BENTWORTH MIDDLE SCHOOL

BENTLEYVILLE, PENNSYLVANIA

KYLE COURTNEY | MECHANICAL OPTION | DUSTIN EPLEE

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  - GEOTHERMAL HYBRID SYSTEM
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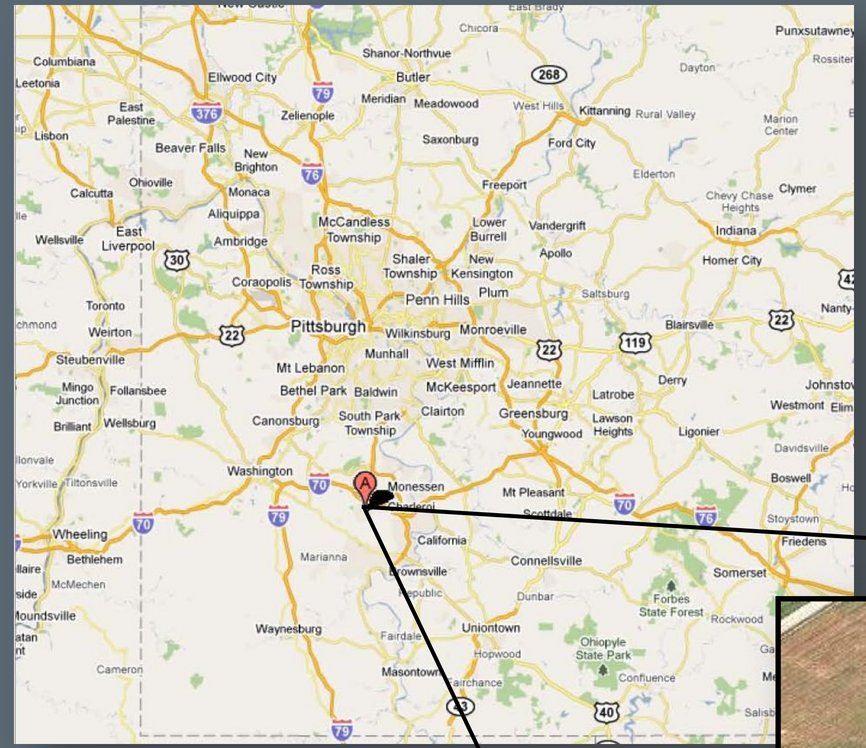
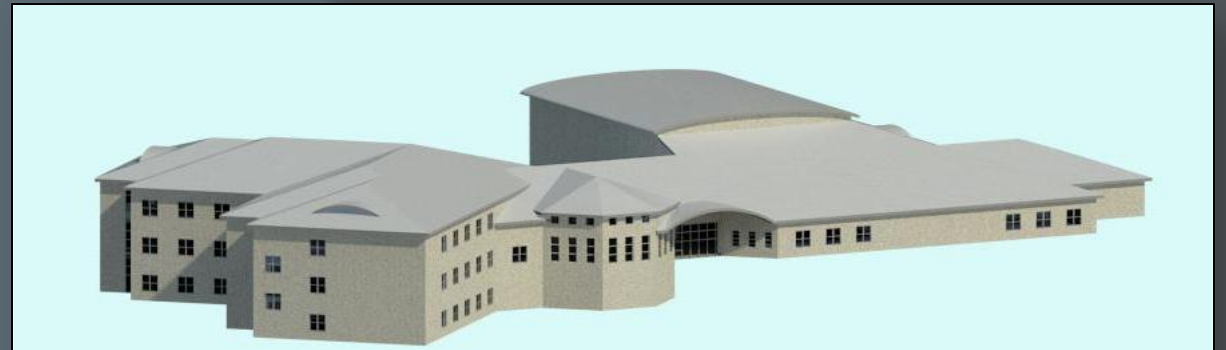
Building Name:	Bentworth Middle School
Location:	Bentleyville, PA
Building Owner:	Bentworth School District
Architect and MEP Engineer:	Hayes Large Architects
Occupancy Type:	Educational
Size:	83,800 Square Feet
Stories Above Grade:	3 Stories
Start Construction Date:	May 2007
End Construction Date:	January 2009
Cost:	$18 Million
Project Delivery Method:	Design-Bid-Build




Front Entrance View


Rear View

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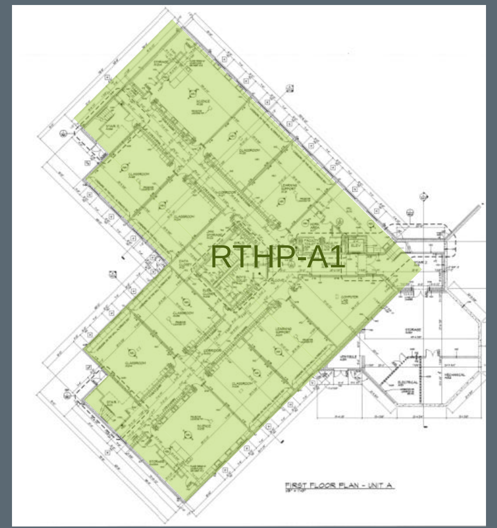
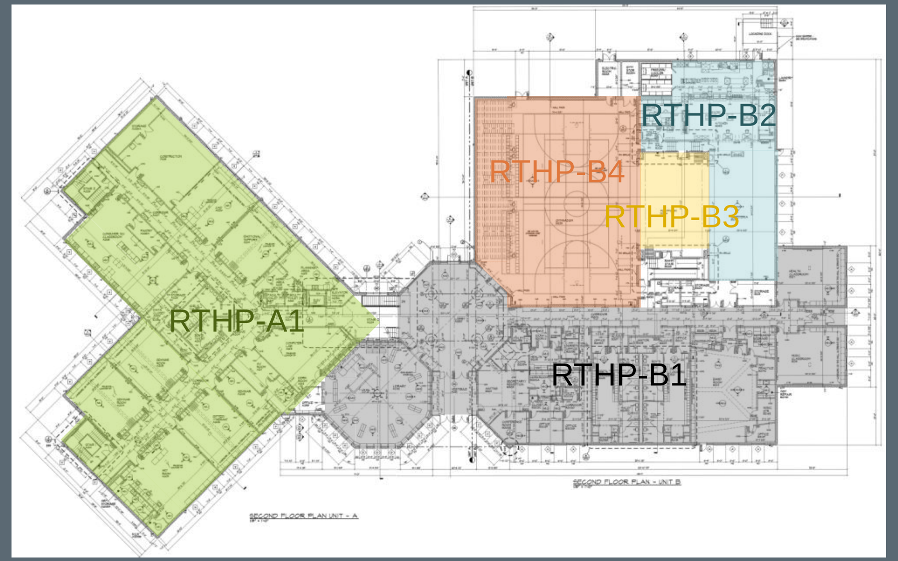
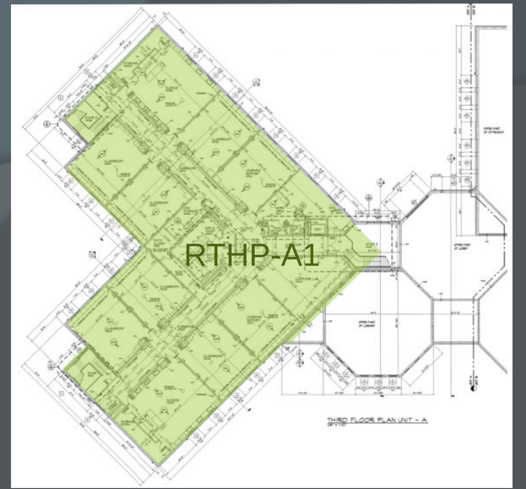
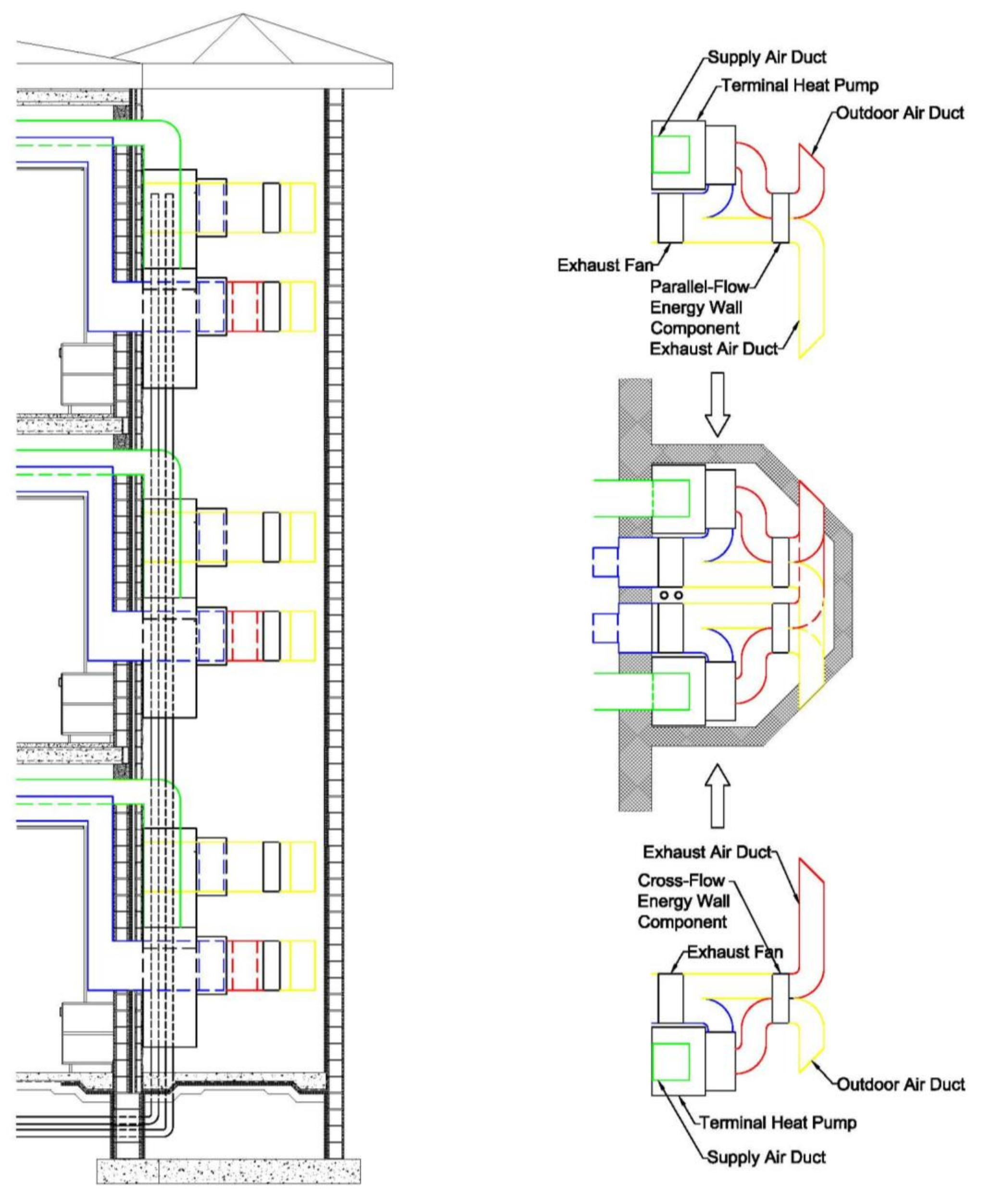
Mechanical System Overview

