North Pocono High School

Building System Integration
Energy and Cost Analysis

Dan Hanley
Architectural Engineering Senior Thesis Presentation
Pennsylvania State University
Mechanical Option

PENNSTATE 1855

Presentation Outline

Project Outline

- Existing Mechanical System
  - Design Conditions
  - Air Side System
  - Hydronic System
- ASHRAE Standards
  - Standard 90.1
  - Standard 62.1
- Mechanical System Redesign
  - Redesign Objectives
  - Sizing the Ground Loop
  - Ground Source Heat Pump
  - Dedicated Outdoor Air System
- System Comparison
  - Energy Comparison
  - Cost Comparison
  - Environmental Comparison
- Structural Breadth
  - Load Comparison
  - Member Comparison
  - Cost Comparison
- Electrical Breadth

Project Outline

Project Location:
Covington Township, PA

Delivery Method:
Design – Bid – Build

Design Base Bid:
$30 Million

Construction Dates:
July 2007 – Sept. 2009

Project Size:
3 Levels
230,000 ft^2

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Presentation Outline

Project Outline

Existing Mechanical System

- **Design Criteria**
- **Air Side System**
- **Hydronic System**

Existing Conditions

Design Criteria:
Restrained by Budget

Follow the 2005 International Mechanical Code

Design Conditions:

Indoor Design Conditions

Cooling DBT	72 °F
Heating DBT	72 °F
Relative Humidity	50 %

Outdoor Design Conditions

Latitude	41.14°
Longitude	75.52°
Elevation	550 ft
Cooling Design DBT	87 °F
Heating Design DBT	5 °F

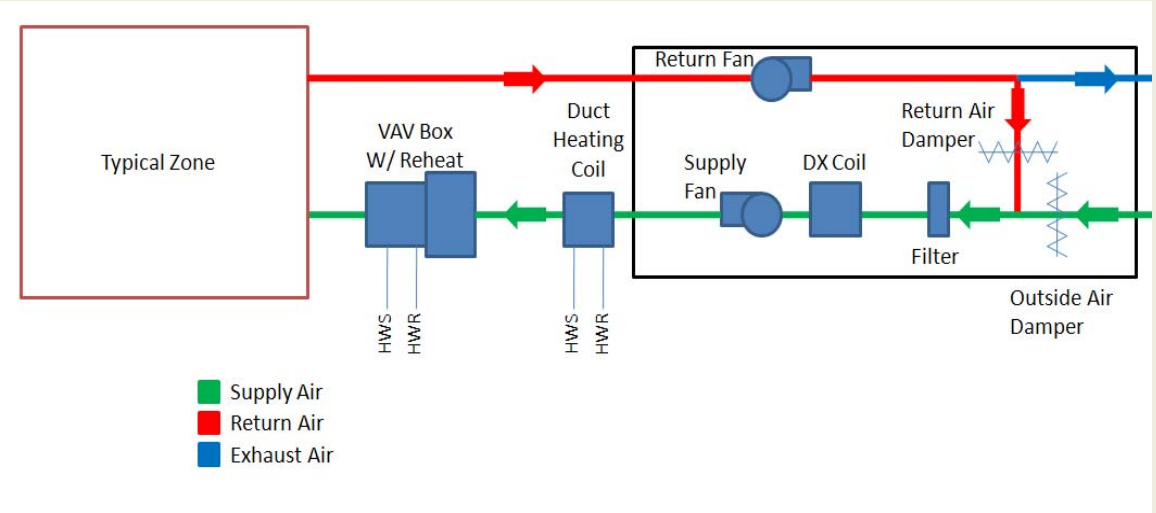
Existing Conditions

Air Side System

16 Direct Expansion Rooftop Air Handlers

12 VAV AHU with Duct Mounted Hot Water Coils

100 VAV Box Reheat Coils



Existing Conditions

Air Side System

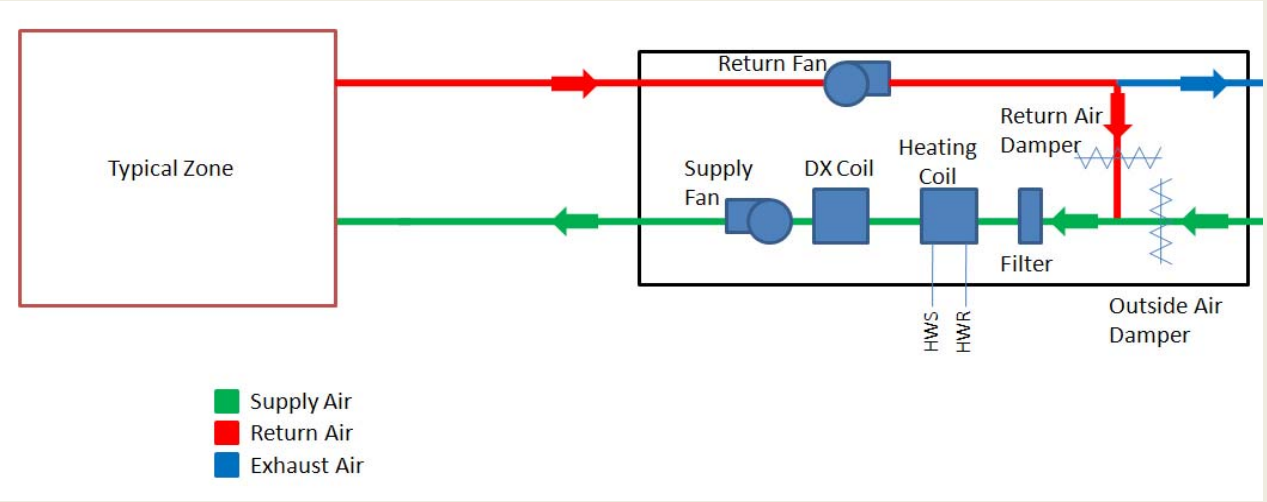
16 Direct Expansion Rooftop Air Handlers

