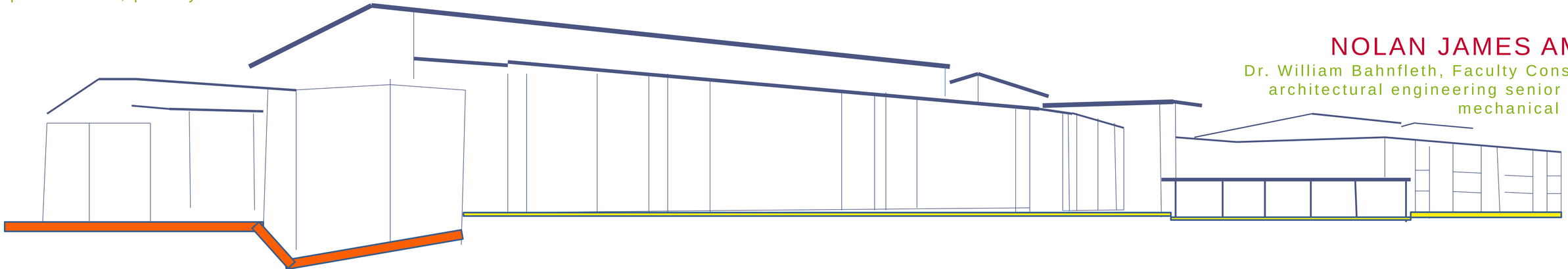
PHOENIXVILLE EARLY LEARNING CENTER AND ELEMENTARY SCHOOL

phoenixville, pennsylvania



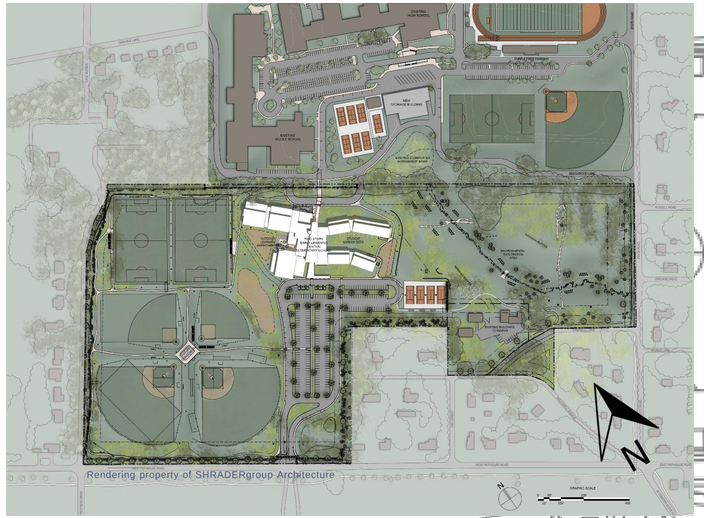
NOLAN JAMES AMOS

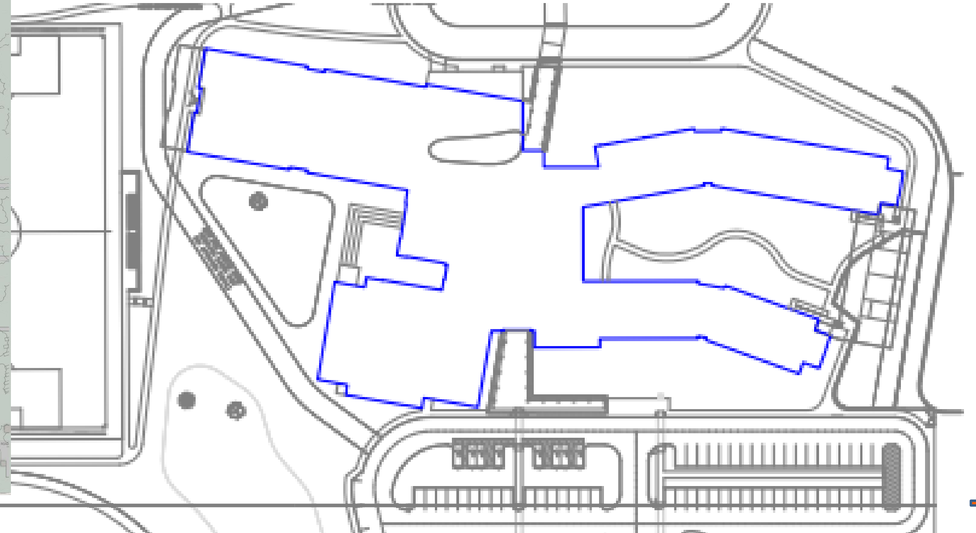
Dr. William Bahnfleth, Faculty Consultant