- 96 bore (350’ deep each) geothermal loop field
- 2 DOAS rooftop heat pump units
- Terminal heat pump units located in the academic and administrative areas
- 3 single zone rooftop heat pump units
- Design heating thermostat setpoint is 70°F
- Design cooling thermostat setpoint is 75°F
- Hydronic side is driven by 2 VSD pumps in parallel
- Entering water temperature from loop field for heating is 42°F
- Entering water temperature from loop field for cooling is 75°F









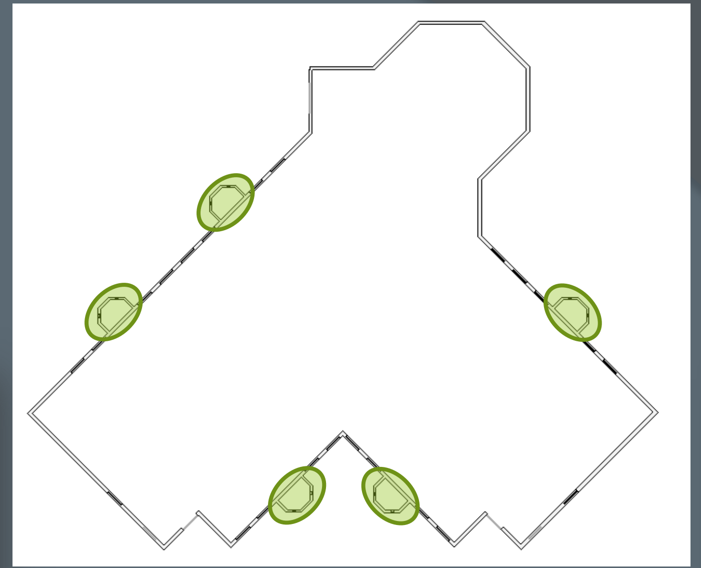
Mechanical Tower Section Cut

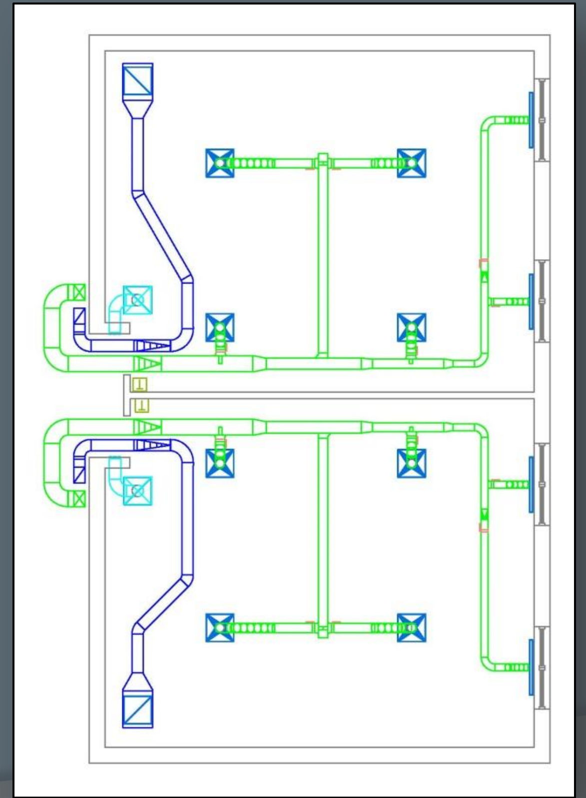
Mechanical Tower Plan

Goals of Redesigned Air System
- Eliminate mechanical mezzanine
  - Reduce ductwork
  - Reduce fan energy
  - Provide additional usable space
- Ensure proper ventilation but reduce the amount of conditioned outdoor air
- Achieve energy savings through the use of a higher efficiency flat plate heat exchanger
- Improved air quality
- Maintain ease of maintenance access
- Maintain remote location of heat pumps for acoustical purposes

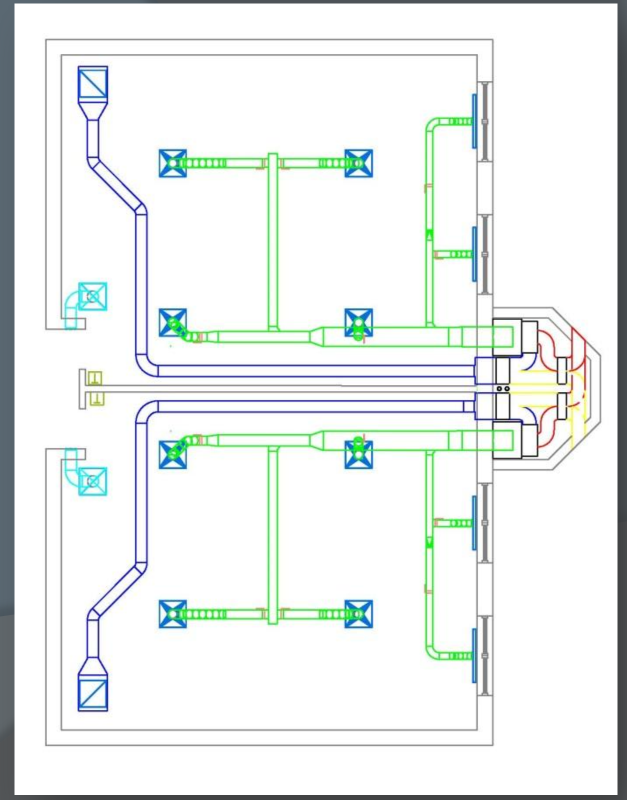
Design Considerations
- Location
- Tower construction
- Component selections
  - Outdoor air intake control
  - Energy recovery core selection and usage
- A slightly modified version of this system could also be used in the Administration area

Tower Locations





Mechanical Plan of as Designed Typical Classrooms



Mechanical Plan of Redesigned Typical Classrooms

Energy Analysis

- Carrier HAP was used as the modeling tool
- All heat pumps in the building were considered
- Schedule

System	Cooling	Heating	Air System Fans	Pumps	Total Consumption
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
Designed	59,538	27,048	71,872	17,992	183,585
Redesigned	64,339	1,282	40,900	15,648	122,171

Result Analysis

- 33% reduction in the building's mechanical energy consumption
- Unanticipated increase in cooling load
- Unusually low heating load

Cost Analysis

Material	Unit	Total Price/Unit	Total Price
	SF/LF/Unit	$	$
Ductwork	180	4.41	794
Split Face Masonry Wall	2785	7.87	21,918
CO_2 Sensor	39	800	31,200
Insulation	2785	0.63	1,755
Roofing	740	9.70	7,178
Energy Wall	5019	1.44	7,227
Piping	960	30.65	29,424
Exhaust Fans	30	1465	43,950
RTHP-A1	1	44,475	-44,475
RTHP-B1	1	18,250	-18,250
		Total Cost	**80,721**

Cost Analysis Results

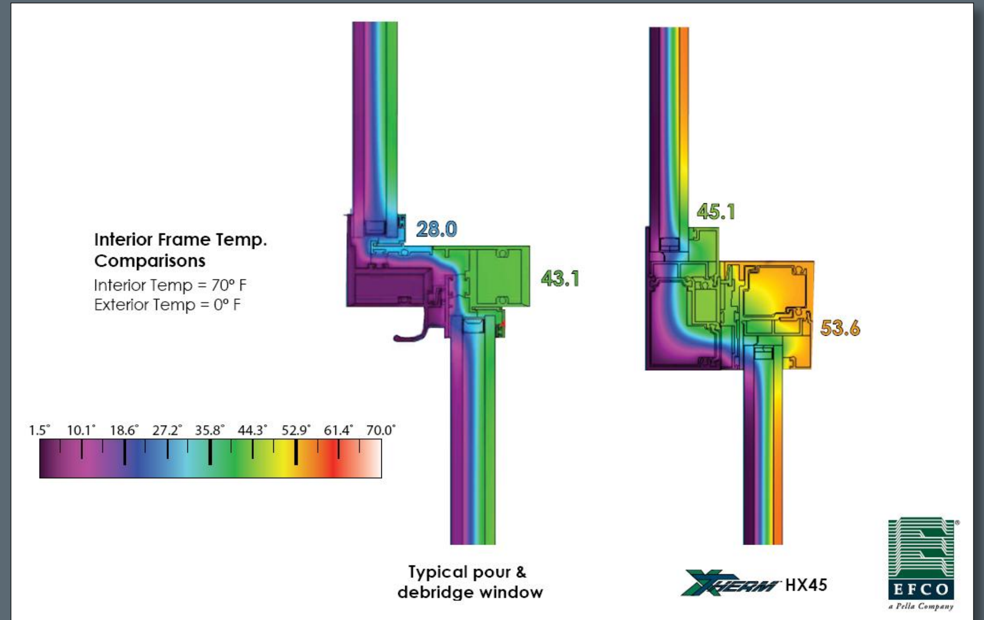
- System costs total to $80,721
- Annual electric savings of $6,755
- Simple payback period of 12 years

Goals of Natural Ventilation System

- Reduce mechanical system loads
- Improved air quality
- Maintain thermal barrier

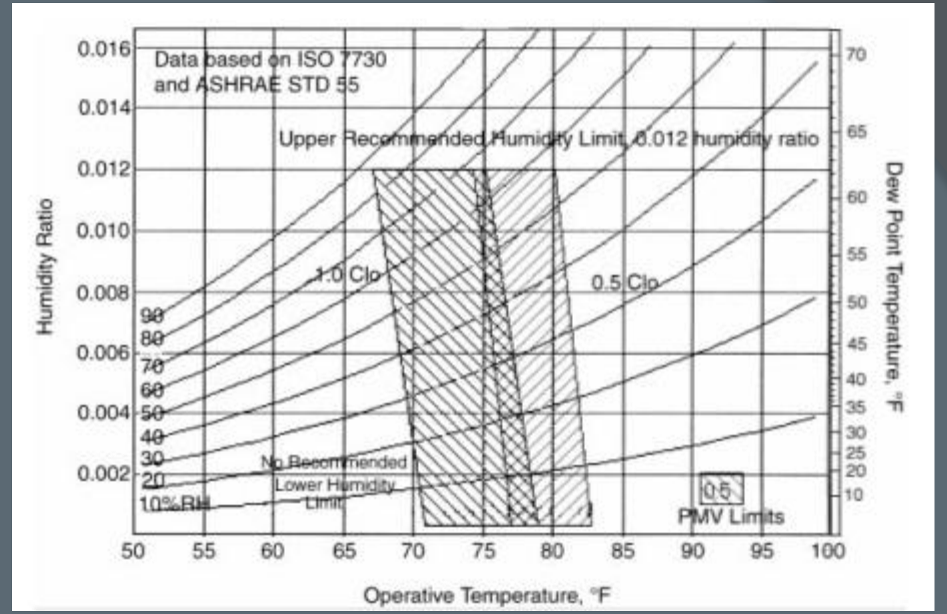
Design Considerations

- ASHRAE Standard 62.1 requirements
- System operation
- Window selection and placement



System Analysis

- Analyzed through the use of Carrier HAP and Excel
- Appropriate outdoor conditions for natural ventilation