4 CV AHU with Hot Water Coils

Condition: Auditorium

2 – Multi-Use Space

Locker Room Area



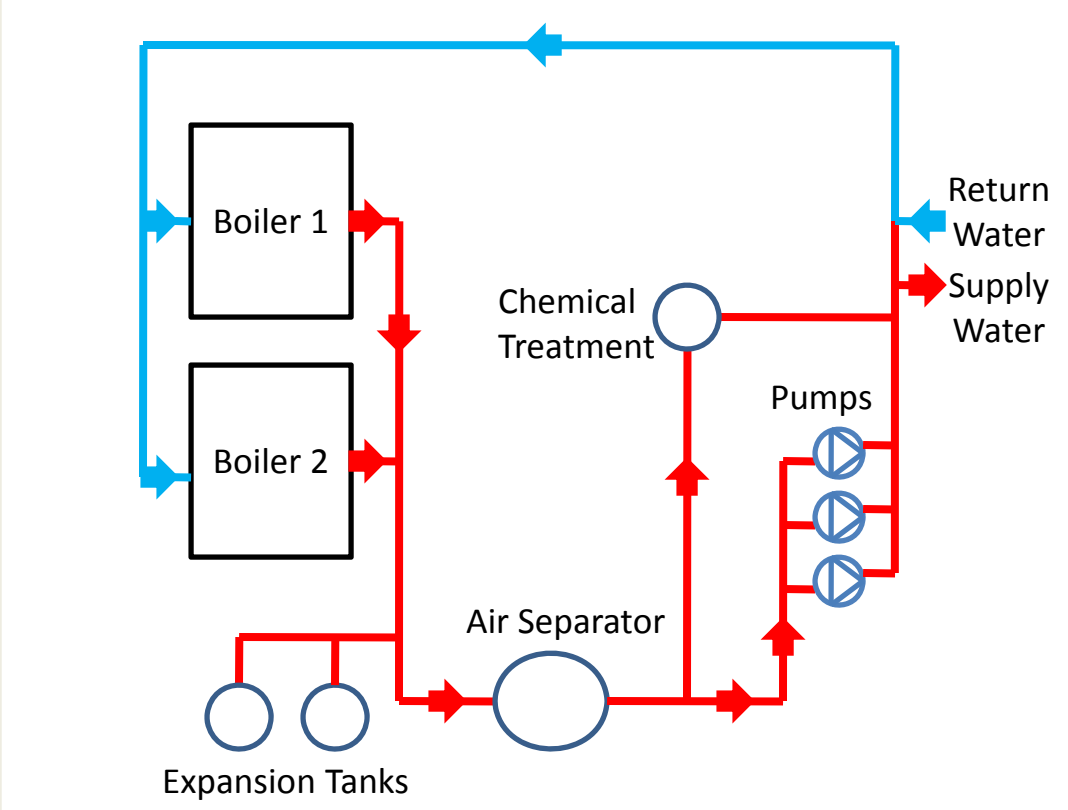
Existing Conditions

Hydronic System

2 – 7,000 MBH Oil Fired Boilers

Heating Coils in the AHU

Reheat Coils in the VAV Terminal Units



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Presentation Outline

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ASHRAE Standards
- **Standard 90.1**
- **Standard 62.1**

ASHRAE Standards

ASHRAE Standard 90.1

Building Envelope

Fenestration is <40% of Total Enclosure

Opaque Surfaces

Element	Insulation R-Value	Standard Min. R-Value	Compliant	Assembly U-Value	Assembly Max. U-Value	Compliant
Roof	10	20	**No**	0.681	0.48	**No**
Wall Type 1	10	11.4	**No**	0.67	0.09	**Yes**
Wall Type 2	10	11.4	**No**	0.093	0.09	**No**
Slab on Grade	NR	NR	**NR**	0.213	0.73	**Yes**

Fenestration

Fenestration	Assembly U-Value	Assembly Max. U-Value	Assembly SHGC	Max SHGC	Compliant
Metal Framing	0.5	0.45	0.55	0.4	No

ASHRAE Standards

ASHRAE Standard 90.1

Building Equipment

Building Area >25,000 ft^2

Air Handler Compliancy

Unit	Air Flow (cfm)	CFM*0.0015	Fan HP	Complaint
AHU-1	15,850	23.8	25	No
AHU-2	16,415	24.6	25	No
AHU-3	36,000	54.0	25	Yes
AHU-4	3,700	5.6	5	Yes
AHU-5	6,800	10.2	15	No
AHU-6	19,500	29.3	20	Yes
AHU-7	13,500	20.3	20	Yes
AHU-8	12,650	19.0	20	No
AHU-9	14,195	21.3	25	No
AHU-10	8,565	12.8	15	No
AHU-11	3,000	4.5	5	No
AHU-12	3,800	5.7	NA	NA
AHU-13	18,200	27.3	30	No
AHU-14	10,300	15.5	10	Yes
AHU-15	15,300	23.0	25	No
AHU-16	3,000	4.5	5	No

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ASHRAE Standards

ASHRAE Standard 62.1

Label	ASHREA Standard (cfm)	Designer Value (cfm)
AHU-1	4,195	4,355
AHU-2	5,025	7,360
AHU-3	4,810	10,270
AHU-5	2,750	3,860
AHU-6	2,865	19,500
AHU-7	4,525	4,800
AHU-8	3,895	4,315
AHU-9	5,370	6,225
AHU-10	1,670	3,685
AHU-11	465	3,000
AHU-12	2,400	2,255
AHU-13	5,105	10,725
AHU-14	1,985	2,470
AHU-15	3,950	5,890
AHU-16	470	3,000
Total	**49,480**	**91,710**
Difference	**42,230**	

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Presentation Outline

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ASHRAE Standards
- Standard 90.1
- Standard 62.1

Mechanical System Redesign
- **Redesign Objectives**
- **Sizing the Ground Loop**
- **Ground Source Heat Pump**
- **Dedicated Outdoor Air System**

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Mechanical System Redesign

Redesign Objectives

- Lower Energy Use
- Lower Life Cycle Cost
- Lower Emissions

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Mechanical System Redesign

Dedicated Outdoor Air System (DOAS)
15 DOAS Units Replaced 15 DX AHU
Saved Energy
Saved in Operating Cost

Ground Source Heat Pumps (GSHP)
Sized to Handle the Majority of the Sensible Load
3 Different Models were Selected

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Mechanical System Redesign

DOAS

ASHRAE Standard 90.1

DOAS Compliancy

Unit	Air Flow (cfm)	CFM*0.0015	Fan HP	Compliant
DOAS-1	4,195	6.3	5	Yes
DOAS-2	4,815	7.2	5	Yes
DOAS-3	4,810	7.2	5	Yes
DOAS-5	2,750	4.1	3	Yes
DOAS-6	2,865	4.3	3	Yes
DOAS-7	4,525	6.8	5	Yes
DOAS-8	3,895	5.8	5	Yes
DOAS-9	4,910	7.4	5	Yes
DOAS-10	1,670	2.5	1.5	Yes
DOAS-11	935	1.4	1	Yes
DOAS-12	2,115	3.2	3	Yes
DOAS-13	5,105	7.7	5	Yes
DOAS-14	1,985	3	2	Yes
DOAS-15	3,950	5.9	5	Yes

