Stengel Hall
Center for Academic Excellence

Linden Hall School for Girls, Lititz, PA

Madeline Haus | Mechanical Option | Advisor: Dr. Treado

- BUILDING INTRODUCTION
- EXISTING MECHANICAL SYSTEM
- GEOTHERMAL INVESTIGATION
- BIOMASS INVESTIGATION
- CONSTRUCTION BREADTH
- FINAL RECOMMENDATION

Building Introduction

- Stengel Hall – Center for Academic Excellence
  - Originally built in 1748
  - Classrooms
  - Administrative Offices
- Current Construction
  - May 2011-August 2012
  - Renovate – 14,000SF
  - Expand – 23,000SF
- Project Objectives
  - Positive Learning Environment
  - Technology Based Classrooms
  - Functionality of Facility

Plan Courtesy of Chambers & Associates | Colors Added

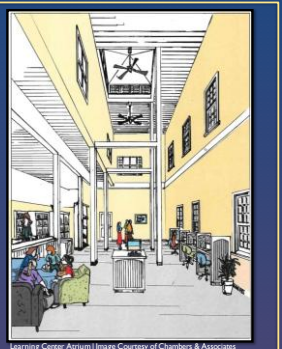
- Existing Stengel Hall & Chapel
- Existing Steinman Performing Arts Center
- New Stengel Hall Addition
- New Entrance from Main Street

View from Main Street | Image courtesy of Chambers & Associates

View from courtyard | Image courtesy of Chambers & Associates

Existing Classroom

Main Lobby | Image Courtesy of Chambers & Associates



Learning Center Atrium | Image Courtesy of Chambers & Associates

Existing Mechanical System

Existing Mechanical System

- Water-Side Components:

Split System Condensing Unit

(5) Units concealed on roof

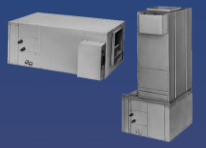
90 Tons of cooling total

Gas-Fired Boiler

(4) Units located in basement

310,000 BTU/hr each

- Air-Side Components:

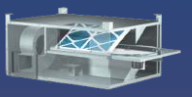


Horizontal & Vertical Fan Coil Units

(10) Units in BASEMENT

(13) Units in ATTIC

(5) Units in alternate locations



Energy Recovery Ventilator

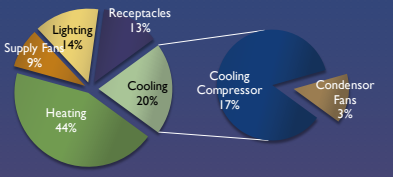
(3) Units in BASEMENT

(7) Units in ATTIC

Pre-condition air for classrooms

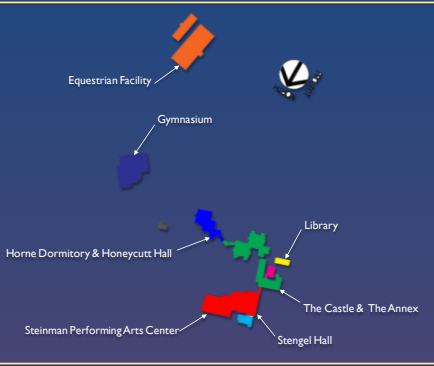
- Designed Mechanical System Cost
  - ~ $1 million ($26.00 per SF)
  - 17% of total project cost
- Annual Operating Cost: $24,326.77

Energy Consumption



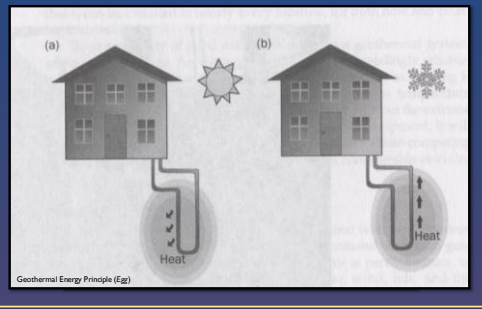
Proposed Solutions & Goals

- Sustainability
  - Not driving force for current project
- 2006 Facility Study Considerations
- Alternate Solutions Evaluation
  - Total Energy Use
  - Emissions

