ELEMENTARY SCHOOL ONE
TOWN, MARYLAND

www.nps.gov/nr/

Jonathan Cann

Mechanical Option

Advisor: Dr. Treado

BAE/MAE Integrated Program

Spring 2015

www.janneyschool.org

Presentation Outline

- Project Background
- Existing Conditions
- Proposal
- Mechanical Depth
- Acoustical Breadth
- Conclusion

Building Statistics

Existing Building: Built 1925
National Register of Historic Places

Gross Square Feet : 84,400
Overall Project Budget: $25 Million
Completion Date: August 2011
3 stories above grade, 1 below
Function: Educational

maps.google.com

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Location and Weather

Town, Maryland

Relative Humidity – 50%

	Summer	Winter
Designed Dry Bulb (°F)	91	13
Designed Wet Bulb (°F)	77	-
Indoor Air Temperature (°F)	75	72

Weather data based on Baltimore, Maryland

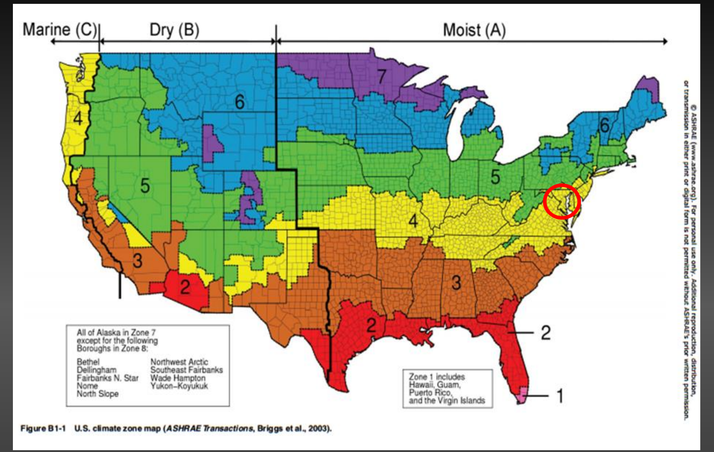

Figure B1-1 U.S. climate zone map (*ASHRAE Transactions*, Briggs et al., 2003).

www.ashrae.org

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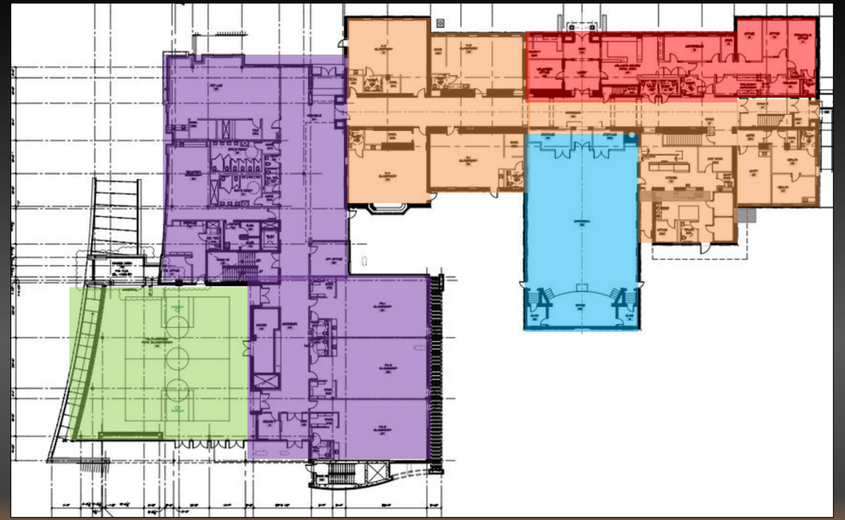
Mechanical Layout

Blue:	RTU-1 & 2 Cafeteria
Orange:	RTU-3 &4 (DOAS) and VRF
Purple:	RTU- 5 (DOAS) and VRF
Green:	RTU-6 & 7 Multipurpose
Red:	AHU-1 Administrative Offices

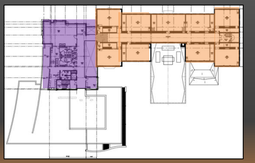
First Floor



Basement

Second Floor

Third Floor



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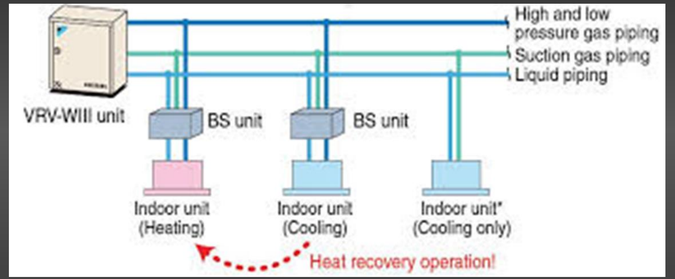
Mechanical Schedule