Mechanical System Redesign

Sizing the Ground Loop

Building Heat Gains and Losses

Hours	Heat Losses (MBh)	Heat Gains (MBh)
8 a.m. – Noon	15186.2	11621.7
Noon – 4 p.m.	15779.0	11133.4
4 p.m. – 8 p.m.	851.0	623.2
8 p.m. – 8 a.m.	0	0

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Option

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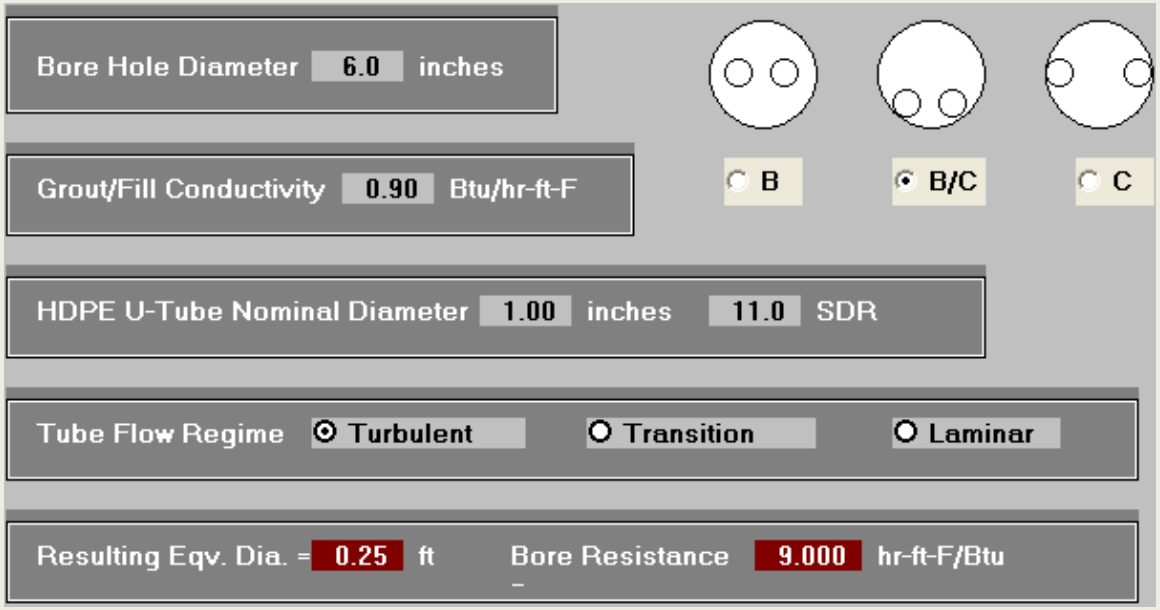
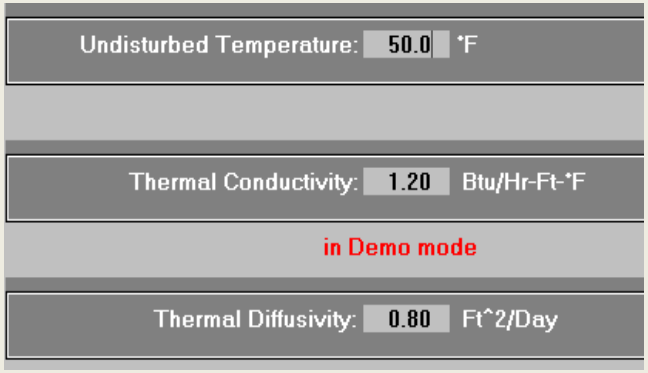
Mechanical System Redesign

Sizing the Ground Loop

Piping Properties



Ground Properties



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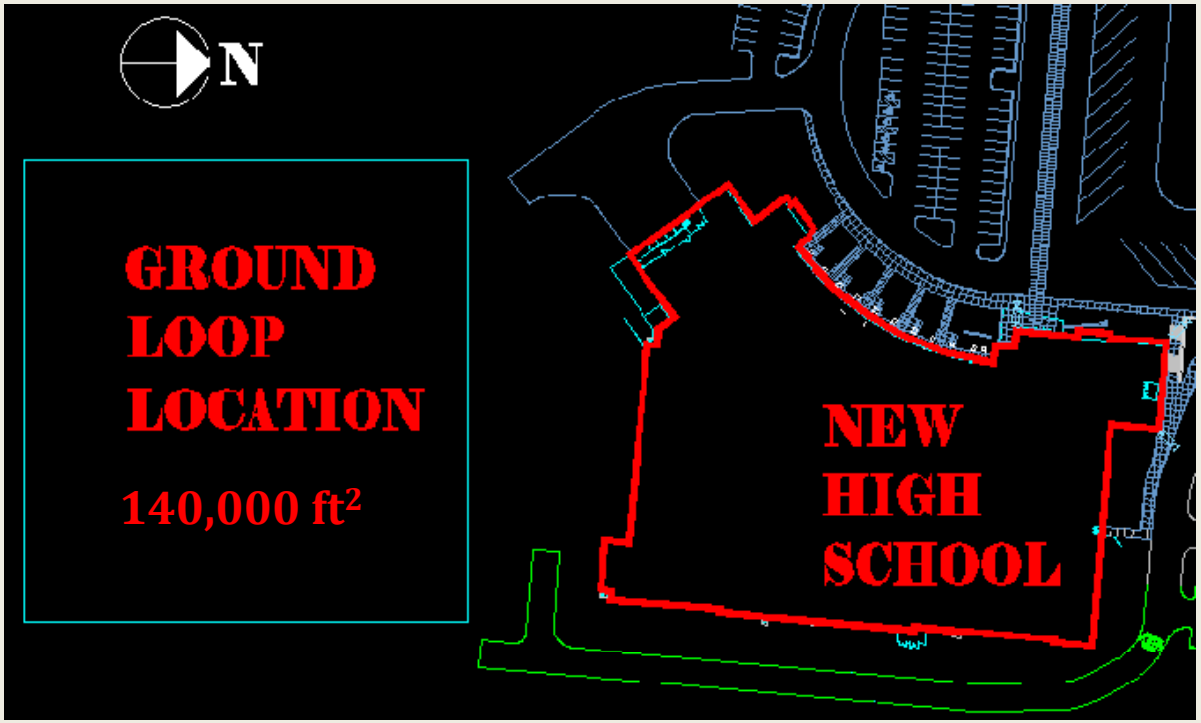
Mechanical System Redesign