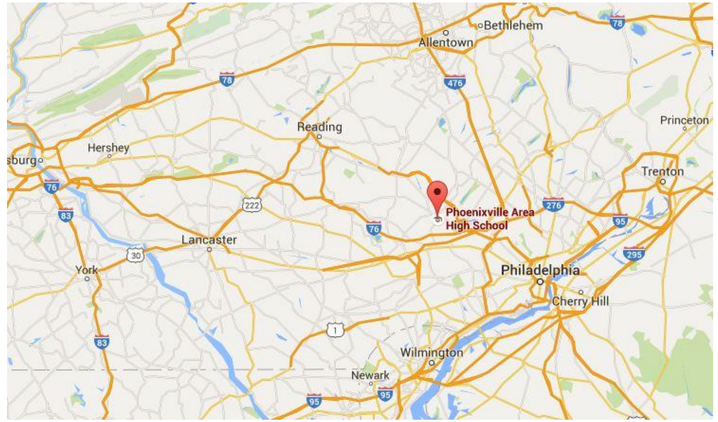
architectural engineering senior thesis

mechanical option

PHOENIXVILLE EARLY LEARNING CENTER AND ELEMENTARY SCHOOL







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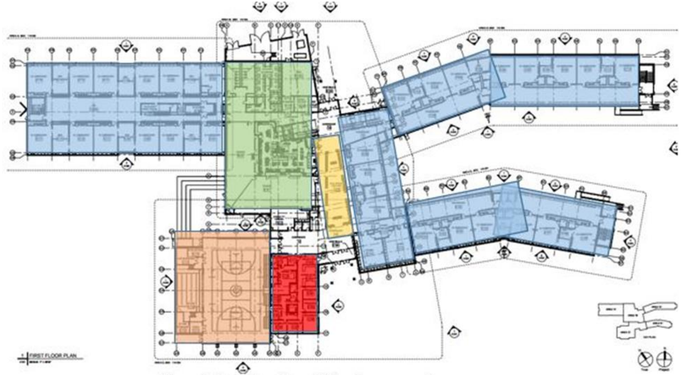


Figure 1: First Floor Plan with basic programming.

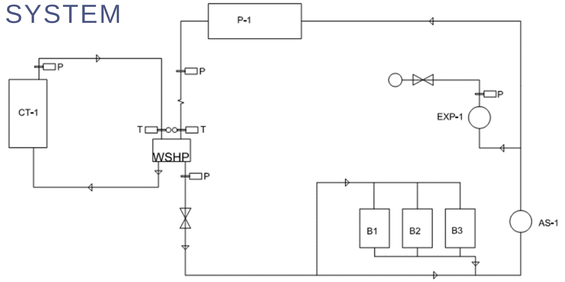
Legend:

- Learning Spaces –
- Gymnasium –
- Administrative –
- Kitchen and Dining -
- Media Center –