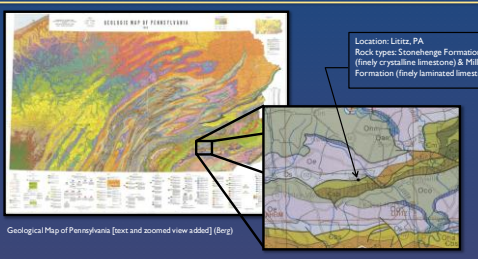



Aerial View of Linden Hall | Image Courtesy of bing.com (shading added)

GEOTHERMAL INVESTIGATION



Geothermal Energy Principle (Egg)


Geological Map of Pennsylvania [text and zoomed view added] (Berg)

Location: Lititz, PA
Rock types: Stonehenge Formation (finely crystalline limestone) & Millbach Formation (finely laminated limestone)

Thermal Properties of Soil (from 2011 ASHRAE Handbook of Fundamentals)		
Rocks	Conductivity [Btu/h*ft*°F]	Diffusivity [ft²/day]
Limestone	1.4 to 2.2	0.9 to 1.4
Value used in analysis	1.8	1.15

- Design Characteristics
  - Vertical Piping Layout
    - 6" Boreholes with 1 ¼" HDPE U-Tube Piping
  - Grout Conductivity
    - 15% Bentonite/85% Sand (conductivity of 1.0 BTU/h*ft*°F)
  - Building Design Loads

Building Design Loads		
	Peak Heating Load [Btu/h]	Peak Cooling Load [Btu/h]
Stengel Hall	764,300	-1,087,200
Entire Linden Hall Campus	3,190,300	-4,525,200

Geothermal Investigation

- Pipe Loop Size
  - Method outlined by ASHRAE

$$L_c = \frac{q_a R_{ga} + (q_{lc} - 3.41 W_c)(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p}$$

$$L_h = \frac{q_a R_{ga} + (q_{lh} - 3.41 W_h)(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_g - \frac{t_{wi} + t_{wo}}{2} - t_p}$$

  - 400' borehole depth recommended
  - Reverse return piping
  - 20' x 20' grid layout

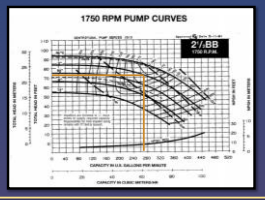
- Stengel Hall Loop
  - 25,000' of bore
  - 63 total boreholes
- Linden Hall Loop
  - 108,800' of bore
  - 1st Loop – 114 boreholes
  - 2nd Loop – 104 boreholes
  - 3rd Loop – 59 boreholes

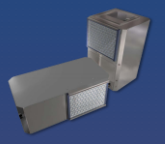
Stengel Hall borehole layout (image courtesy of bing.com; layout added)

Linden Hall campus borehole layout (image courtesy of Bing.com; layout added)

Geothermal Investigation

- Equipment Selection
  - 1 ½ - 5 Ton Water Source Heat Pumps
  - (2) 7 ½ hp centrifugal pumps
    - 270 gpm (3 gpm/ton)
    - 71 ft of head loss





Water Source Heat Pump | Image courtesy of Trane

Base-mounted centrifugal pump | Image courtesy of Bell & Gossett

Energy Consumption Summary				
	Electricity		Gas	
	kWh		kBtu	
	Boilers & Condensing Units	Ground Source Heat Pumps	Boilers & Condensing Units	Ground Source Heat Pumps
Heating				
Primary Heating	0	32,670	586,424	0
Other Heating Accessories	4,305	62	0	0
Cooling				
Cooling Compressor	39,706	28,963	0	0
Tower/Cond Fans	16,039	0	0	0
Other Heating Accessories	1,901	55	0	0
Auxiliary				
Supply Fans	25,192	24,877	0	0
Pumps	0	48,391	0	0

Combined Existing Energy Use: 789,928 kBTU/year

GSHP Energy Use: 460,681 kBTU/year

41% Reduction in Energy Consumption

Initial Cost: $285,080.00 increase

Electric Cost: $4,026.44/year increase

Gas Cost: $9,790.83/year decrease

32 year payback

Biomass Investigation

- Fuel Types
  - Green Wood Chips ($40.00 per ton)
  - Equestrian Waste (cost savings)
- Case Studies
  - Bennington College, Bennington, VT
  - Sullivan County Schools, Sullivan County, PA
  - Penns Valley School District, Centre County, PA
- Recommended System
  - Provide heat for entire campus
  - 100 hp wood-fired boiler
  - Low pressure steam (15 psig)