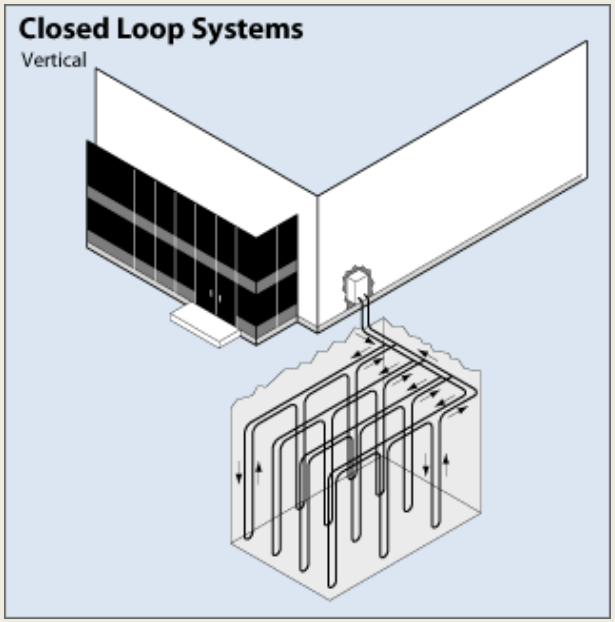
Sizing the Ground Loop

Ground Loop Layout and Location

Vertical Closed Loop

30 rows x 35 loops with 8 bores per a loop





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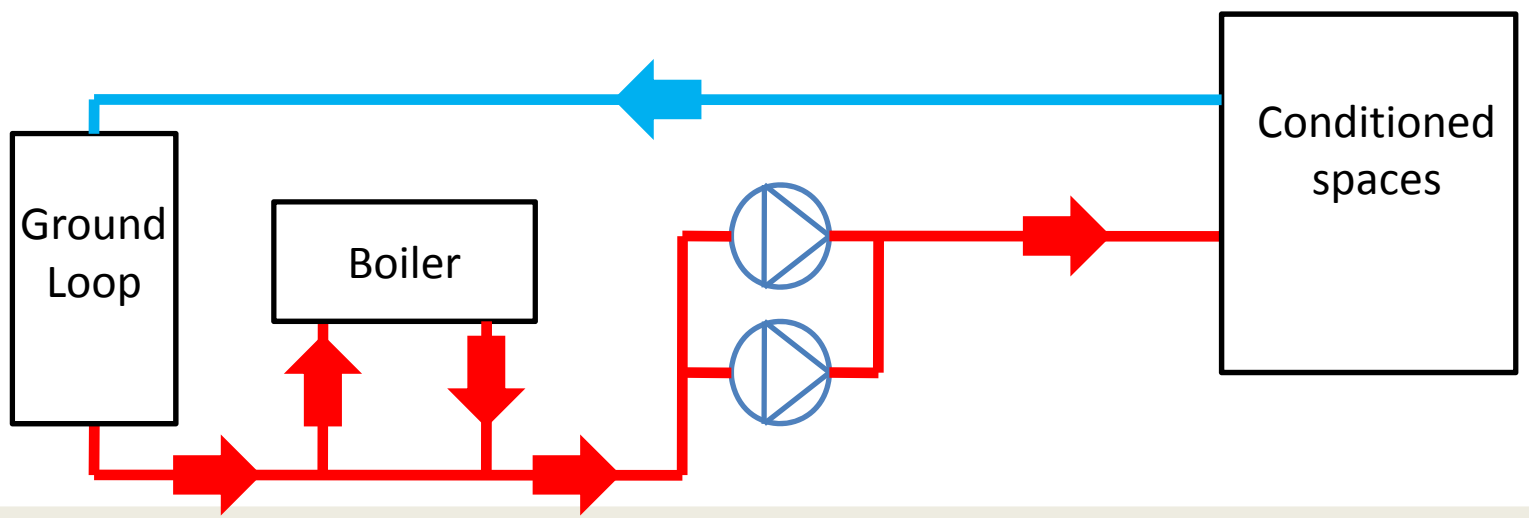
Mechanical System Redesign