2 Stories – 41’-10”
Area: 152,000 SQ. FT.
Occupancy: 1526
Grades: K-5

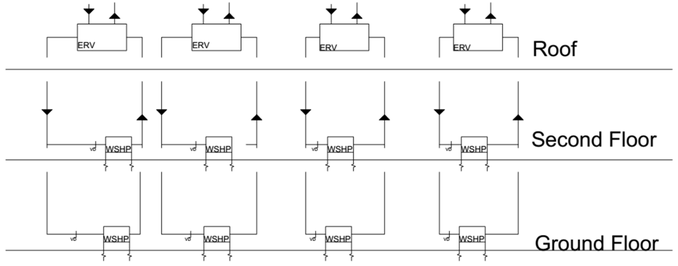
PHOENIXVILLE EARLY LEARNING CENTER AND ELEMENTARY SCHOOL

WATER-SIDE EXISTING SYSTEM



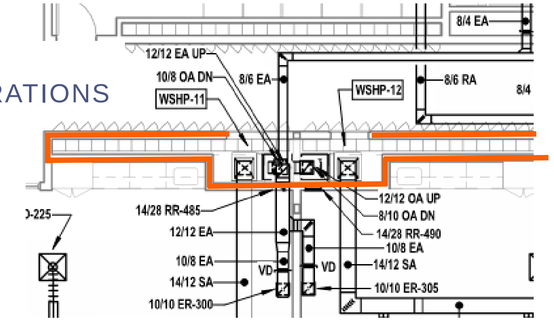
Major Equipment: Boilers						
	Gas Boiler					Boiler
	Tons		GPM	LWT	Boiler HP	Motor HP
Unit	Input	Output				
B-1	166.7	160	190	140	57.4	1.18
B-2	166.7	160	190	140	57.4	1.18
B-3	166.7	160	190	140	57.4	1.18

AIR-SIDE EXISTING SYSTEM



Major Equipment: Energy Recovery Ventilators				
	OA CFM	EA CFM	OA FAN HP	EA FAN HP
ERV-1	8915	8470	10	10
ERV-2	6480	5845	7.5	5
ERV-3	6155	5945	5	5
ERV-4	6125	5600	5	5
ERV-5	3775	3050	3	1.5
ERV-6	5000	4500	3	3
ERV-7	600	550	1/3	1/3
ERV-8	600	550	1/3	1/3
ERV-9	3870	3870	3	3
ERV-10	4375	4155	5	5

SPACE CONSIDERATIONS



Floor Space Lost											
Zone	1A	1B	1C	1D	1E	2A	2B	2C	2D	2E	Total
Area (SF)	251	72	34	309	159	272	155	21	183	119	1575

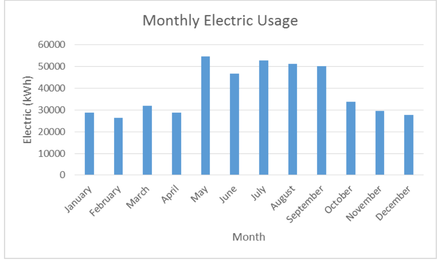
PHOENIXVILLE EARLY LEARNING CENTER AND ELEMENTARY SCHOOL

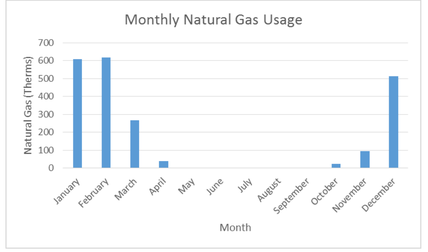
MODELED ENERGY LOADS

Model System Design Loads					
		Airflow (CFM)		Total Capacity (Tons)	
	Sq Ft	Supply	Exhaust	Heating	Cooling
ERV -1	27605	22394	10258	42.5	54.9
ERV -2	19080	25187	7553	48.3	62.4
ERV -3	12808	19751	6196	37.4	49.8
ERV -4	23263	11174	7060	23.6	30.6
ERV -5	8940	3591	2950	6.55	11.4
ERV -6	10980	11226	2351	18.3	27.8
ERV -7	6255	5925	0	2.9	12.1
ERV -8	6600	6539	90	3.9	12.9
ERV -9	9870	5471	84	3.2	12.9
ERV -10	24415	21369	6748	32.3	51.7
Total	149816	**132627**	**43290**	**218.95**	**326.5**

Accuacy of Energy Model						
		(%)	Airflow (%)		Total Capacity (%)	
		Sq Ft	Supply	Exhaust	Heating	Cooling
% Accuracy		11.1	**0.38**	**3.64**	**6.81**	**1.63**

MONTHLY UTILITY USAGE

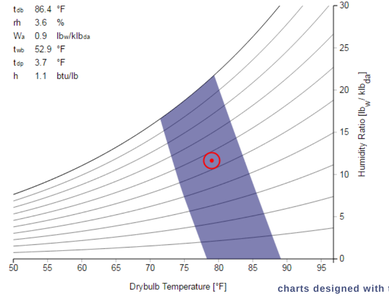


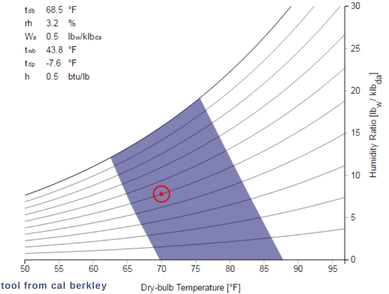


Energy Rates		
Source	Rate	Units
Natural Gas	**$8.90**	/MMBTU
Electric	**$0.08**	/KWh