Cost Analysis

- Excel analysis resulted in a $1200 annual electric savings
- "Green light" system cost approximately $8000
- Window upgrade cost approximately $10,000
- Simple payback period of 15 years

Goals of Geothermal Hybrid System

- Reduce environmental impact
- Reduce initial costs
- Reduce operation costs

Disadvantages of System

- Increased maintenance costs due to additional equipment
- Increased mechanical space

System Analysis

- Ground loop design software is ideal but unavailable
- Spreadsheet used by designers at McClure Company was utilized
- Spreadsheet inputs were available from previously designed loop field, schedule, and Carrier HAP model

GEOTHERMAL VERTICAL GROUND LOOP DESIGN

Project: Bentworth Middle School
Job Number:
Date: 04/07/11
User: Kyle Courtney

INPUT DATA

Total Building Load (Ton)= 100
Outdoor Design Temp. (°F)= 95
Indoor Design Temp. (°F)= 75
Balance Temp. (°F)= 65
Total Heat Pump Capacity (Ton)= 202
$COP_{COOLING}$= 3.5
Pipe Resistance (Hr-Ft-°F/BTU)= 0.141
Soil Resistance (Hr-Ft-°F/BTU)= 0.5
Average Water Temp. (°F)= 75
Mean Earth Temp.(°F)= 55

Bldg Area 60000 Sq Ft
Sq. Ft / Ton 600

BIN DATA

Design Month: July
Location: Bentlyville PA

BIN Range		Mean	Hours	WB(°F)
90	95	92.5	14	74.9
85	90	87.5	69	73.1
80	85	82.5	400	68.7
75	80	77.5	465	66.1
70	75	72.5	703	64.0
65	70	67.5	603	61.3
60	65	62.5	1060	57.0
55	60	57.5	708	50.9
			4022	

CALCULATIONS

BIN Range	Bldg Load Tons	Heat Pump Hours
95/100	137.50	9.53
90/95	112.50	38.43
85/90	87.50	173.27
80/85	62.50	143.87
75/80	37.50	130.51
70/75	12.50	37.31
65/70	-12.50	-65.59
		467.33

Run Fraction= 0.63
Ground Loop Heat Exchanger Length(Ft/Ton)= 310.60
Total Ground Loop Length= 31060.00

Bores Required:

Depth (Ft)	Number
400	78
375	83
350	89
325	96
300	104
250	124
200	155
600	52

GEOTHERMAL VERTICAL GROUND LOOP DESIGN

Project: Bentworth Middle School
Job Number:
Date: 04/11/11
User: Kyle Courtney

INPUT DATA

Total Building Load (MBH)= 876
Outdoor Design Temp. (°F)= 0
Indoor Design Temp. (°F)= 70
Balance Temp. (°F)= 55
Total Heat Pump Capacity (MBH)= 2160
$COP_{HEATING}$= 3.3
Pipe Resistance (Hr-Ft-°F/BTU)= 0.141
Soil Resistance (Hr-Ft-°F/BTU)= 0.5
Average Water Temp. (°F)= 42
Mean Earth Temp.(°F)= 55

Bldg Area 60000 Sq Ft
BTUH / SF 15

BIN DATA

Design Month: January
Location: Bentleyville

BIN Range		Mean	Hours	WB(°F)
60	65	62.5	1060	57.0
55	60	57.5	708	50.9
50	55	52.5	693	46.8
45	50	47.5	595	42.5
40	45	42.5	540	38.3
35	40	37.5	853	33.8
30	35	32.5	705	29.4
25	30	27.5	523	24.9
20	25	22.5	334	20.5
15	20	17.5	298	16.1
10	15	12.5	112	10.9
5	10	7.5	50	5.3
0	5	2.5	29	-0.1
-5	0	-2.5	6	-2.7

6506

CALCULATIONS

BIN Range	Bldg Load	Heat Pump Hours
62.5	-93.86	0.00
57.5	-31.29	0.00
52.5	31.29	10.04
47.5	93.86	25.85
42.5	156.43	39.11
37.5	219.00	86.48
32.5	281.57	91.90
27.5	344.14	83.33
22.5	406.71	62.89
17.5	469.29	64.74
12.5	531.86	27.58
7.5	594.43	13.76
2.5	657.00	8.82
-2.5	719.57	2.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
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0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
0	688.29	0.00
		516.50

Run Fraction= 0.69
Ground Loop Heat Exchanger Length(Ft/MBH)= 23.86
Total Ground Loop Length= 20899.38

Bores Required:

Depth (Ft)	Number
400	52
375	56
350	60
325	64
300	70
250	84
200	104
600	35

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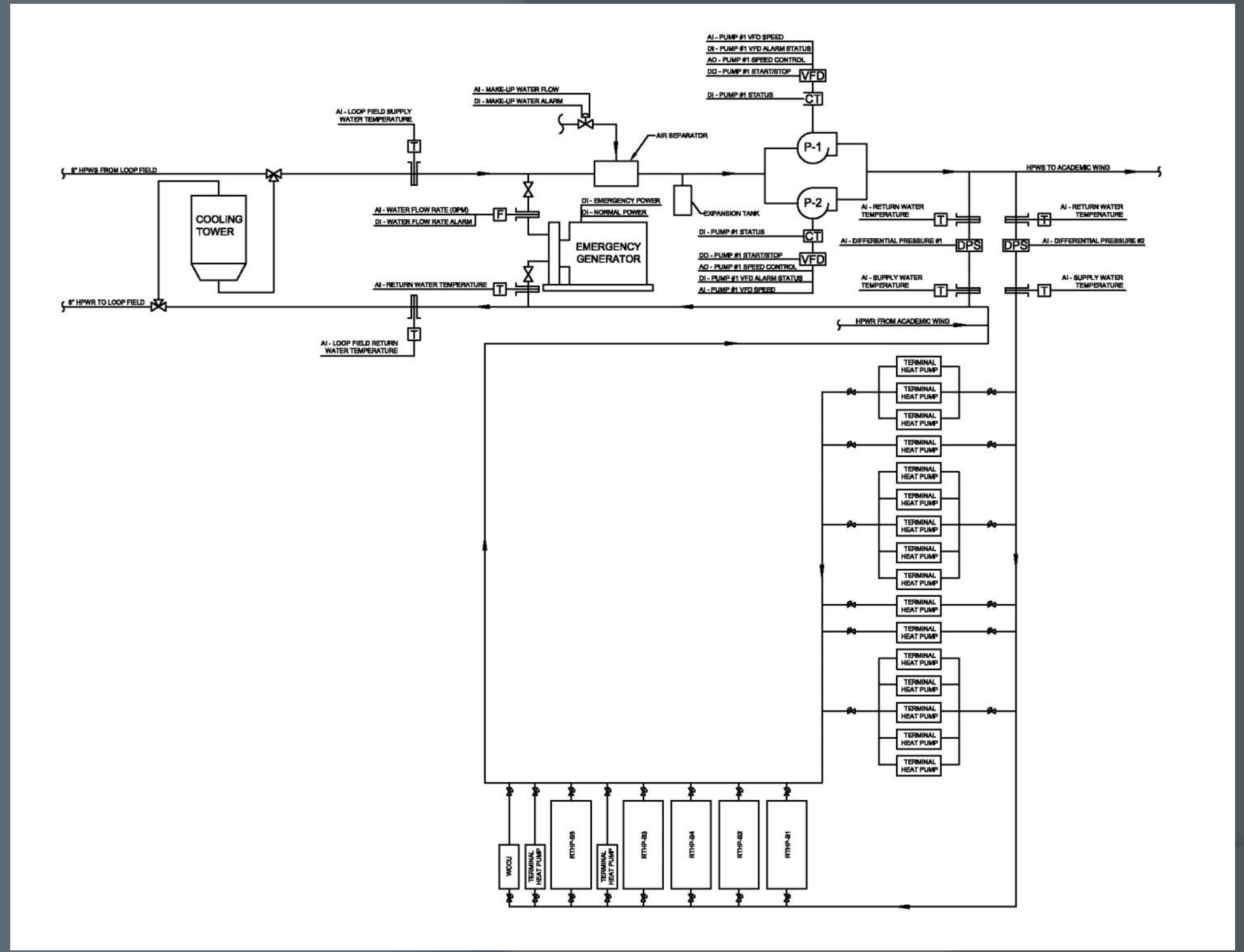
Analysis Results

- 89 bores needed for cooling
- 60 bored needed for heating
- 27 ton cooling tower needed to cover the difference

Cost Analysis

- Based on an average price of $6350 per well, $184,450 can be saved on initial upfront cost
- Cooling tower cost is equal to $90,000
- Assumed pumping savings due to 10’ less head
- Cooling tower only used 8% of the total system operation time



Schematic of Hydronic System with Supplemental Cooling Tower

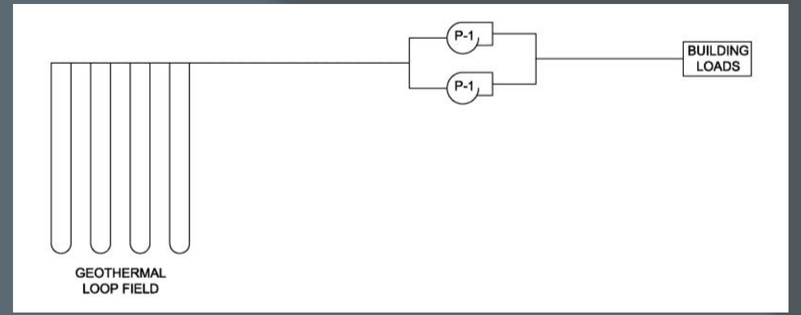
Goals of Decentralized Pump System
- Reduce overall required pumping energy
- Minimize the introduction of noise into areas adjacent to pump locations

Disadvantages of System
- Increase in maintenance costs
- No redundancy
- Additional mechanical space required

System Analysis
- Hourly profiles exported from Carrier HAP to Excel
- Based upon a 3gpm/ton load
- Affinity laws and pump curves

Analysis Results
- Unexpected that the decentralized pumps used more than twice the amount of energy
- Possible explanation – high amount of head
- Second alternative – primary/secondary system also used much more energy
- Due to the infeasibility of the design no cost analysis was performed

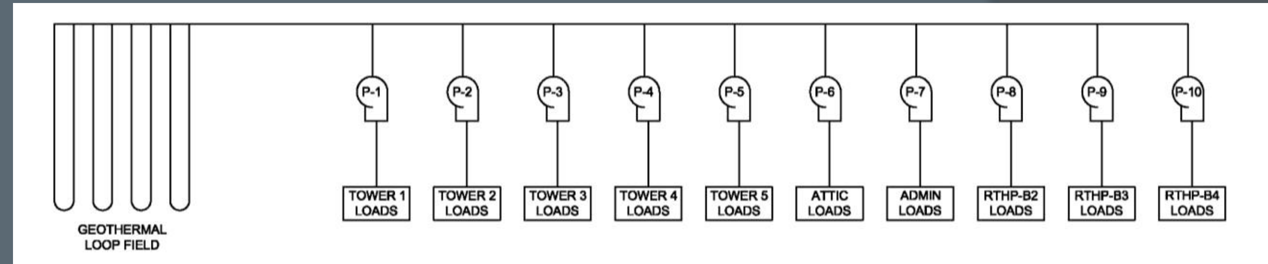
Central Pumping System



Central System - 2 VSD Pumps in Parallel

Pump Location	Total Head	Total GPM	Pump Selection Manuf	Size	RPM	Impeller Size	Effciency	GPM	Head	Annual Hours Operation	Annual kW
Mechanical Room	130	275	B&G 1510	2G	1750	13 in	0.58	0-180	56	3480	11389
	56	180	B&G 1510	2G	1150	13 in	0.58	180-275	130	663	7695
								275-360	112	319	4176
								360-455	186	55	1511
								455-550	260	10	464
										Total	25236