Ground Loop Performance
Heating Capacity - 3,200 MBH
Heating Needed - 5,100 MBH



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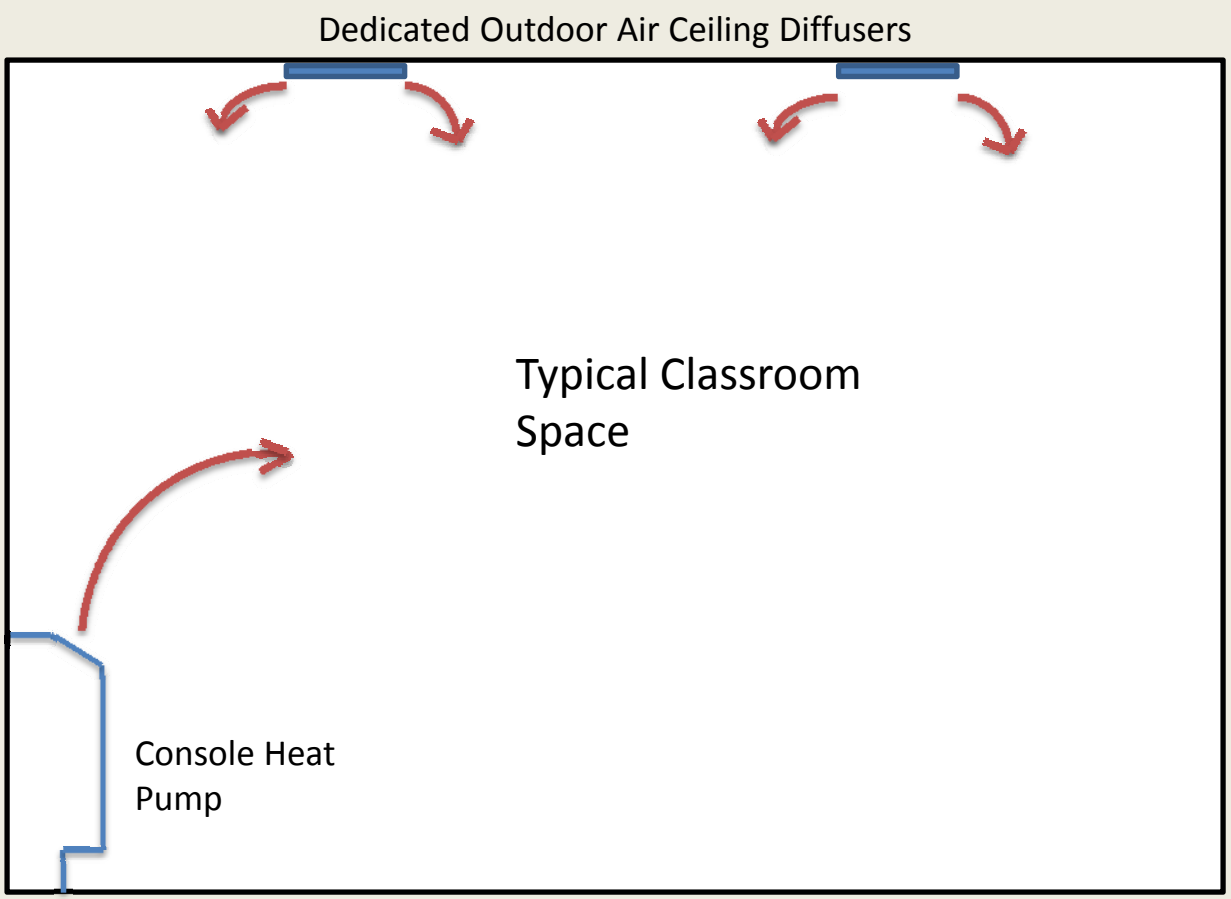
Mechanical System Redesign

GSHP Selection

Classroom Spaces

Console Water Source Heat Pumps



Carrier's Console Model

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Mechanical System Redesign

GSHP Selection

Gymnasium
Auditorium

Carrier's
Rooftop Heat Pump

Administrative Area
Cafeteria

Carrier's Packaged
Heat Pump

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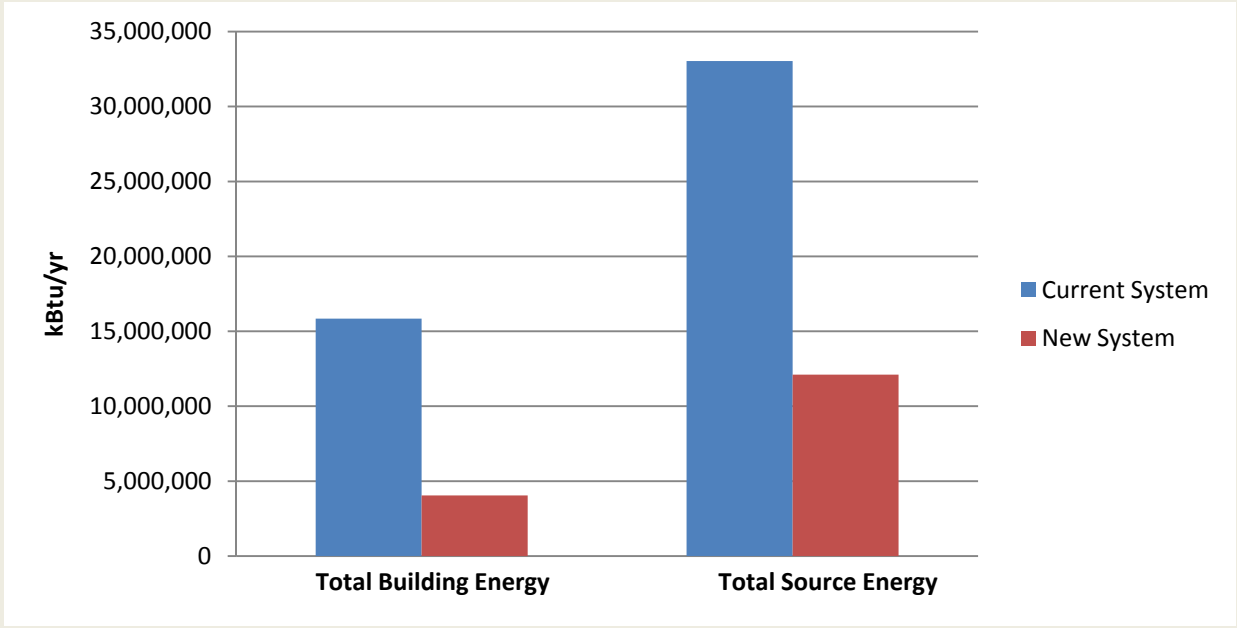
System Comparison