Annual Fuel Cost ($)	
Electric	**$71,369.00**
Natural Gas	**$8,599.00**

SUMMER AND WINTER DESIGN CONDITIONS





charts designed with tool from cal berkley

Summer Design Conditions

Winter Design Conditions

Conditioned Spaces (°F)			
Season	DB	WB	RH
Summer	79	68.2	\
Winter	70	\	30

PHOENIXVILLE EARLY LEARNING CENTER AND ELEMENTARY SCHOOL

PROJECT GOALS

- ❑ increase energy efficiency
- ❑ space utilization
- ❑ ease of maintenance
- ❑ lower costs
  - ❑ maintenance
  - ❑ upfront
  - ❑ lifecycle

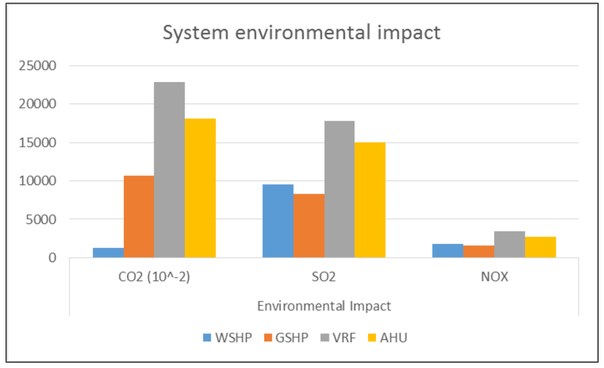
ALTERNATIVES CONSIDERED

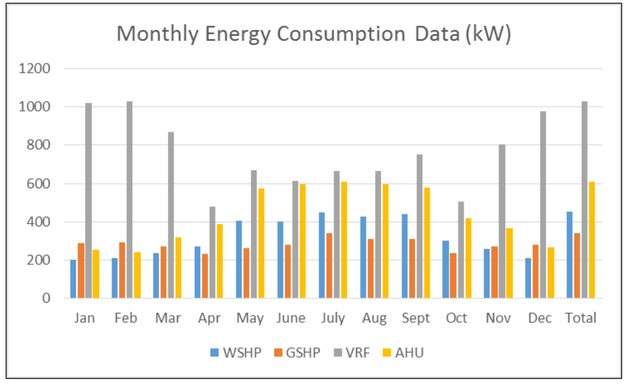
1. ground-coupled heat pump system
2. variable refrigerant flow system
3. centralized air handling unit