Decentralized Pumping System



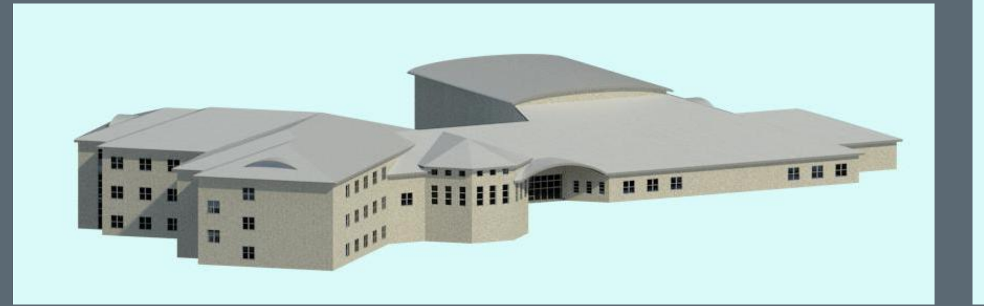
Decentralized Pump Calculations

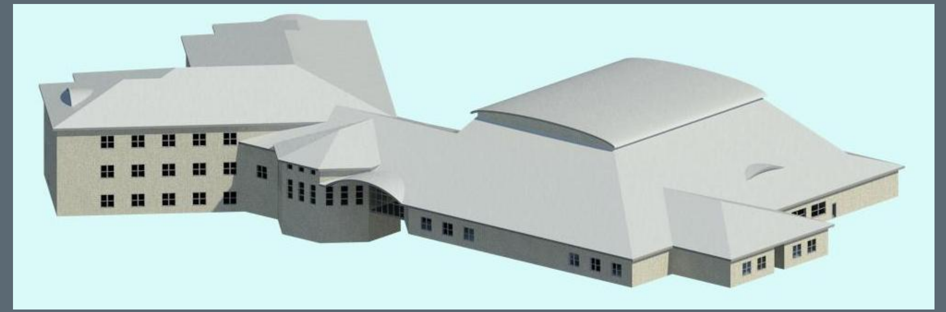
Pump Location	Piping PD	Unit PD	Well Field PD	Total Head	Total GPM	Pump Selection Manuf	Size	Impeller Size	RPM	Effciency	Annual Hours of Operation	Annual kW
Tower 1	20'	6'	90'	130	40	Arm 4300IVS	1.5x1.5x6	6.19 in	3500	0.46	2328	4956
				32	20	Arm 4300IVS	1.5x1.5x6	6.19 in	1740	0.47	550	141
Tower 2	20'	6'	90'	130	40	Arm 4300IVS	1.5x1.5x6	6.19 in	3500	0.46	2238	4764
				32	20	Arm 4300IVS	1.5x1.5x6	6.19 in	1740	0.47	687	176
Tower 3	20'	6'	90'	130	40	Arm 4300IVS	1.5x1.5x6	6.19 in	3500	0.46	2359	5022
				32	20	Arm 4300IVS	1.5x1.5x6	6.19 in	1740	0.47	645	165
Tower 4	20'	6'	90'	130	40	Arm 4300IVS	1.5x1.5x6	6.19 in	3500	0.46	2240	4768
				32	20	Arm 4300IVS	1.5x1.5x6	6.19 in	1740	0.47	752	193
Tower 5	15'	6'	90'	125	40	Arm 4300IVS	1.5x1.5x6	6.19 in	3500	0.45	2692	5633
				31	20	Arm 4300IVS	1.5x1.5x6	6.19 in	1740	0.47	232	58
Interior Area	19'	6'	90'	115	85	Arm 4300IVS	2x2x6	5.81 in	3500	0.53	1757	6102
				28	42	Arm 4300IVS	2x2x6	5.81 in	1740	0.51	1648	716
Admin Area	25'	3'	90'	115	65	Arm 4300IVS	2x2x6	5.81 in	3500	0.42	2139	7169
				28	33	Arm 4300IVS	2x2x6	5.81 in	1740	0.45	1056	408
RTHP-B2	20'	6.2'	90'	125	69	Arm 4300IVS	2x2x6	5.81 in	3500	0.44	1746	6445
				31	34	Arm 4300IVS	2x2x6	5.81 in	1740	0.46	42	18
RTHP-B3	20'	5.4'	90'	125	26	Arm 4300IVS	1.5x1.5x6	5.89 in	3500	0.32	3526	6743
				31	13	Arm 4300IVS	1.5x1.5x6	5.89 in	1740	0.41	0	0
RTHP-B4	20'	7.1'	90'	125	102	Arm 4300IVS	2x2x6	5.81 in	3500	0.55	1755	7661
				31	51	Arm 4300IVS	2x2x6	5.81 in	1740	0.58	677	348
											Total	61138

Goals of Redesigned Façade
- Provide area for redesigned mechanical system
- Allow for natural ventilation
- Incorporate elements previously used in the building
- Maintain views
- Balance vertical and horizontal elements
- Provide structural support

Disadvantages of Redesigned Façade
- Additional material and construction costs
- Concerns about removable panels

As Designed Building Renderings





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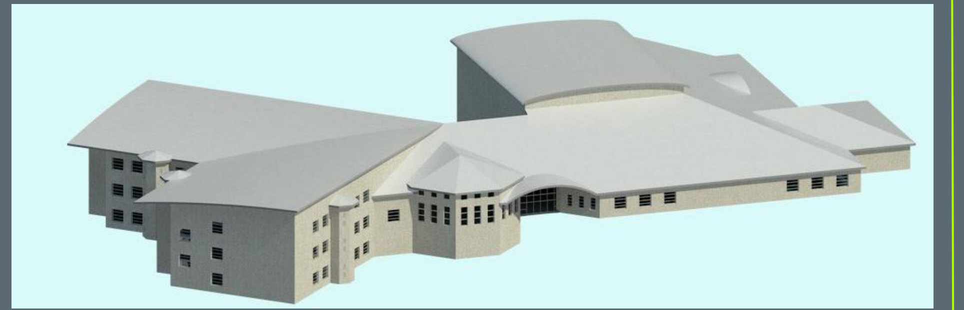
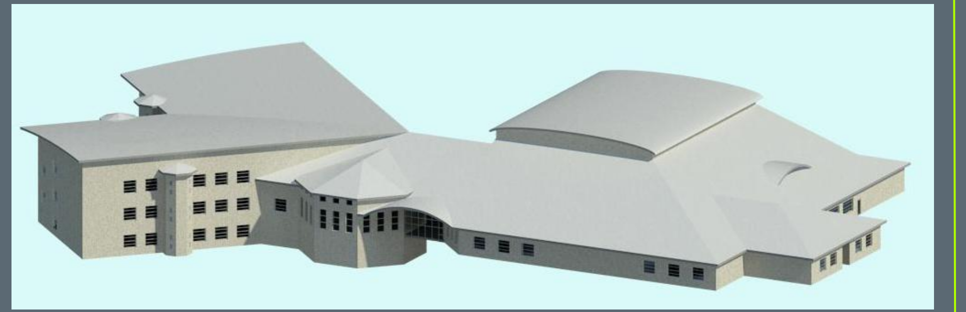
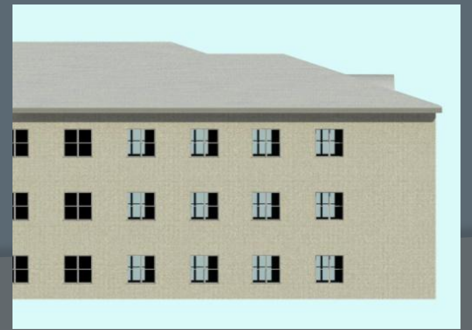