Energy Comparison

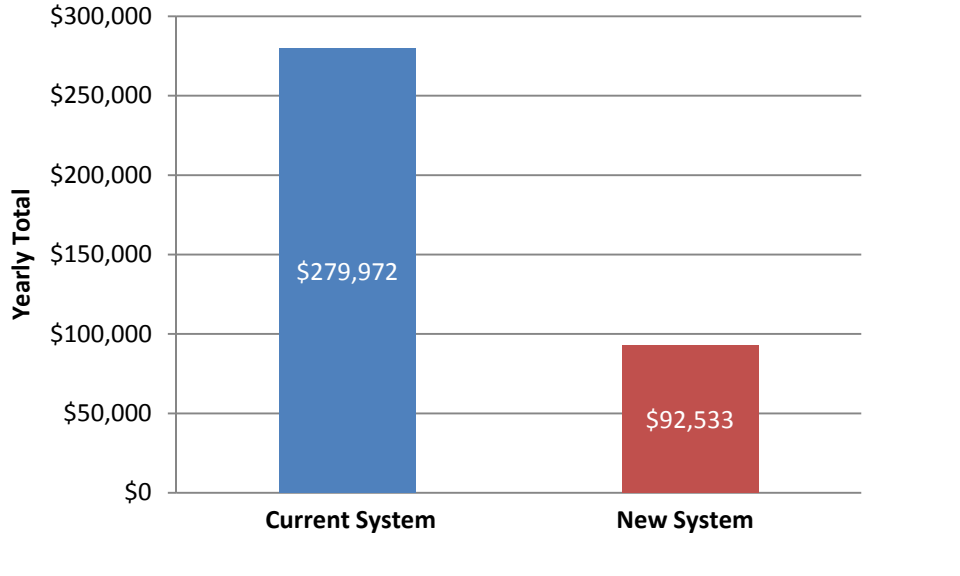


75% Reduction In Building Energy
63% Reduction In Source Energy

System Comparison

Cost Comparison

Total Utility Cost per Year



Current System – $1.30/ft^2-yr
New System – $0.43/ft^2-yr

Initial Cost

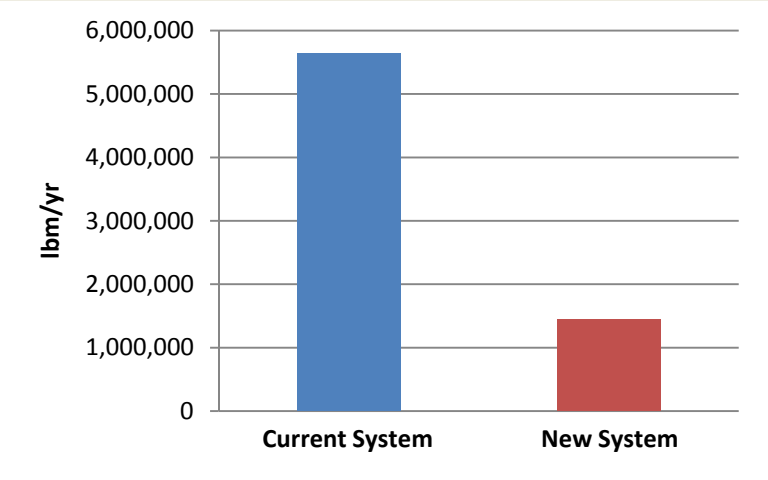
	Cost ($)
New Mechanical Cost	50,291,756
Original Initial Cost	4,300,000
Difference	**45,991,756**

New System Saves $187.4 Thousand

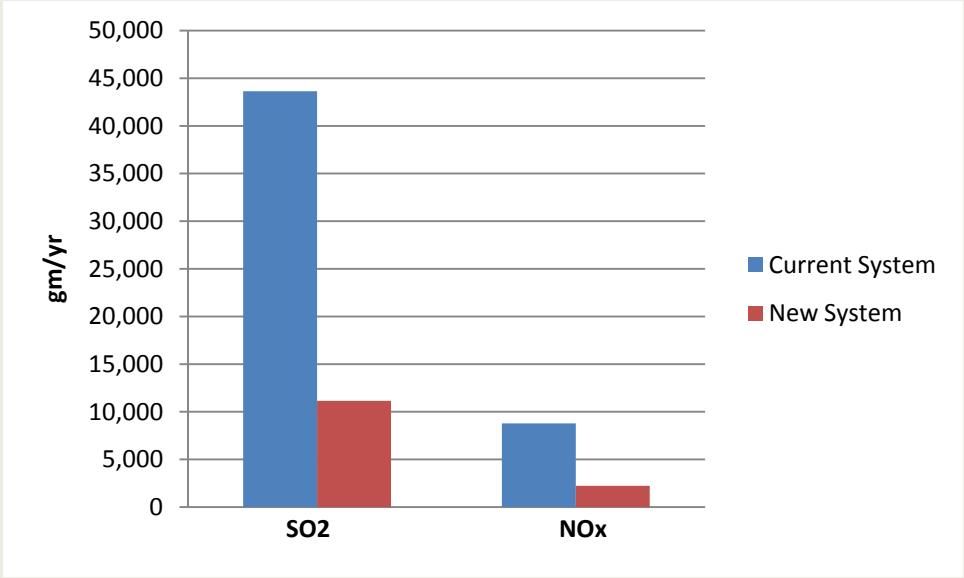
System Comparison

Environmental Comparison

CO_2 Yearly Emissions



SO_2 and NO_x Yearly Emissions



Total Emissions Reduced by 75%

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- **Structural Breadth**
  - **Load Comparison**
  - **Member Comparison**
  - **Cost Comparison**

Structural Breadth

Roof Structure

Non- Composite 1.5” 20 gauge steel deck – 7.0 psf
Supported by Steel Joists
Joists Bear on 8” CMU Walls

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Structural Breadth

Load Comparison

Controlling Snow Load – 39 psf

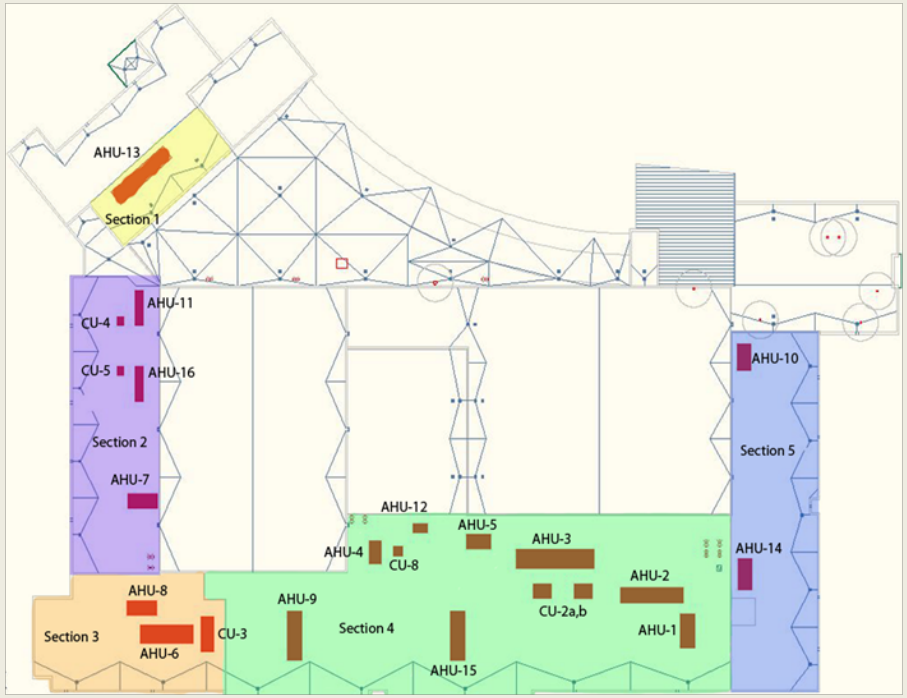
CURRENT ROOF LOADS			REDESIGNED ROOF LOADS		
Unit	Weight (lbs)	Weight (lbs/ft^2)	Unit	Weight (lbs)	Weight (lbs/ft^2)
AHU-1	8,295	61.4	DOAS-1	4,975	43.7
AHU-2	9,360	32.8	DOAS-2	4,975	43.7
AHU-3	23,752	52.8	DOAS-3	5,575	49.0
AHU-4	2,816	33.4	AHU-4	2,816	33.4
AHU-5	4,903	45.5	DOAS-5	3,280	38.2
AHU-6	12,815	46.1	DOAS-6	3,260	38.0
AHU-7	6,602	43.2	DOAS-7	4,975	43.7
AHU-8	5,553	39.6	DOAS-8	3,260	38.0
AHU-9	8,364	41.2	DOAS-9	4,975	43.7
AHU-10	4,903	45.5	DOAS-10	3,160	36.8
AHU-11	4,891	55.7	DOAS-11	2,720	31.7
AHU-12	1,896	26.2	DOAS-12	2,855	33.3
AHU-13	9,965	32	DOAS-13	5,075	44.4
AHU-14	4,731	39.1	DOAS-14	3,160	36.8
AHU-15	8,364	41.2	DOAS-15	3,260	38.0
AHU-16	4,891	55.7	RTG-1 (3)	1,960	59.6
CU-2a	4,057	43.4	RTG-2 (2)	1,770	53.9
CU-2b	4,057	43.4	x	x	x
CU-3	3,998	29.4	x	x	x
CU-4	484	28.9	x	x	x
CU-5	484	28.9	x	x	x
CU-8	531	20.9	x	x	x
Total	**135,712**	**886.3**	**Totals**	**62,051**	**705.9**