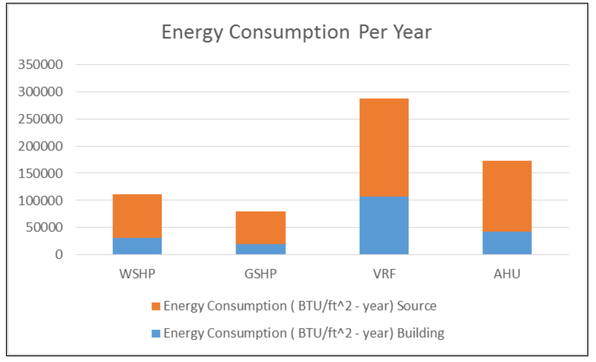
BASE SYSTEM

1. water source heat pumps

ENERGY AND EMISSIONS ANALYSIS

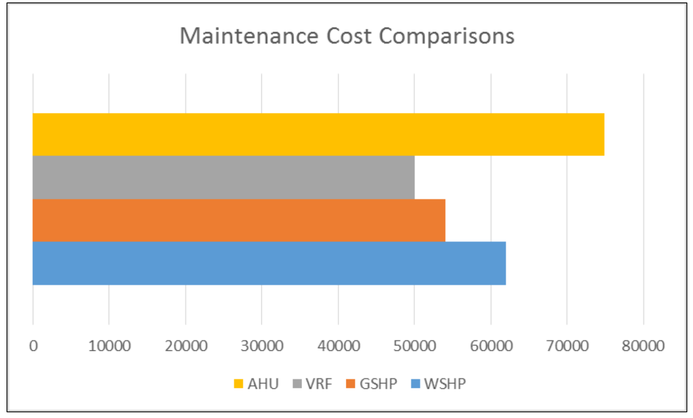


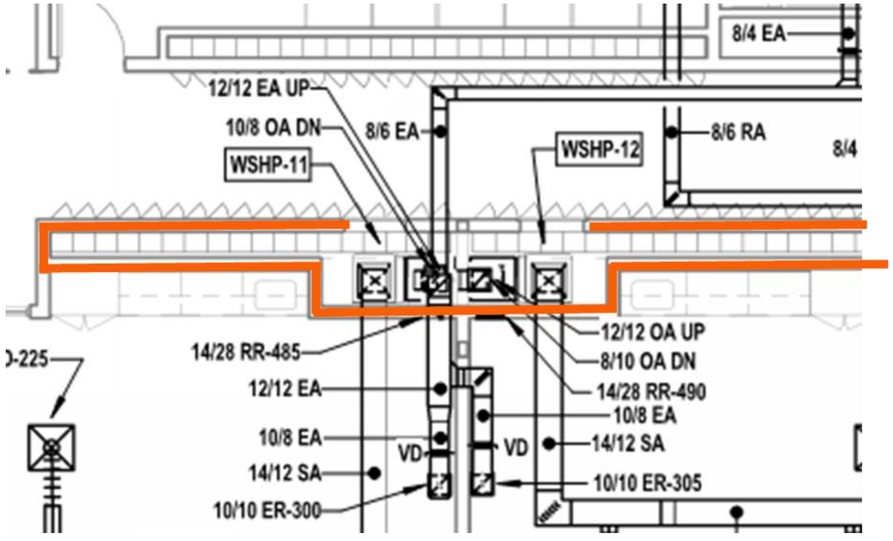




MAINTENANCE

Typical Replacement Life			
	Equipment Name	Median Service Live Years	% Replaced
WSHP	Cooling Tower	>22	14
	Boilers	>22	21
	Heat Pumps	>24	/
	DX Air Dist Equip	>24	15
GSHP	Geothermal Pumps	20	/
	Heat Pumps	>24	/
VRF	Pumps	20	/
	Condensate pumps	15	/
	Condensors, evaporative	20	/
AHU	Rooftop air conditioners	15	/