As Designed Windows

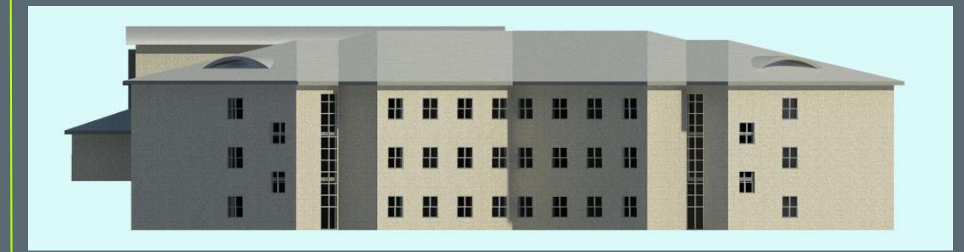


Redesigned Windows

Building Elevations

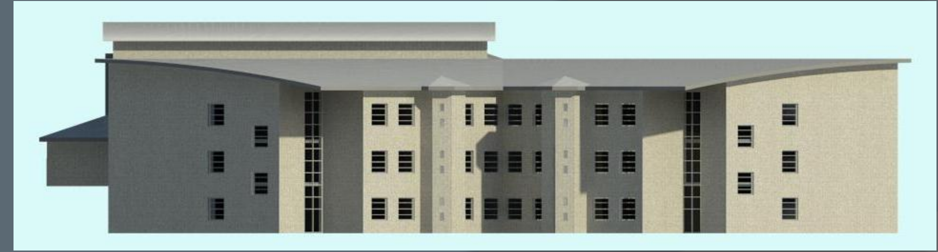
As Designed Elevations






As Designed Elevations



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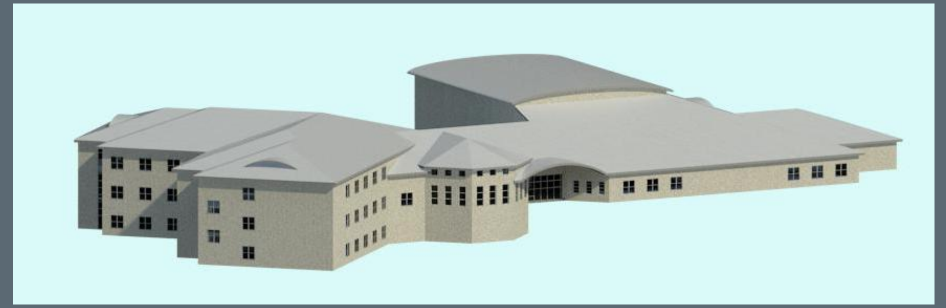
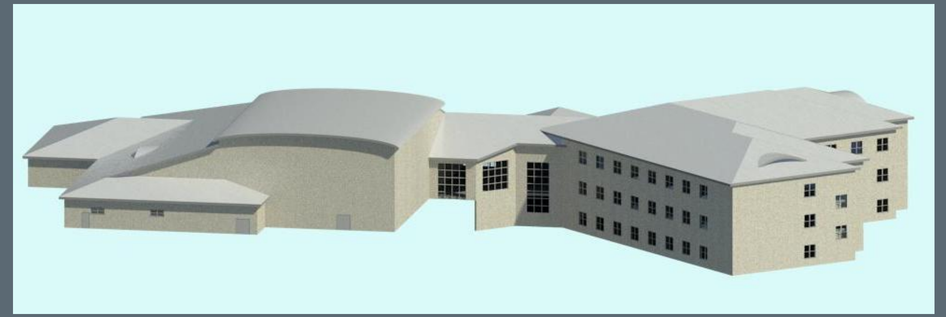
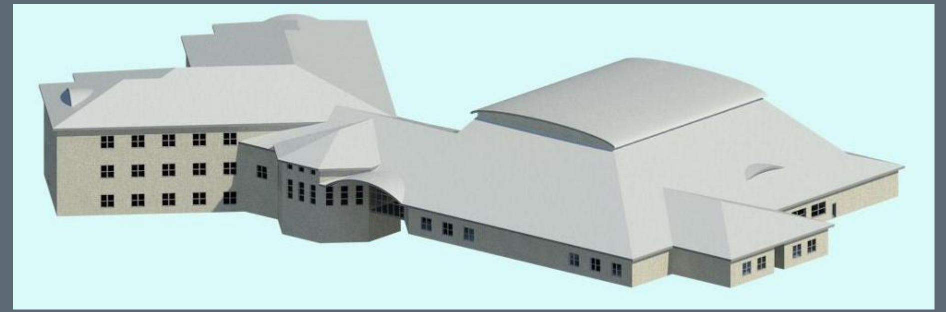
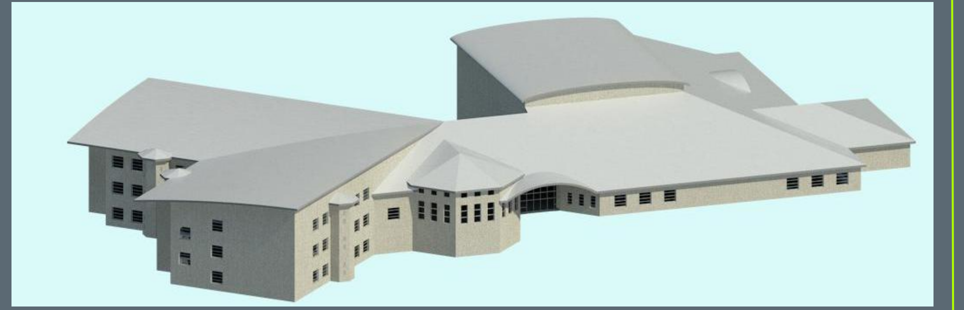
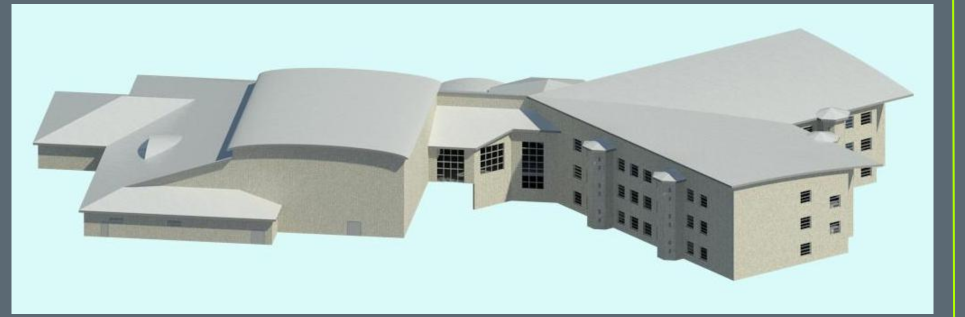
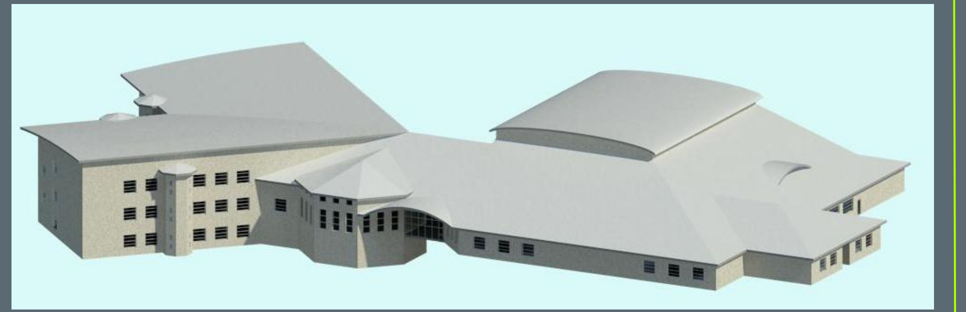
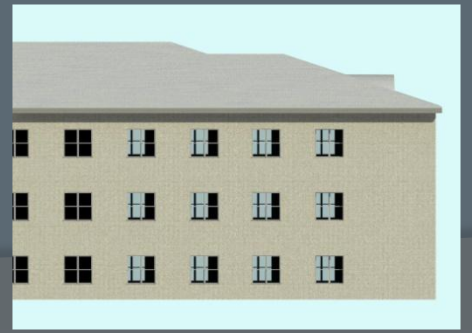




Redesigned Building Renderings

As Designed Windows

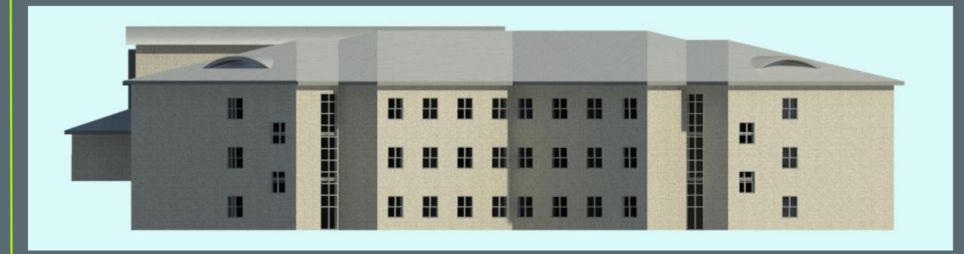


Redesigned Windows

Building Elevations

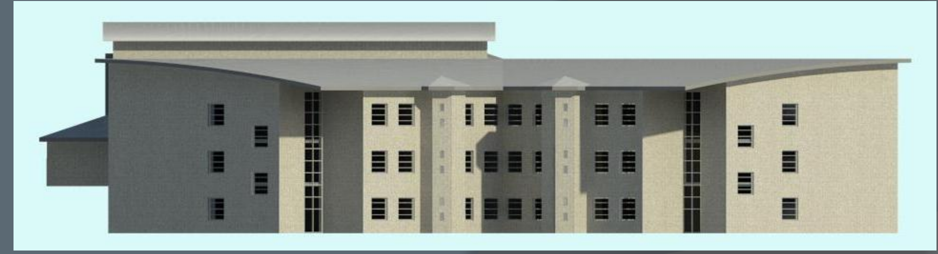
As Designed Elevations






As Designed Elevations





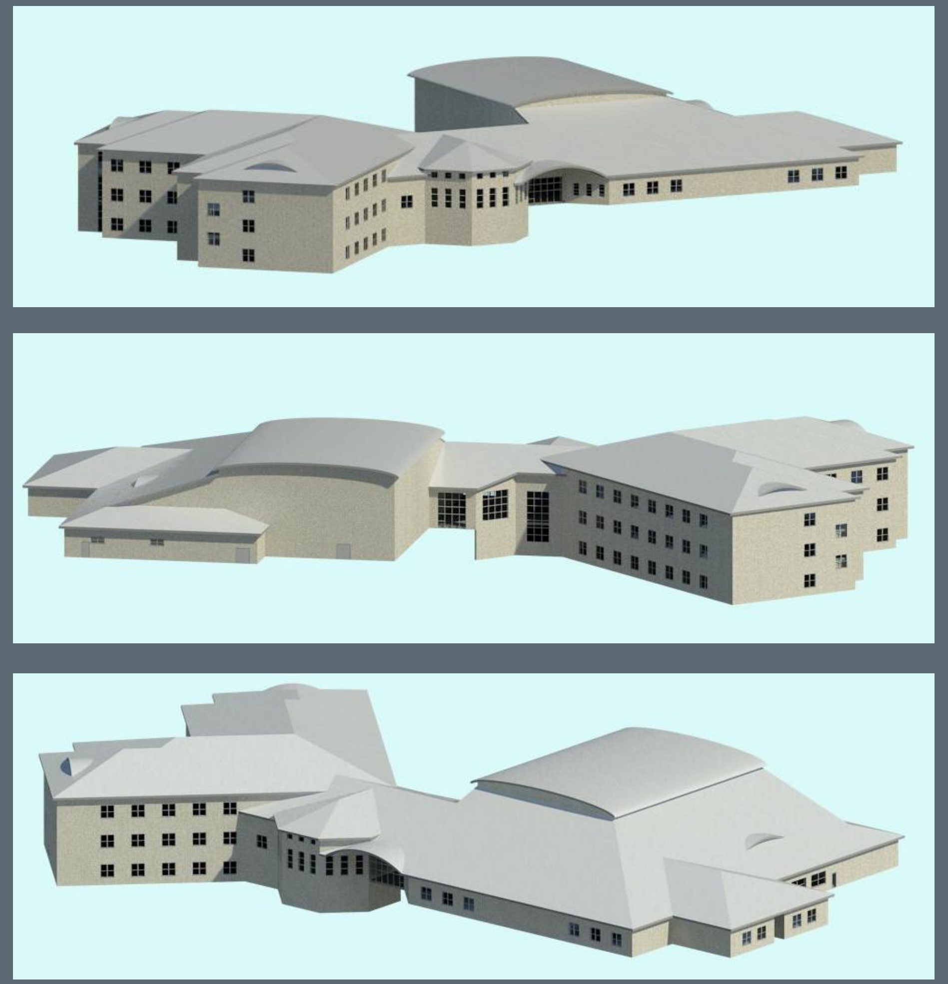

Goals of Redesigned Roof

- Reduce the overall height of the academic wing
- Tie the two wings of the building together
- Give the roof a lighter appearance
- Utilize previously used materials
- Design with appropriate slope to maintain proper water drainage