55% Reduction in Weight

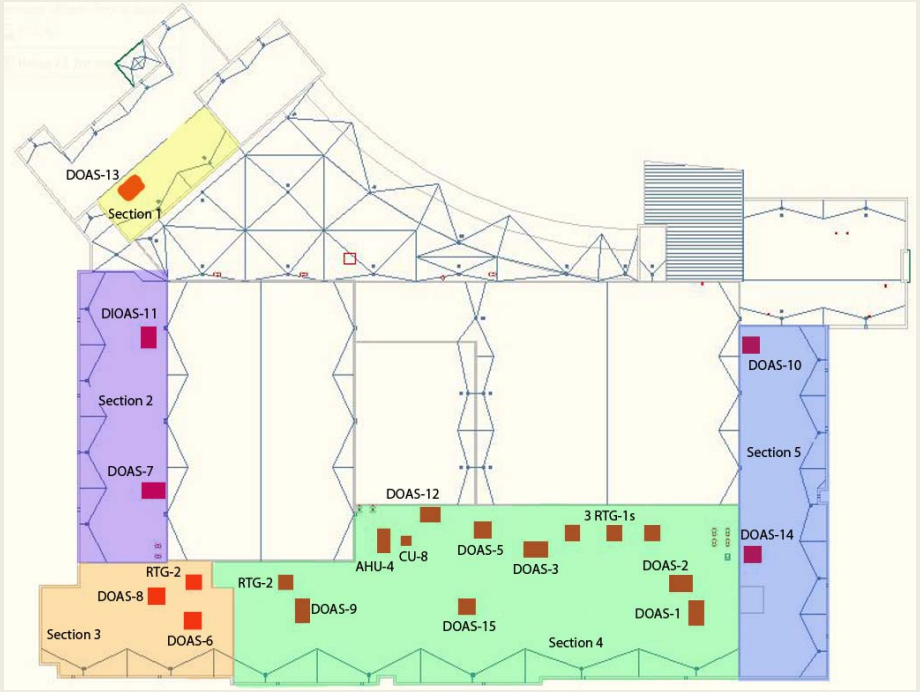
Structural Breadth

Equipment Location

Current Locations



Redesigned Locations



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Structural Breadth

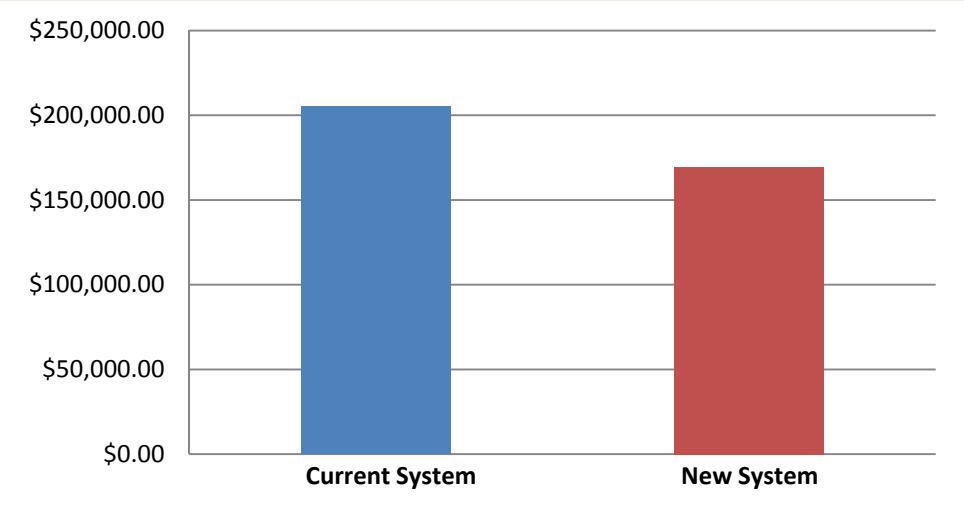
Member Comparison

Joist Comparison

Section	Joist Span	Joist Spacing	Current Joist	Redesigned Joist
Section 1	29'- 4"	5'-2"	22K9	16K2
Section 2	34'-8"	5'-8"	24K9	18K3
	13'-1"	5'-6"	16KCS3	10K1
Section3	13'-0"	5'-10 1/8"	12K3	10K1
	34'-8"	5'-7 1/2"	24k9	26k6
	13'-4"	5'-0"	16KCS3	10K1
Section 4	38'-0"	5'-7 1/2"	24K9	28k6
	13'-0"	5'-10 1/8"	12K3	10K1
	13'-0"	5'-4"	16KCS3	10K1
	11'-4"	4'-9"	16KCS3	10K1
	10'-0"	4-9"	12K5	10K1
	43'-8"	5'-6 1/2"	28K12	30K9
	10'-8"	6'-2"	12K3	10K1
	25'-8"	5'-7 1/2"	20K6	24K4
Section 5	13'-0"	5'-10 3/4"	12K3	10K1
	34'-4"	5'-9"	24K9	22K4