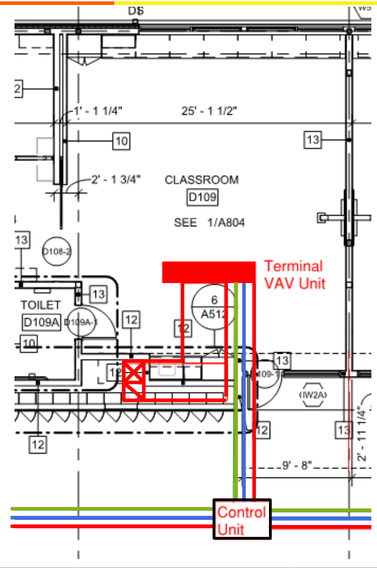




SPACE CONSIDERATIONS

Ground Source Heat Pumps

Closets in Corridors –
1575 sqft + ~150,000 sqft borefield



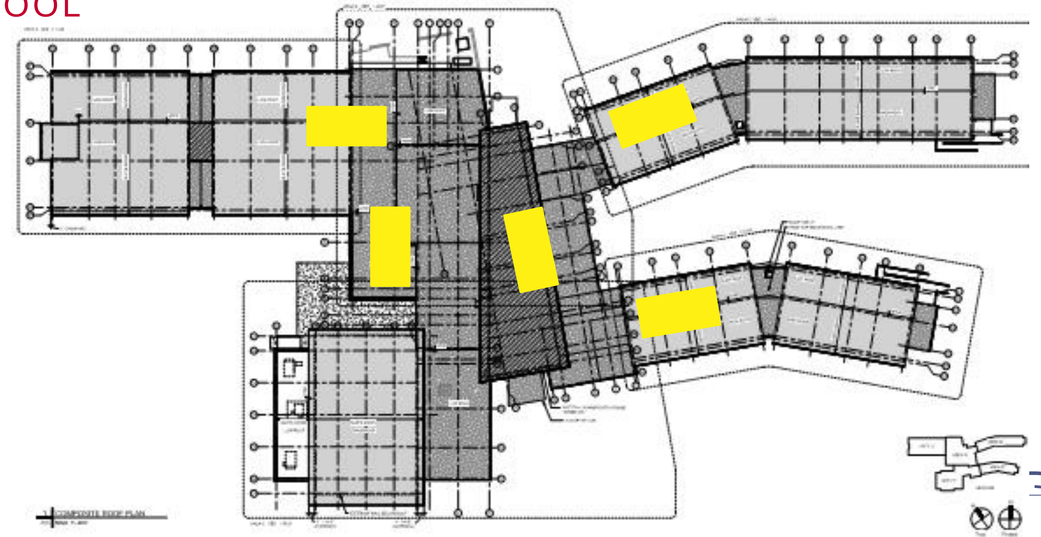
SPACE CONSIDERATIONS

Variable Refrigerant Flow system

Terminal Units in Classrooms
Control Units in Corridors

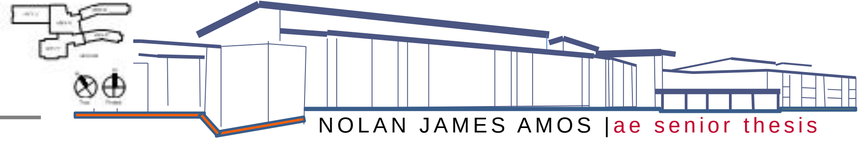
SPACE CONSIDERATIONS

= Centralized Air Handling Unit



Centralized Air Handling Unit

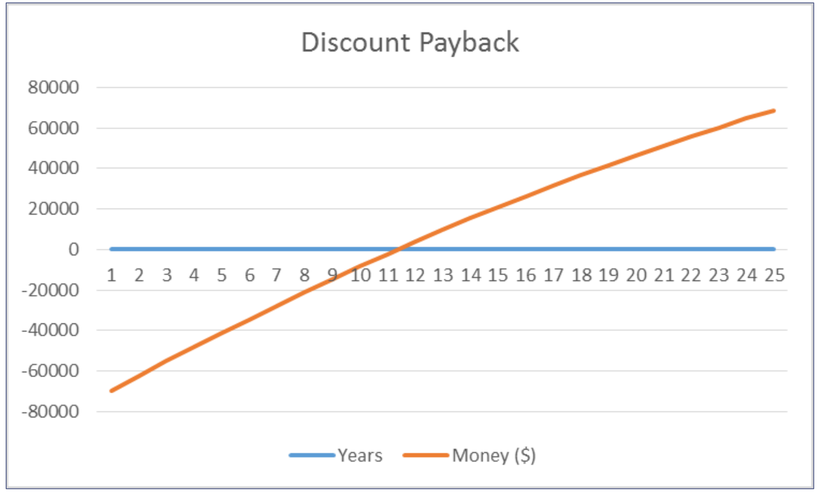
Multiple Units on Ceiling



Cost Analysis

VRF – Did not pay back
AHU – Did not pay back

Simple Payback = 9.34 years
Discount Payback = 11.37 years



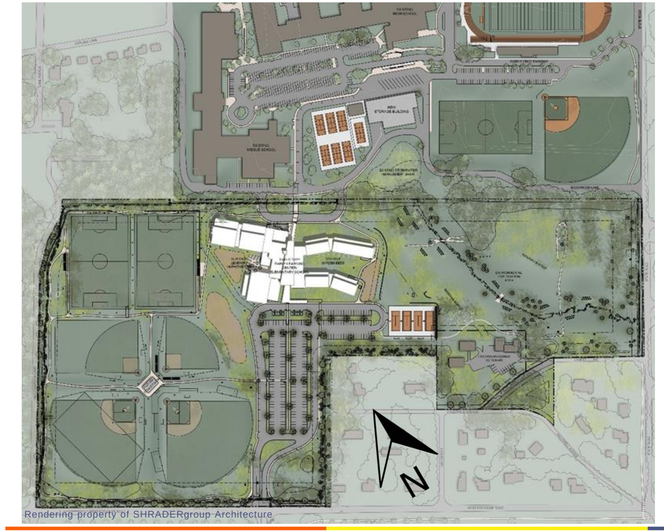
	LCC	NPV @ 25 Years
WSHP	$ 7,662,769.02	$ 4,453,323.65
GSHP	$ 7,444,722.42	$ 4,446,055.87