Rooftop Unit Schedule			
Unit No.	Area Served	Supply CFM	Total Load (MBH)
RTU-1	Cafeteria	7500	227
RTU-2	Cafeteria	7500	227
RTU-3	Exist. Bldg.	8300	350
RTU-4	Exist. Bldg.	5600	236.9
RTU-5	Addition	10650	538
RTU-6	Multi-purpose	7500	235
RTU-7	Multi-purpose	7500	235

Air Cooled Condensing Units Schedules (VRF System)			
Unit No.	Cooling (MBH)	Heating (MBH)	Condenser CFM
CU-VRF-1	439	494	20100
CU-VRF-2	343	386	20100
CU-VRF-3	305	343	13400



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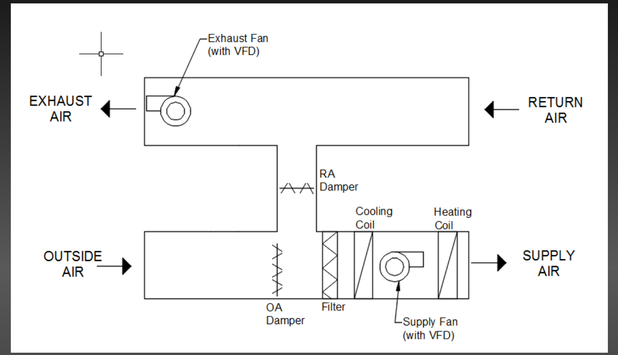
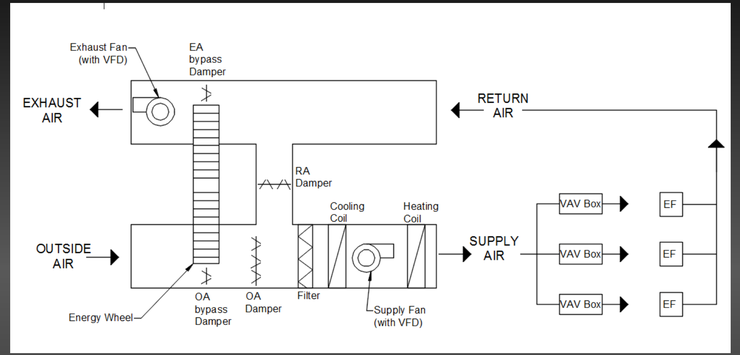
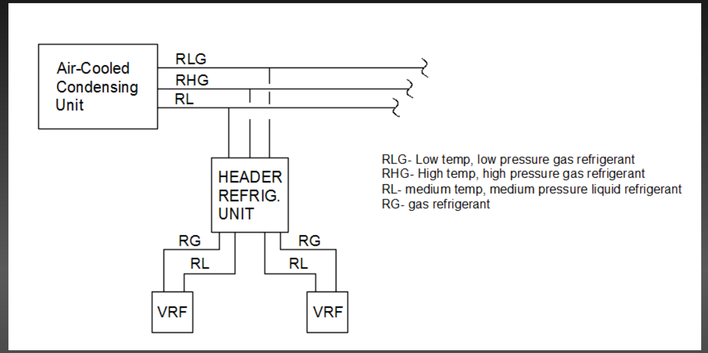
Mechanical Schematics



RTU- 1, 2, 6 & 7



RTU- 3, 4, & 5
DOAS



VRF System

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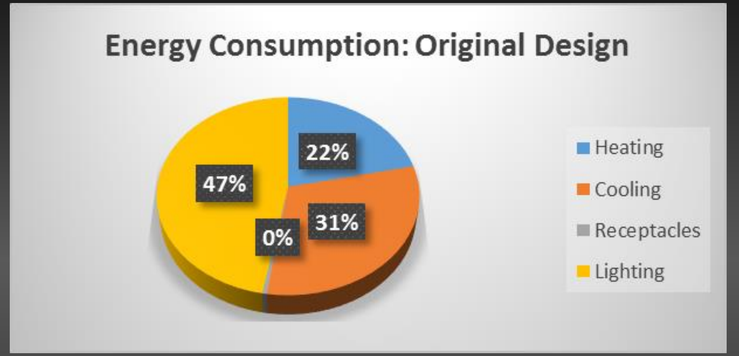
Energy Use & Emissions



	% of Total Building Energy	Total Building Energy (kBtu/yr)
Heating	21.56%	894,258
Cooling	30.80%	1,277,511
Receptacles	0.51%	21,069
Lighting	47.13%	1,954,985
Total	100%	4,147,823

	CO2 (lbm/year)	SO2 (gm/year)	NOx (gm/year)
Building Emissions	1,626,597.0	14,638.5	2,801.8

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Proposal Goals

Depth: Implement a geothermal system to improve the buildings energy use.

Breadth: The impact of a geothermal system on the construction management of the project.