Image courtesy of Union of Concerned Scientists

Image courtesy of Weaber Lumber

Image courtesy of Weaber Lumber

Image courtesy of Biomass Magazine

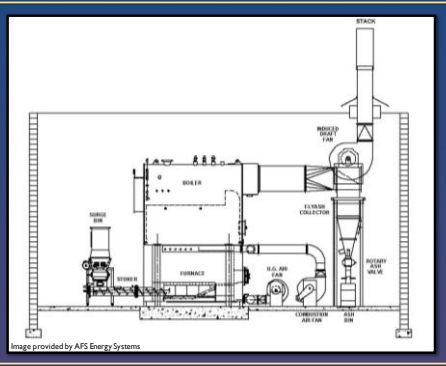


Image provided by AFS Energy Systems

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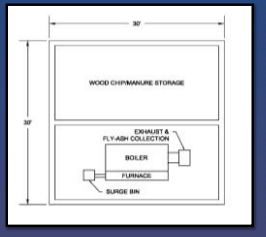
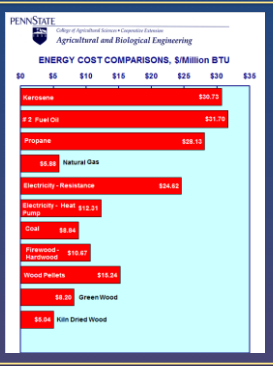


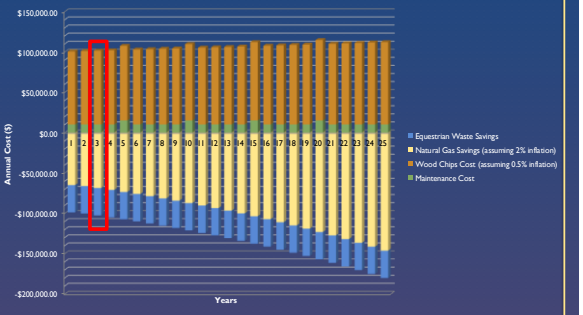
Biomass Investigation

- Energy Use
  - Compared to natural gas boiler
  - Demand remains constant
  - Efficiency changes
    - Natural Gas: 100,000 BTU/therm & 85% efficient
    - Green Wood: 4,692 BTU/lb & 65% efficient
  - Energy Cost Comparison
    - $25,572/year increase
- Cost Analysis
  - Maintenance Cost: $10,000/year + $5,000 /5 years
  - Equestrian Waste Utilization: $33,960/year savings



Initial Cost of Boiler System:
$2.8 Million

Not Cost Efficient



Construction Breadth Summary

- Geothermal Estimate

Geothermal Estimate Summary			
Activity	Material Cost	Labor Cost	Total Cost
Drilling	$0.00	$162,500.00	$162,500.00
Trenching	$0.00	$3,623.54	$3,623.54
Piping	$55,187.62	$0.00	$55,187.62
Welding	$7,618.20	$0.00	$7,618.20
Backfill/Grout	$11,920.80	$1,103.22	$13,024.02
7-1/2 hp Pump	$15,200.00	$930.00	$16,130.00
Water Source Heat Pumps	$162,000.00	$45,000.00	$207,000.00
TOTAL			**$465,083.38**

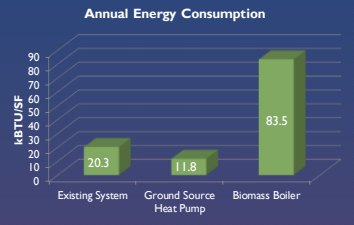
- Biomass Estimate

Biomass Boiler Estimate Summary			
Activity	Cost/SF	Area	Total Cost
New Boiler Building	$71.41	900	$58,998.94*
Steam Piping Repairs/Installation	$22.00	99,995	$2,199,890.00
Wood-Fired Boiler System	-	-	$600,000
TOTAL			**$465,083.38**

*Includes location correction of 0.918

System Recommendation

- Energy Comparison



Emissions Comparison				
		System Emissions (lbs/sf)		
	SYSTEM:	Existing	Ground Source Heat Pump	Wood-Fired Boiler
	AREA:	39,000	39,000	144,275
Pollutant	NO_x	0.011	0.0145	0.047
	SOx	0.0027	0.0042	0.00018
	CO_2	3.84	3.18	0.274