BREADTH STUDIES

Electrical Breadth – Electrical Load

Results: VRF System used Less Power

Construction Breadth – Scheduling and cost impacts of geothermal system

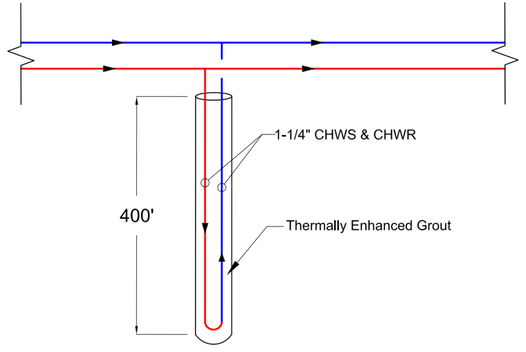


Rendering property of SHRADERgroup Architecture

GEOTHERMAL BORE FIELD

Required Number of Bores		
Bore Depth	Number of Bores	20% Safety
100	669	803
200	334	401
300	223	268
400	**167**	**201**
500	134	161

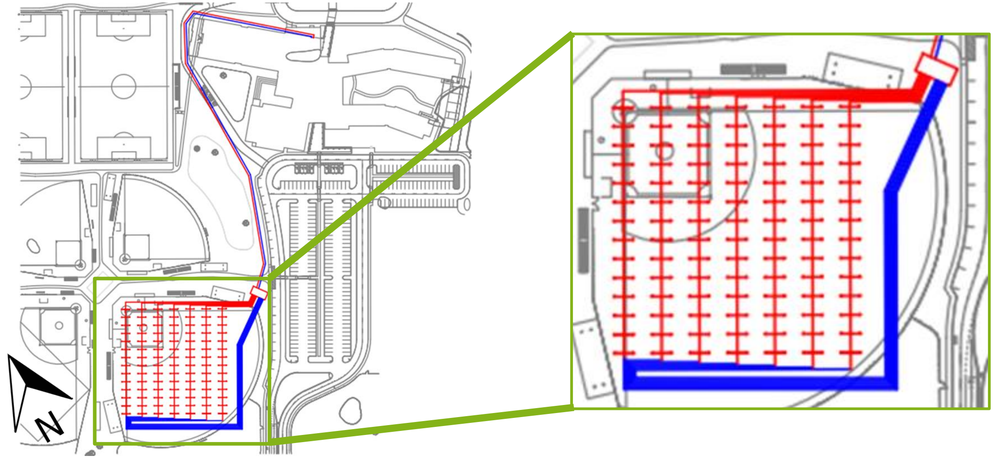
Total Head Loss through well field: 363 feet



PHOENIXVILLE EARLY LEARNING CENTER AND ELEMENTARY SCHOOL

GEOTHERMAL BORE FIELD

WELL FIELD LAYOUT



Construction Schedule Impact		
	Number of Days	Cost
WSHP	5	$150,000.00
GSHP	42	$1,540,000.00

CONCLUSIONS

Energy Emissions: GSHP
Space Utilization: VRF
Maintenance: GSHP/WSHP
Cost: GSHP

AKNOWLEDGEMENTS

Dr. Bahnfelth
Barton Associates
SCHRADERgroup Architecture
Phoenixville School District
AE Class of 2016
My Parents

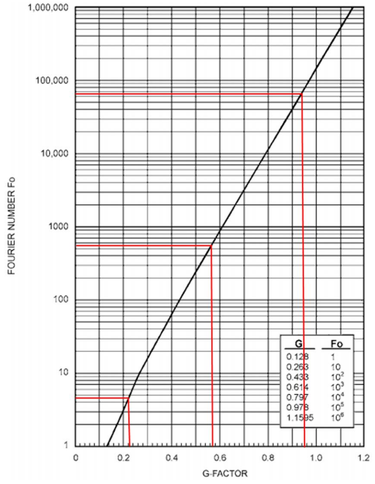
Rendering courtesy of Phoenixville Area School District

Questions?