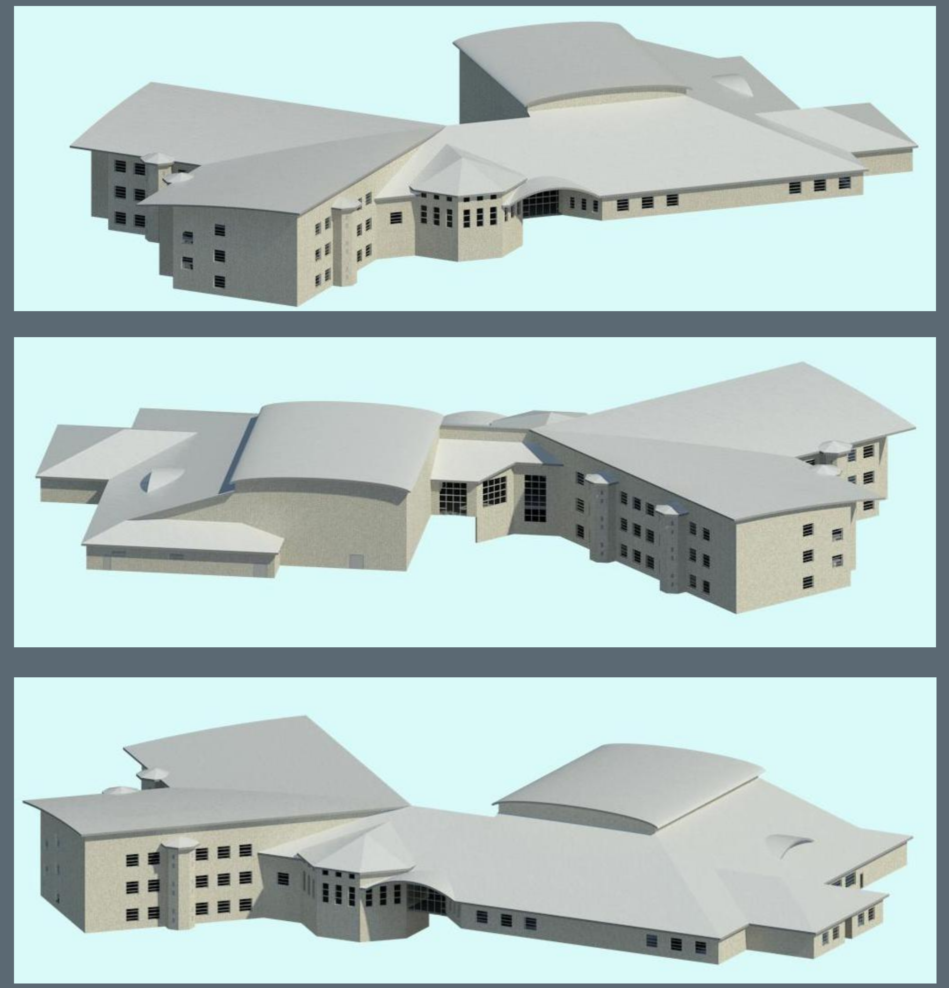
Disadvantages of Redesigned Roof

- Possibly more expensive

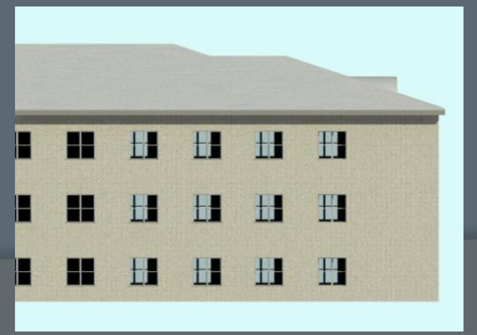
As Designed Building Renderings



Redesigned Building Renderings



As Designed Windows



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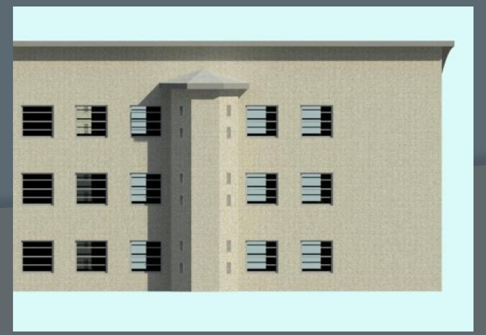
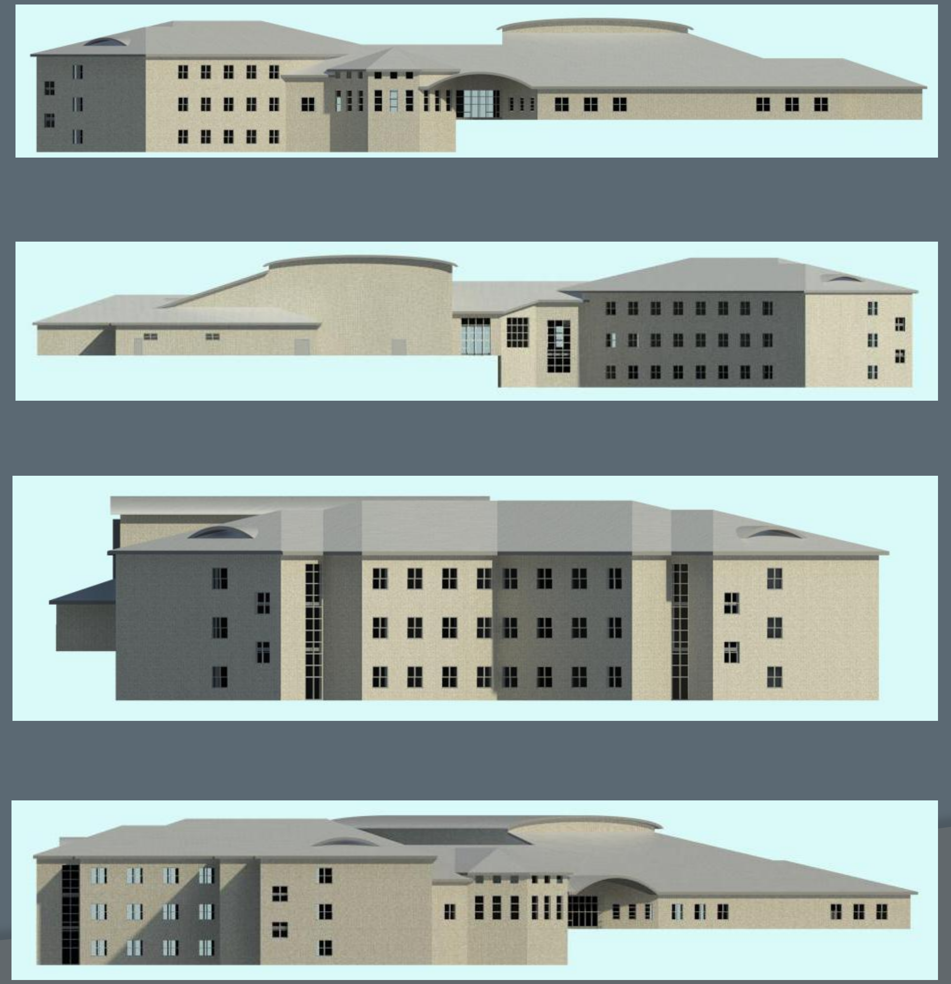
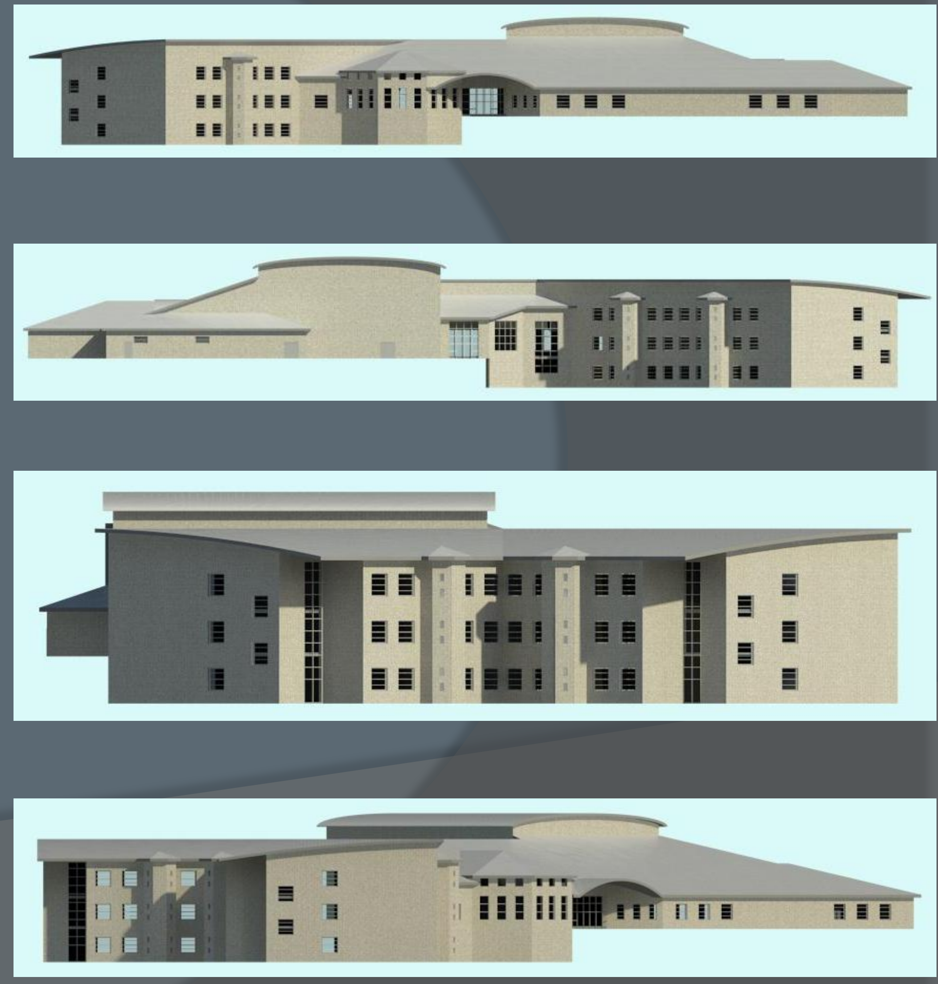