- Stengel Hall Recommendation
  - Ground Source Heat Pump
    - Potential Energy Savings
    - Educational Value to Students
- Linden Hall Campus Recommendation
  - Wood-fired Boiler
    - Reduce Overall Emissions
    - Educational Value to Students
  - Evaluate Existing Heating Requirements
  - Explore Possible Rebates

Questions

Acknowledgements

- Dr. Stephen Treado – Faculty Advisor
- Jeff Chambers – Chambers & Associates
- Linden Hall School for Girls – Project Owner
- Paul Lewandowski – AFS Energy

Presentation Navigation

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- GEOTHERMAL INVESTIGATION
- BIOMASS INVESTIGATION
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- FINAL RECOMMENDATION

Supporting Geothermal Values

Figure C.4 - Required Bore Length for Cooling

Variable	Units	Coefficient	Stengel Hall	Linden Hall Campus
Short Circuit Heat Loss Factor		F_{sc}	1.04	
Part Load Factor During Design Month		PLF_m	1.0	
Building Design Cooling Block Load	Btu/h	q_c	-1087200	-4525200
Net Annual Average Heat Transfer to Ground	Btu/h	q_a	-322900	-1334900
Thermal Resistance of Pipe	$h*ft^{*\circ}F/Btu$	R_b	0.09	
Effective Thermal Resistance of Ground (annual pulse)	$h*ft^{*\circ}F/Btu$	R_{ga}	0.117	
Effective Thermal Resistance of Ground (monthly pulse)	$h*ft^{*\circ}F/Btu$	R_{gm}	0.172	
Effective Thermal Resistance of Ground (daily pulse)	$h*ft^{*\circ}F/Btu$	R_{gd}	0.133	
Undisturbed Ground Temperature	°F	t_g	52	
Temperature Penalty for Interference of Adjacent Bores	°F	t_p	1.8	
Liquid Temperature at Heat Pump Inlet	°F	t_{wi}	65	
Liquid Temperature at Heat Pump Outlet	°F	t_{wo}	75	
Power Input at Design Cooling Load	W	W_c	10000	10000
Required Bore Length for Cooling	ft	L_c	24605	100177

Figure C.5 - Required Bore Length for Heating

Variable	Units	Coefficient	Stengel Hall	Linden Hall Campus
Short Circuit Heat Loss Factor		F_{sc}	1.04	
Part Load Factor During Design Month		PLF_m	1.0	
Building Design Heating Block Load	Btu/h	q_h	764300	3190300
Net Annual Average Heat Transfer to Ground	Btu/h	q_a	-322900	-1334900
Thermal Resistance of Pipe	$h*ft^{*\circ}F/Btu$	R_b	0.09	
Effective Thermal Resistance of Ground (annual pulse)	$h*ft^{*\circ}F/Btu$	R_{ga}	0.117	
Effective Thermal Resistance of Ground (monthly pulse)	$h*ft^{*\circ}F/Btu$	R_{gm}	0.172	
Effective Thermal Resistance of Ground (daily pulse)	$h*ft^{*\circ}F/Btu$	R_{gd}	0.133	
Undisturbed Ground Temperature	°F	t_g	52	
Temperature Penalty for Interference of Adjacent Bores	°F	t_p	1.8	
Liquid Temperature at Heat Pump Inlet	°F	t_{wi}	35	
Liquid Temperature at Heat Pump Outlet	°F	t_{wo}	45	
Power Input at Design Heating Load	W	W_h	10000	10000
Required Bore Length for Heating	ft	L_h	25006	108779