Appendix

$$l_f = f\frac{L}{D}\frac{\bar{V}^2}{2g}$$

If	1039592	Lost Head
f	0.025	Moody Friction Factor
L	69600	length of pipe, ft
D	0.105417	Diameter of pipe ft
V	63.66183	average velocity, ft/sec
g	32.174	acceleration due to gravity, ft/sec^2



$$R_{ga} = \frac{G_f - G_1}{k_g} \qquad R_{gm} = \frac{G_1 - G_2}{k_g} \qquad R_{gst} = \frac{G_2}{k_g}$$

$$R_{ga} = \frac{(0.943 - 0.562)}{1.67} = 0.228 \qquad R_{gm} = \frac{(0.562 - 0.220)}{1.67} = 0.205 \qquad R_{gst} = \frac{0.220}{1.67} = 0.132$$

$$F_o = \frac{4\alpha_g \tau}{d^2}$$

$$Fo_1 = \frac{4 + 1.06 * (3680.25 - 3650)}{0.5^2} = 513.04$$

$$\tau_1 = 3650\ days$$

$$Fo_2 = \frac{4 * 1.06 * (3680.25 - 3680)}{0.5^2} = 4.24$$

$$\tau_2 = 3650 + 30 = 3680\ days$$

$$Fo_f = \frac{4 * 1.06 * 3680.25}{0.5^2} = 62417$$

$$\tau_f = 3650 + 30 + 0.25 = 3680.25\ days$$

$$L_C = \frac{q_a R_{ga} + (q_{lh} - 3.41 W_h)(R_b + PLF_m R_{gm} + F_{sc} R_{gd})}{t_g - \frac{ELT + LLT}{2} + t_p} \quad (4)$$

$$L_h = \frac{q_a R_{ga} + (q_{lc} - 3.41 W_c)(R_b + PLF_m R_{gm} + F_{sc} R_{gd})}{t_g - \frac{ELT + LLT}{2} + t_p} \quad (4)$$

Required Number of Bores		
Bore Depth	Number of Bores	20% Safety
100	669	803
200	334	401
300	223	268
400	**167**	**201**
500	134	161

Bore Length Calculation			
Cooling	Heating	Variable	Description
1.04	1.04	Fsc	Short-circuit heat loss factor
1	1	PLFm	Part-load factor
248319	248319	qa	Net annual average heat transfer to the ground
0.228	0.228	Rga	Thermal resistance of the ground (annual pulse)
0.132	0.132	Rgd	Thermal resistance of the ground (daily pulse)
0.205	0.205	Rgm	Effective thermal resistance of the ground (monthly pulse)
0.09	0.09	Rb	Thermal resistance of bore
54	54	tg	Undisturbed ground temperature
1.8	1.8	tp	Ground temperature penalty
79	40	ELT	heat pump entering liquid temperature
89	34	LLT	heat pump leaving liquid temperature
401040	376200	qlc/qlh	Building design block load
4474.2	4474.2	Wc/Wh	Pump Power
62275	**66882**	Lc/ Lh	Required bore length

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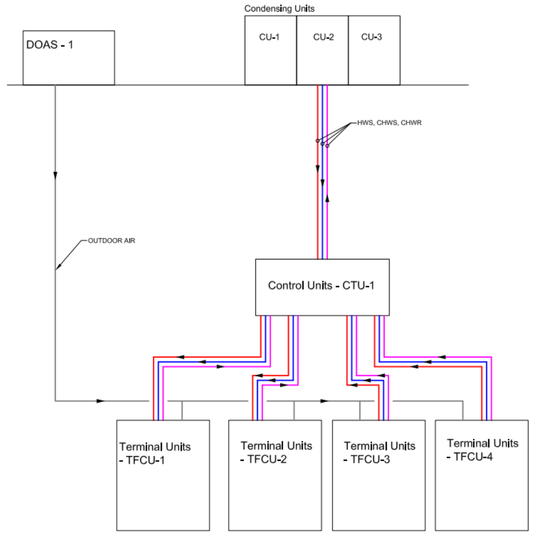
Appendix



Paragraph	Designation	Cooling or heating source	Air or substance to be cooled or heated
5.1.1	Direct system		
5.1.2.1	Indirect open spray system		
5.1.2.2	Double indirect open spray system	Vent	
5.1.2.3	Indirect closed system	Liquid expansion	
5.1.2.4	Indirect vented closed system