Building Elevations

As Designed Elevations



As Designed Elevations



INTRODUCTION

BUILDING OVERVIEW

MECHANICAL SYSTEM OVERVIEW

MECHANICAL DEPTHS

AIR SYSTEM MODIFICATIONS

NATURAL VENTILATION SYSTEM

GEOTHERMAL HYBRID SYSTEM

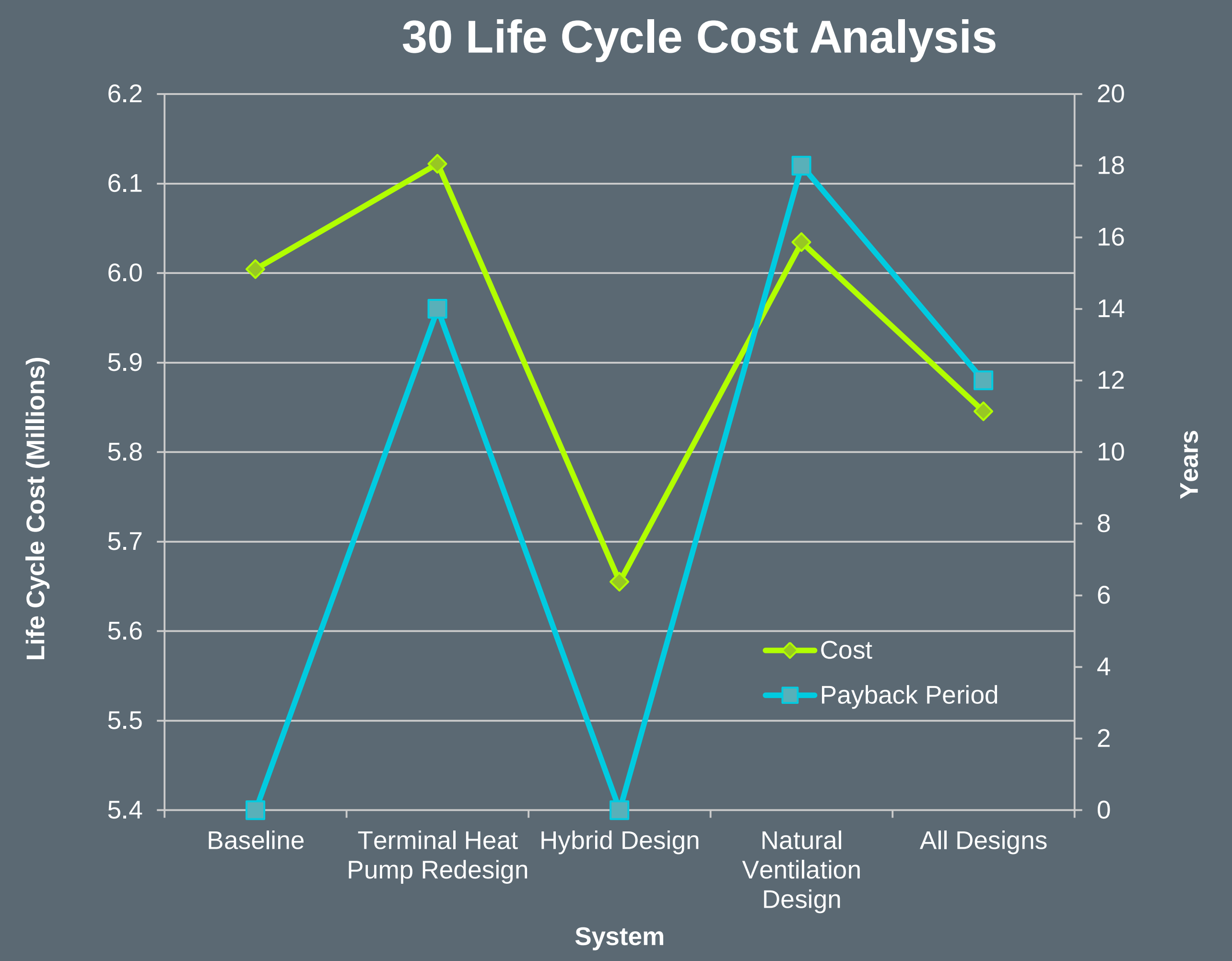
DECENTRALIZED PUMPS SYSTEM

ARCHITECTURAL BREADTH

FAÇADE REDESIGN

ROOF REDESIGN

CONCLUSION



Life Cycle Cost Assumptions

Baseline

- Maintenance - $1900/year
- Periodic Cost - $30,000 every 20 years

Terminal Unit Redesign

- Maintenance - $1900/year
- Periodic Cost - $30,000 every 20 years

Natural Ventilation System

- Maintenance - $1950/year
- Periodic Cost - $30,000 every 20 years

Hybrid System

- Maintenance - $2200/year
- Periodic Cost - $90,000 every 17 years
- Periodic Cost - $30,000 every 20 years

Recommendations

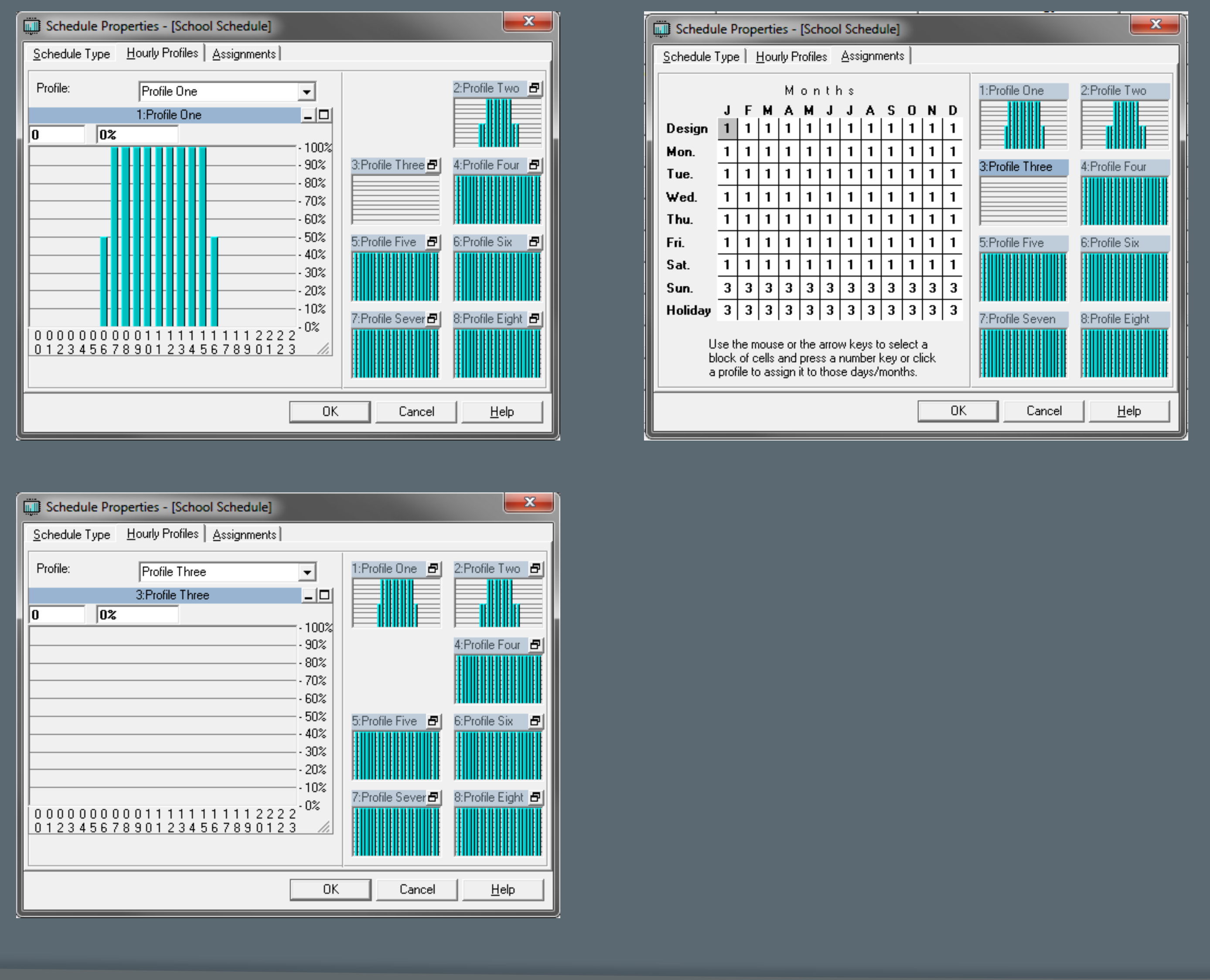
- All of the proposed systems are viable options with reasonable payback periods

ACKNOWLEDGEMENTS

- The Pennsylvania State University Architectural Engineering Faculty and Staff
- Thesis Advisor: Dustin Eplee
- Professor William Bahnfleth, Ph.D., PE
- Project Sponsor: Hayes Large Architects
- Sponsor Contact: Donald Goodman, PE
- David Barto and Barton Associates
- Alyssa Adams and McClure Company
- My fellow classmates who have supported me over the last five years, especially the gentlemen and ladies of 612
- My friends and family for all their love and encouragement

QUESTIONS?

APPENDICES



System Psychrometrics for Tower 1

Project Name: BMS New Windows and Air
Prepared by: PSUAE

04/06/2011
06:24PM

January DESIGN COOLING DAY, 1400

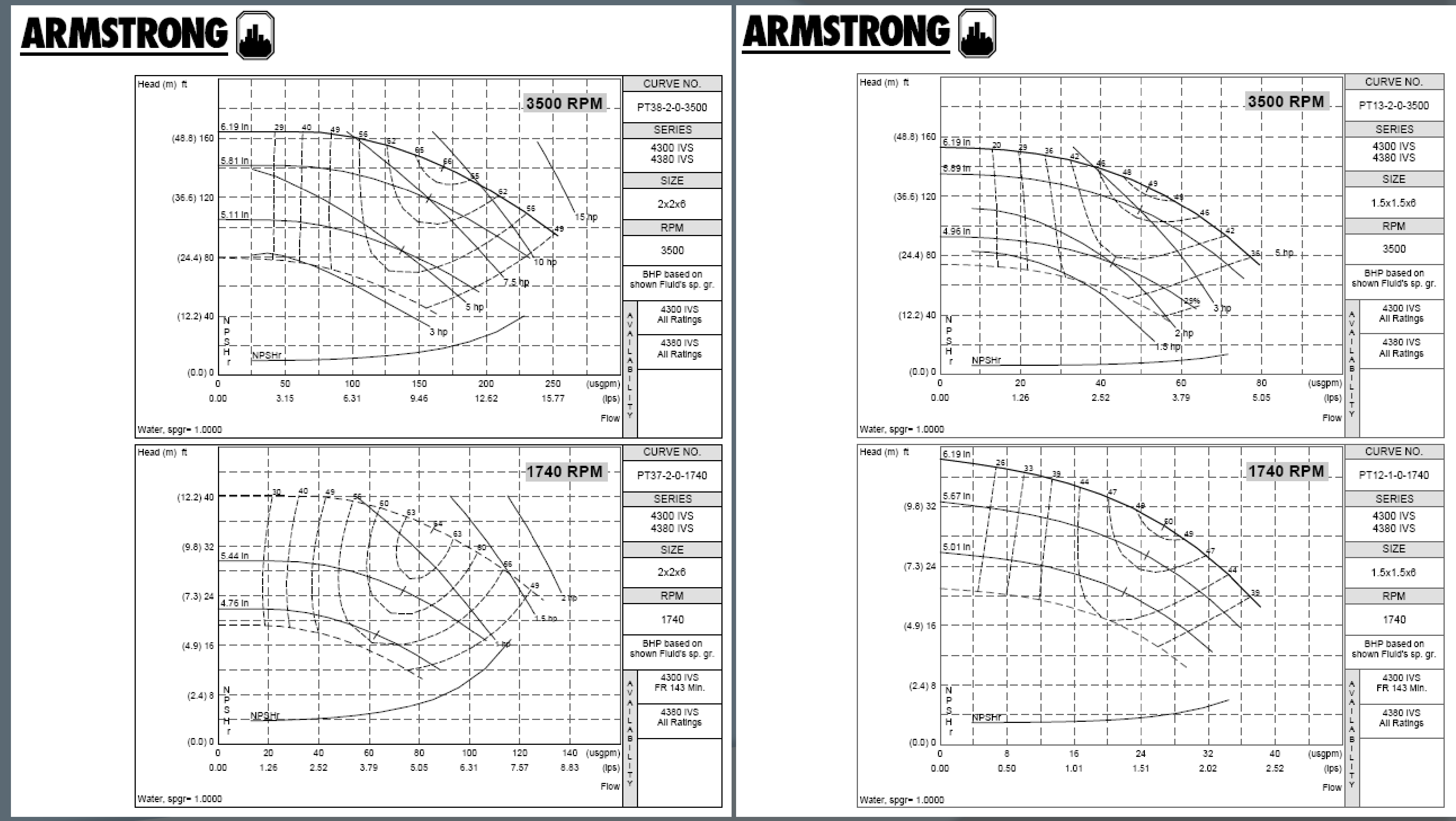
TABLE 1: SYSTEM DATA

Component	Location	Dry-Bulb Temp (°F)	Specific Humidity (lb/lb)	Airflow (CFM)	CO2 Level (ppm)	Sensible Heat (BTU/hr)	Latent Heat (BTU/hr)
Ventilation Air	Inlet	45.8	0.00605	2303	400	-14602	-19927
Ventilation Reclaim	Outlet	70.3	0.01377	2303	400	-58407	-80714
Vent - Return Mixing	Outlet	0.0	0.00000	0	0	-	-
Ventilation Fan	Outlet	70.3	0.01377	2303	400	0	-
Cold Supply Duct	Outlet	70.3	0.01377	2303	400	0	-
Zone Air	-	75.7	0.01567	2303	1223	45343	32390
Return Plenum	Outlet	75.7	0.01567	2303	1223	0	-
Exhaust Fan	Outlet	76.4	0.00000	2303	1223	1707	-

