282	1,855.71	51935	1824
	2919	8	360	12.81	30965	4251.2	730	14349	1,855.71	52150	1926
	2919	9	340	12.88	31126	4254.87	730	14423	1,855.71	52390	2039
225 < D < 325	2919	9	320	10.04	21241	4098.94	730	11248	1,855.71	39173	2166
	2919	10	300	10.13	21421	4103.62	730	11343	1,855.71	39453	2311
	2919	10	280	10.23	21626	4108.97	730	11452	1,855.71	39773	2476
	2919	11	260	10.34	21864	4115.15	730	11578	1,855.71	40143	2666
	2919	12	240	10.47	22141	4122.35	730	11725	1,855.71	40573	2889
D < 225	2919	13	220	7.70	13367	3969.84	730	8619	1,855.71	28541	3151
	2919	15	200	7.88	13690	3980.06	730	8827	1,855.71	29082	3466
	2919	16	180	8.11	14084	3992.54	730	9081	1,855.71	29744	3851
	2919	18	160	8.39	14577	4008.15	730	9399	1,855.71	30570	4333
	2919	21	140	8.76	15211	4028.22	730	9808	1,855.71	31632	4952

loads & schedule

Table 2 Heating, Cooling, Ventilating Factors Contributing to Building Load	
Weather	Design Outdoor Conditions • Dry Bulb Temp: 84 F (summer), 9 F (winter) • Wet Bulb Temp: 73 F (summer) Desired Indoor Conditions • Heating & Cooling Setpoint: 75 F • Relative Humidity: 50%
Occupancy	367 persons [*1st: 140, 2nd: 112, 3rd: 115*] • Atrium: 200 sqft/person • Break Room: 16 people • Classroom: 31 people • Conference: 10 people • Lobby: 200 sqft/person • Office: 20 people • Reception: 143 sqft/person
Schedules	Office (Weekdays Year-Round) • 6am-8am: 50% load • 8am-5pm: 100% load • 5pm-7pm: 50% load

Power Densities *Lighting, Electrical, Mechanical*	Lights for the open office areas are high performance, energy efficient T-5 fluorescents or LEDs. • Classrooms: 1.4 W/sqft, 2 workstations • Conference: 1.3 W/sqft, 1 workstation • Mechanical: 20 W/sqft • Open Office: 1.1 W/sqft, 20 workstations (based upon the number of chairs from design documents) • Reception: 1.3 W/sqft, 1 workstation
Envelope Construction	The facade is a combination of: • Salvage barn siding • Motorized upper glazing • Metal light shelf • Operable windows: High performance, low-e (low-emissivity) windows provide solar and thermal control and energy efficiency, while admitting maximum daylight. • Glass Fiber Reinforced Concrete Precast Panels • Backup of exterior studs • High performance wall and roof insulation reduce winter heat losses and summer heat gains

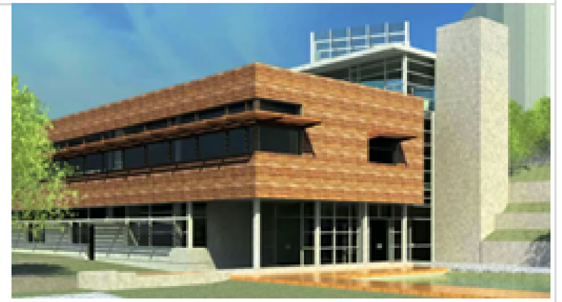


Figure 4 Facade of CSL

Table 11 Pumps / Equipment / Stand-alone Base Utilities Demands & Schedules

TYPE	HOURLY DEMAND [kW]	SCHEDULE
Elevator Fan	0.0373	Office Schedule (Table 5)
Parking Lot Lights	2.973	6pm – 7am: 100%
Elevator	18	Office Schedule (Table 5)
Wetland Pumps (2)	0.2487	1 hr / day
Sand Filter Pump	0.373	1 hr / day
Lagoon Pump	1.492	April – October: 100%
Stormwater Pump	0.9325	1 hr / day