Structural Breadth

Cost Comparison



New System saves 17% of the Initial Cost

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- **Electrical Breadth**

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Electrical Breadth

Electrical Load Comparison

Current Electrical Data

Equipment	Amps	KVA
AHU-1	230.56	110.67
AHU-2	226.25	108.60
AHU-3	66.51	138.56
AHU-5	134.40	64.53
AHU-6	71.00	34.08
AHU-7	180.10	86.46
AHU-8	166.25	79.80
AHU-9	230.00	110.40
AHU-10	135.94	65.25
AHU-11	17.19	8.25
AHU-12	49.6	23.82
AHU-13	135.69	282.69
AHU-14	109.12	52.38
AHU-15	103.02	214.63
AHU-16	17.19	8.25
Pump-1	46.75	22.44
Pump-2	46.75	22.44
Pump-3	46.75	22.44
Boiler -1	6.33	13.19
Boiler -2	6.33	13.19
CU-2a	230	110.4
CU-2b	230	110.4
CU-3	75.81	157.93
CU-4	43.38	20.82
CU-5	43.38	20.82
Total	**2648.3**	**1902.44**

New Electrical Data

Equipment	Amps	KVA
DOAS-1	95.62	45.90
DOAS-2	105.63	50.70
DOAS-3	103.75	49.80
DOAS-5	67.50	32.40
DOAS-6	72.50	34.80
DOAS-7	88.12	42.30
DOAS-8	80.00	38.40
DOAS-9	175.00	84.00
DOAS-10	59.37	28.50
DOAS-11	49.37	23.70
DOAS-12	62.50	30.00
DOAS-13	292.50	140.40
DOAS-14	59.37	28.50
DOAS-15	80	38.4
Pump-1	46.75	22.44
Pump-2	46.75	22.44
RTG-1a	67.36	32.34
RTG-1b	67.36	32.34
RTG-1c	67.36	32.34
RTG-2a	40.31	19.35
RTG-2b	40.31	19.35
Total	**1767.43**	**848.4**

33% Reduction in Amps
55% Reduction in KVA

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Electrical Breadth

Current Main Panel

MAIN		MAIN SWITCHBOARD MSB41 SCHEDULE				(NORMAL)	
ELECTRIC RM							
VOLTAGE:	277/480	3 PHASE		4 WIRE		65,000	AIC
MAIN BUS SIZE:	4000A	NEUTRAL:		FULL	GROUND BUS:	FULL	
MAIN DEVICE:	**4000A MCB	MOUTING:		SURFACE			
CIRCUIT		OVERCURRENT DEVICE					
NUMBER	LOAD ITEM	FRAME	TRIP	POLE	FEEDER SIZE	REMARKS	
1	FIRE PUMP TAP	---	---	3	SEE RISER DIAGRAM		
2	M4U1	**1200**	**1200**	3	SEE PANEL SCHEDULE		
3	M4U2	**1200**	**1200**	3	SEE PANEL SCHEDULE		
4	M4U3	**600**	**500**	3	SEE PANEL SCHEDULE		
5	ED4U1	600	600	3	SEE PANEL SCHEDULE		
6	K4U1	**600**	**600**	3	SEE PANEL SCHEDULE		
7	**L4U1/L4M1/L4L1**	600	600	3	SEE PANEL SCHEDULE		
8	**L4U2/L4M2/L4L2**	600	**400**	3	SEE PANEL SCHEDULE		
9	L4U3	**100**	**100**	3	SEE PANEL SCHEDULE		
10	**L4U4**	**100**	**100**	3	SEE PANEL SCHEDULE		
11	**EQ4U1**	**225**	**225**	3	SEE PANEL SCHEDULE		
12	**E4U1**	**225**	**125**	3	SEE PANEL SCHEDULE		
13	**R2U4 XFMER**	**100**	**60**	3	SEE RISER DIAGRAM		
14	SPARE	400	400	3			
15	SPACE	600	600	3			
16	SPACE	400	400	3			

Redesigned Main Panel

MAIN BUS SIZE:	4000A	NEUTRAL:		FULL	GROUND BUS:	FULL
MAIN DEVICE:	**4000A MCB	MOUTING:		SURFACE		
CIRCUIT		OVERCURRENT DEVICE				
NUMBER	LOAD ITEM	FRAME	TRIP	POLE	FEEDER SIZE	REMARKS
1	FIRE PUMP TAP			3	SEE RISER DIAGRAM	
2	M4U1	**800**	**800**	3	SEE PANEL SCHEDULE	
3	M4U2	**800**	**800**	3	SEE PANEL SCHEDULE	
4	M4U3	**600**	**600**	3	SEE PANEL SCHEDULE	
5	ED4U1	600	600	3	SEE PANEL SCHEDULE	
6	K4U1	**600**	**600**	3	SEE PANEL SCHEDULE	
7	**L4U1/L4M1/L4L1**	600	600	3	SEE PANEL SCHEDULE	
8	**L4U2/L4M2/L4L2**	600	**400**	3	SEE PANEL SCHEDULE	
9	L4U3	**100**	**100**	3	SEE PANEL SCHEDULE	
10	**L4U4**	**100**	**100**	3	SEE PANEL SCHEDULE	
11	**EQ4U1**	**225**	**225**	3	SEE PANEL SCHEDULE	
12	**E4U1**	**225**	**125**	3	SEE PANEL SCHEDULE	
13	**R2U4 XFMER**	**100**	**60**	3	SEE RISER DIAGRAM	
14	SPARE	400	400	3		
15	SPACE	600	600	3		
16	SPACE	400	400	3		

North Pocono High School

PENNSTATE 1855

Conclusions

- $46 Million Increase in Mechanical First Cost
- $187.4 Thousand in Utility Savings
- Yearly Energy Consumption Reduced by 75%
- Building Emissions Reduced by 75%
- 17% Material and Construction Cost for Smaller Roof Structure
- Electrical Consumption was Reduced by 55%

Acknowledgments

North Pocono School District

Crabtree Rohrbaugh Assoc.

Greenman and Pedersen Inc.

Penn State AE Faculty

Thank You

Questions?