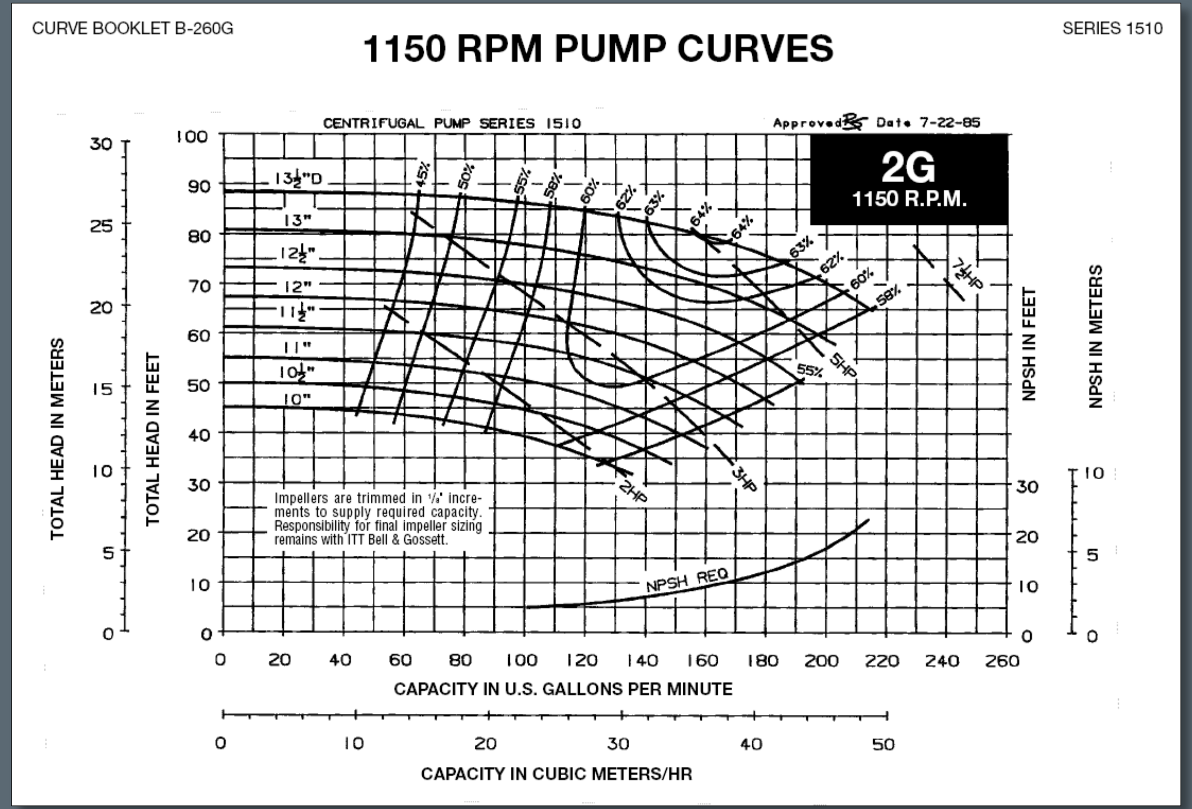
Air Density x Heat Capacity x Conversion Factor: At sea level = 1.080; At site altitude = 1.033 BTU/(hr-CFM-F)
Air Density x Heat of Vaporization x Conversion Factor: At sea level = 4746.6; At site altitude = 4540.4 BTU/(hr-CFM)
Site Altitude = 1224.0 ft

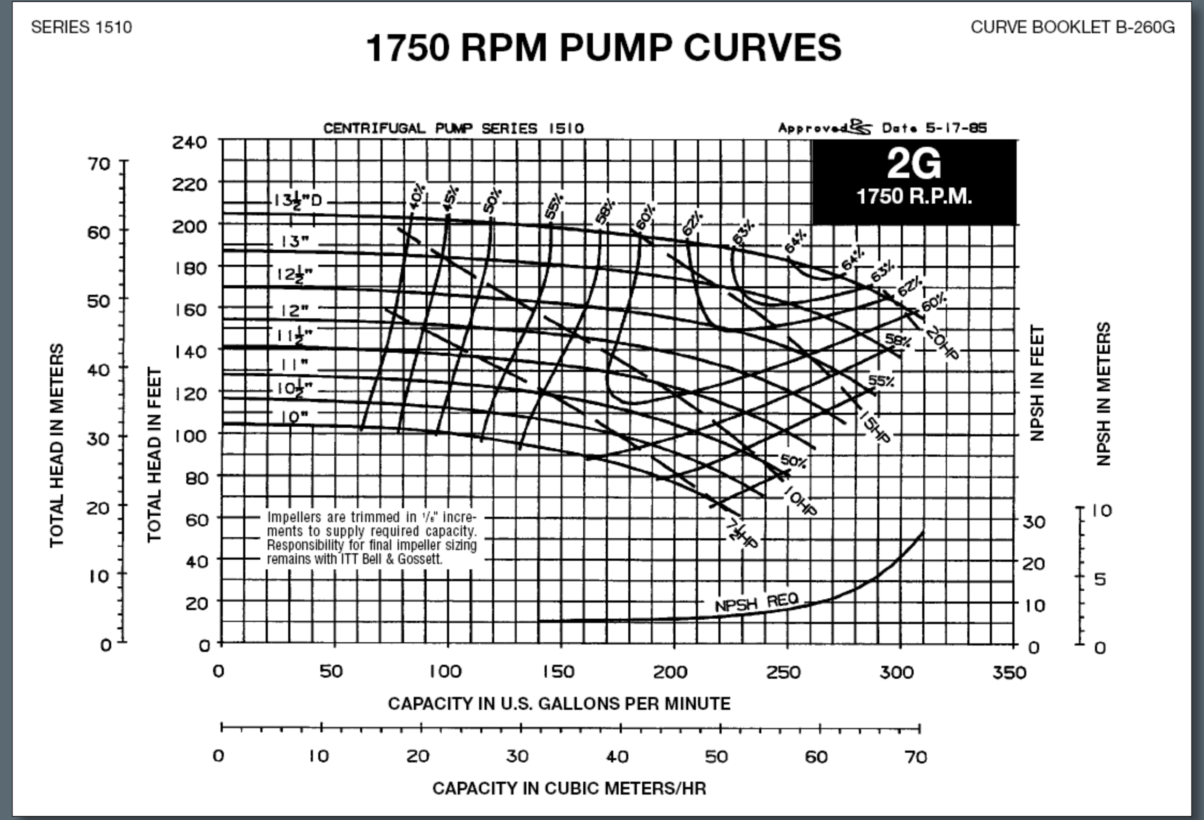
TABLE 2: ZONE DATA

Component	Location	Dry-Bulb Temp (°F)	Specific Humidity (lb/lb)	Airflow (CFM)	CO2 Level (ppm)	Sensible Heat (BTU/hr)	Latent Heat (BTU/hr)
Zone 1 (Cooling)							
Ventilation Air	-	-	-	392	-	-	-
Cooling Coil Inlet	-	73.9	0.01486	815	0	-	-
Cooling Coil Outlet	-	66.4	0.01418	815	0	6317	2556
Heating Coil Inlet	-	66.4	0.01418	815	0	-	-
Heating Coil Outlet	-	66.4	0.01418	815	0	0	-
Zone Air	-	75.7	0.01588	815	1195	7858	-
Zone 2 (Cooling)							
Ventilation Air	-	-	-	342	-	-	-
Cooling Coil Inlet	-	73.6	0.01418	634	0	-	-
Cooling Coil Outlet	-	64.3	0.01313	634	0	6056	3027
Heating Coil Inlet	-	64.3	0.01313	634	0	-	-
Heating Coil Outlet	-	64.3	0.01313	634	0	0	-
Zone Air	-	75.8	0.01466	634	1277	7476	-
Zone 3 (Cooling)							
Ventilation Air	-	-	-	483	-	-	-
Cooling Coil Inlet	-	73.2	0.01473	803	0	-	-
Cooling Coil Outlet	-	66.8	0.01438	803	0	5387	1300
Heating Coil Inlet	-	66.8	0.01438	803	0	-	-
Heating Coil Outlet	-	66.8	0.01438	803	0	0	-
Zone Air	-	75.7	0.01618	803	1145	7445	-
Zone 4 (Cooling)							
Ventilation Air	-	-	-	351	-	-	-
Cooling Coil Inlet	-	74.1	0.01377	784	0	-	-
Cooling Coil Outlet	-	63.2	0.01254	784	0	8878	4390
Heating Coil Inlet	-	63.2	0.01254	784	0	-	-
Heating Coil Outlet	-	63.2	0.01254	784	0	0	-
Zone Air	-	75.8	0.01376	784	1289	10255	-
Zone 5 (Cooling)							
Ventilation Air	-	-	-	392	-	-	-
Cooling Coil Inlet	-	74.0	0.01559	898	0	-	-
Cooling Coil Outlet	-	68.7	0.01547	898	0	4907	529
Heating Coil Inlet	-	68.7	0.01547	898	0	-	-
Heating Coil Outlet	-	68.7	0.01547	898	0	0	-
Zone Air	-	75.5	0.01702	898	1195	6304	-
Zone 6 (Cooling)							
Ventilation Air	-	-	-	342	-	-	-
Cooling Coil Inlet	-	73.9	0.01498	699	0	-	-
Cooling Coil Outlet	-	67.5	0.01477	699	0	4612	709
Heating Coil Inlet	-	67.5	0.01477	699	0	-	-
Heating Coil Outlet	-	67.5	0.01477	699	0	0	-
Zone Air	-	75.8	0.01615	699	1277	6005	-



APPENDICES


CURVE BOOKLET B-260G
1150 RPM PUMP CURVES
SERIES 1510
CENTRIFUGAL PUMP SERIES 1510
2G
1150 R.P.M.
TOTAL HEAD IN METERS
TOTAL HEAD IN FEET
NPSH IN FEET
NPSH IN METERS
NPSH REQ
Impellers are trimmed in ⅛" increments to supply required capacity. Responsibility for final impeller sizing remains with ITT Bell & Gossett.
CAPACITY IN U.S. GALLONS PER MINUTE
CAPACITY IN CUBIC METERS/HR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1750 RPM PUMP CURVES
CURVE BOOKLET B-260G
CENTRIFUGAL PUMP SERIES 1510
2G
1750 R.P.M.
TOTAL HEAD IN METERS
TOTAL HEAD IN FEET
NPSH IN FEET
NPSH IN METERS
NPSH REQ
Impellers are trimmed in ⅛" increments to supply required capacity. Responsibility for final impeller sizing remains with ITT Bell & Gossett.
CAPACITY IN U.S. GALLONS PER MINUTE
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