Figure C.10 – Payback Period of Geothermal System

Year	Increased Electric Cost (assuming 1% inflation)	Gas Savings (assuming 2% inflation)	Sum of Annual Costs & Savings	Cumulative Cost of System
1	$4,026.00	-$9,790.83	$279,315.17	$279,315.17
2	$4,066.26	-$9,986.65	-$5,920.39	$273,394.78
3	$4,106.92	-$10,186.38	-$6,079.46	$267,315.33
4	$4,147.99	-$10,390.11	-$6,242.12	$261,073.21
5	$4,189.47	-$10,597.91	-$6,408.44	$254,664.77
6	$4,231.37	-$10,809.87	-$6,578.50	$248,086.27
7	$4,273.68	-$11,026.06	-$6,752.38	$241,333.89
8	$4,316.42	-$11,246.59	-$6,930.17	$234,403.72
9	$4,359.58	-$11,471.52	-$7,111.94	$227,291.78
10	$4,403.18	-$11,700.95	-$7,297.77	$219,994.01
11	$4,447.21	-$11,934.97	-$7,487.76	$212,506.25
12	$4,491.68	-$12,173.67	-$7,681.99	$204,824.27
13	$4,536.60	-$12,417.14	-$7,880.54	$196,943.72
14	$4,581.96	-$12,665.48	-$8,083.52	$188,860.21
15	$4,627.78	-$12,918.79	-$8,291.01	$180,569.20
16	$4,674.06	-$13,177.17	-$8,503.11	$172,066.09
17	$4,720.80	-$13,440.71	-$8,719.91	$163,346.18
18	$4,768.01	-$13,709.53	-$8,941.52	$154,404.66
19	$4,815.69	-$13,983.72	-$9,168.03	$145,236.64
20	$4,863.85	-$14,263.39	-$9,399.54	$135,837.09
21	$4,912.49	-$14,548.66	-$9,636.17	$126,200.92
22	$4,961.61	-$14,839.63	-$9,878.02	$116,322.90
23	$5,011.23	-$15,136.42	-$10,125.20	$106,197.70
24	$5,061.34	-$15,439.15	-$10,377.81	$95,819.89
25	$5,111.95	-$15,747.94	-$10,635.98	$85,183.90
26	$5,163.07	-$16,062.89	-$10,899.82	$74,284.08
27	$5,214.70	-$16,384.15	-$11,169.45	$63,114.63
28	$5,266.85	-$16,711.84	-$11,444.99	$51,669.64
29	$5,319.52	-$17,046.07	-$11,726.55	$39,943.09
30	$5,372.71	-$17,386.99	-$12,014.28	$27,928.81
31	$5,426.44	-$17,734.73	-$12,308.29	$15,620.51
32	$5,480.70	-$18,089.43	-$12,608.72	$3,011.79
33	$5,535.51	-$18,451.22	-$12,915.71	-$9,903.92

Supporting Biomass Values

Figure D.4 - Simple Payback Calculation of Biomass Boiler

Year	Maintenance Cost	Wood Chips Cost (assuming 0.5% inflation)	Natural Gas Savings (assuming 2% inflation)	Equestrian Waste Savings	Sum of Annual Costs & Savings (includes initial cost)	Cumulative Cost of System
1	$ 10,000.00	$ 90,553.00	$ (64,981.00)	$ (33,960.00)	$ 2,860,500.94	**$2,860,500.94**
2	$ 10,000.00	$ 91,005.77	$ (66,280.62)	$ (33,960.00)	$ 765.14	**$2,861,266.09**
3	$ 10,000.00	$ 91,460.79	$ (68,600.44)	$ (33,960.00)	$ (1,099.65)	**$2,860,166.44**
4	$ 10,000.00	$ 91,918.10	$ (71,001.46)	$ (33,960.00)	$ (3,043.36)	**$2,857,123.08**
5	$ 15,000.00	$ 92,377.69	$ (73,486.51)	$ (33,960.00)	$ (68.82)	**$2,857,054.26**
6	$ 10,000.00	$ 92,839.58	$ (76,058.54)	$ (33,960.00)	$ (7,178.96)	**$2,849,875.30**
7	$ 10,000.00	$ 93,303.77	$ (78,720.58)	$ (33,960.00)	$ (9,376.81)	**$2,840,498.49**
8	$ 10,000.00	$ 93,770.29	$ (81,475.81)	$ (33,960.00)	$ (11,665.51)	**$2,828,832.98**
9	$ 10,000.00	$ 94,239.14	$ (84,327.46)	$ (33,960.00)	$ (14,048.31)	**$2,814,784.66**
10	$ 15,000.00	$ 94,710.34	$ (87,278.92)	$ (33,960.00)	$ (11,528.58)	**$2,803,256.08**
11	$ 10,000.00	$ 95,183.89	$ (90,333.68)	$ (33,960.00)	$ (19,109.79)	**$2,784,146.30**
12	$ 10,000.00	$ 95,659.81	$ (93,495.36)	$ (33,960.00)	$ (21,795.55)	**$2,762,350.75**
13	$ 10,000.00	$ 96,138.11	$ (96,767.70)	$ (33,960.00)	$ (24,589.59)	**$2,737,761.16**
14	$ 10,000.00	$ 96,618.80	$ (100,154.57)	$ (33,960.00)	$ (27,495.77)	**$2,710,265.39**
15	$ 15,000.00	$ 97,101.90	$ (103,659.98)	$ (33,960.00)	$ (25,518.08)	**$2,684,747.31**
16	$ 10,000.00	$ 97,587.40	$ (107,288.08)	$ (33,960.00)	$ (33,660.67)	**$2,651,086.64**
17	$ 10,000.00	$ 98,075.34	$ (111,043.16)	$ (33,960.00)	$ (36,927.82)	**$2,614,158.82**
18	$ 10,000.00	$ 98,565.72	$ (114,929.67)	$ (33,960.00)	$ (40,323.95)	**$2,573,834.87**
19	**$ 10,000.00**	**$ 99,058.55**	**$ (118,952.21)**	**$ (33,960.00)**	**$ (43,853.66)**	**$2,529,981.21**
20	$ 15,000.00	$ 99,553.84	$ (123,115.54)	$ (33,960.00)	$ (42,521.70)	**$2,487,459.52**
21	$ 10,000.00	$ 100,051.61	$ (127,424.58)	$ (33,960.00)	$ (51,332.97)	**$2,436,126.55**
22	$ 10,000.00	$ 100,551.87	$ (131,884.44)	$ (33,960.00)	$ (55,292.57)	**$2,380,833.97**
23	$ 10,000.00	$ 101,054.63	$ (136,500.39)	$ (33,960.00)	$ (59,405.77)	**$2,321,428.20**
24	$ 10,000.00	$ 101,559.90	$ (141,277.91)	$ (33,960.00)	$ (63,678.01)	**$2,257,750.20**
25	$ 10,000.00	$ 102,067.70	$ (146,222.64)	$ (33,960.00)	$ (68,114.94)	**$2,189,635.26**

Supporting Construction Values

Initial Cost of Geothermal System							
System Component	Unit	Material [$/Unit]	Labor [$/Unit]	Quantity	COST		
					Material	Labor	TOTAL
Drill Boreholes, 6" diameter	L.F.	$0.00	$6.50	25,000	$0.00	$162,500.00	$162,500.00
Trench Excavation for Header, 8" wide, 48" deep and backfill	L.F.	$0.00	$1.03	3518	$0.00	$3,623.54	$3,623.54
U-tube piping, 1-1/4" HDPE	L.F.	$0.91	$0.00	52,392	$47,676.72	$0.00	$47,676.72
Header Piping, 4" HDPE	L.F.	$3.05	$0.00	1526	$4,654.30	$0.00	$4,654.30
Fusion for HDPE joint, 1-1/4" (every 40' of piping)	EA	$0.00	$8.30	718	$0.00	$5,959.40	$5,959.40
Fusion for HDPE joint, 4" (every 40' of piping)	EA	$0.00	$18.85	88	$0.00	$1,658.80	$1,658.80
Sand, grout mixture and pipe bedding in trench	C.Y.	$1.60	$0.81	174	$278.40	$140.94	$419.34
Granular Bentonite, 50lb bag (0.625 ft^3)	Bag	$9.80	$0.81	1188	$11,642.40	$962.28	$12,604.68
90d Elbow, 4" HDPE	EA	$18.70	$0.00	36	$673.20	$0.00	$673.20
90d Elbow, 1-1/4" HDPE	EA	$6.70	$0.00	252	$1,688.40	$0.00	$1,688.40
Tee, 4" HDPE	EA	$22.50	$0.00	22	$495.00	$0.00	$495.00
7-1/2 hp, 1750RPM Centrifugal Pump, end suction, base mounted	EA	$7,600.00	$465.00	2	$15,200.00	$930.00	$16,130.00
Water Source Heat Pump	ton	$1,800.00	$500.00	90	$162,000.00	$45,000.00	$207,000.00
					$244,308.42	$220,774.96	$465,083.38

Biomass Boiler Structure:

Concrete Block (Concrete Frame) = 149.25 $/SF for exterior wall perimeters of 220 L.F.

- 18.70 $/100 L.F. (because the 30'x30' building proposed only has a perimeter of 120')
- 22.9% (Interiors)
- 10.2% (HVAC)
- 1.8% (Plumbing)
- 10.4% (Electrical)

= $71.41/SF

$$\frac{\$71.41}{SF} * 30'x30' = \$64{,}269 * 0.918\ (location) = \$\mathbf{58{,}998.94}$$