Breadth: Perform acoustical analysis to insure the comfort of the spaces

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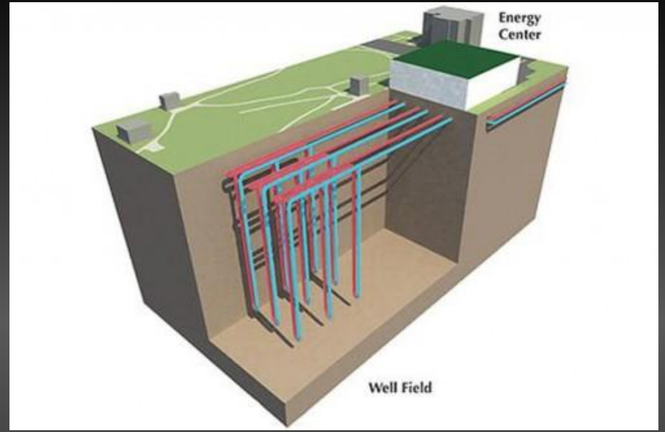
Proposed System

Water-cooled VRF units coupled with closed loop ground coupled heat pump

- More efficient than air-cooled condensers
- Constant thermal properties
- Reduces noise pollution
- Minimal site area loss
- High initial cost (long term owners)
- Renewable energy source (earth)
- Low maintenance



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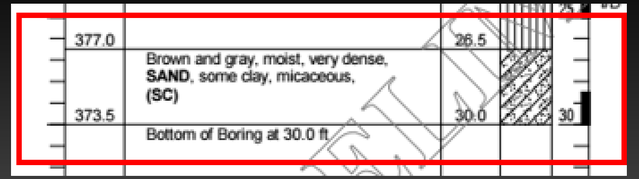
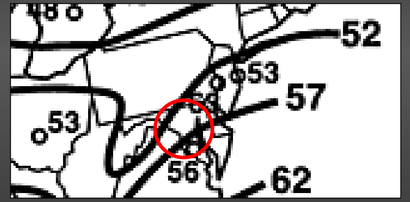
Site & Well Properties



Soil Properties	Wet dense sand
Dry Density	120 lb/ft^3
Conductivity (k)	1.63 Btu/h*ft*°F
Diffusivity (α)	0.91 ft^2/day

Annual Average Ground Temperature - 55ºF



Geothermal Heat Pump Design Manual by McQuay Air Conditioning

Well Design Details		
Radius of bore	0.42	ft
SDR 11	1.00	in
Rpipe	0.10	ft*hr*°F/Btu
Rgrout	0.05	ft*hr*°F/Btu
Rbore	0.15	ft*hr*°F/Btu

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Geothermal Calculations

Required Bore Length for Cooling (ft)

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

Required Bore Length for Heating (ft)

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

Equations from ASHRAE Handbook

	Symbol	Cooling	Heating	Units
Net annual average heat transfer to the ground	Qa	251,250	150,000	Btu/h
Building design cooling block load (or heating)	Qlc (or Qlh)	2,010,000	1,200,000	Btu/h
Power input at design cooling load (or heating)	Wc (or Wh)	130,000	130,000	W
Effective thermal resistance of ground annual pulse	Rga	0.2438	0.2438	ft*hr*°F/Btu
Effective thermal resistance of ground monthly pulse	Rgm	0.223	0.223	ft*hr*°F/Btu
Effective thermal resistance of ground daily pulse	Rgd	0.131	0.131	ft*hr*°F/Btu
Thermal resistance of bore	Rb	0.15	0.15	ft*hr*°F/Btu
Short circuit heat loss factor	Fsc	1.04	1.04	
Part load factor during design month	PLFm	1.00	1.00	
Undisturbed ground temperature	tg	55	55	°F
Liquid temperature at heat pump inlet	twi	74	44	°F
Liquid temperature at heat pump outlet	two	83	36	°F
Temperature penalty	tp	2.00	2.00	°F
	Length	**33,689**	**32,454**	ft
	# of wells	**84.2**	**81.1**	

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Well Layout

85 wells

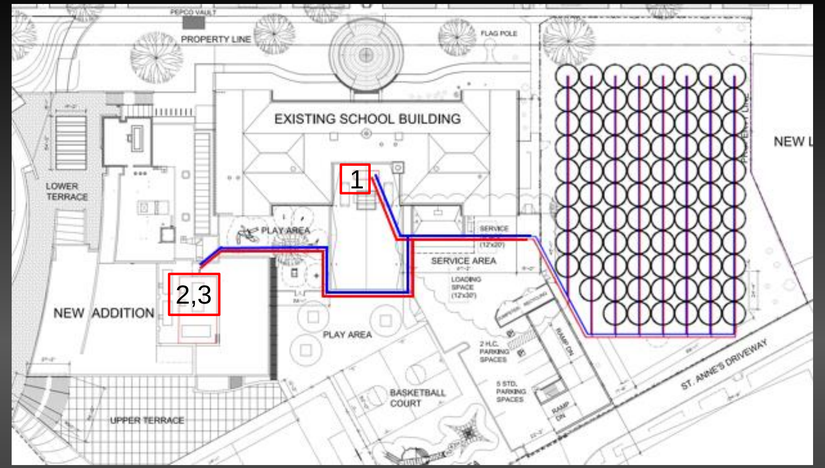
400 ft deep wells

15 ft well spacing

Area used 19,125 sq. ft.

Pump located in East Mechanical Room

Direct return piping



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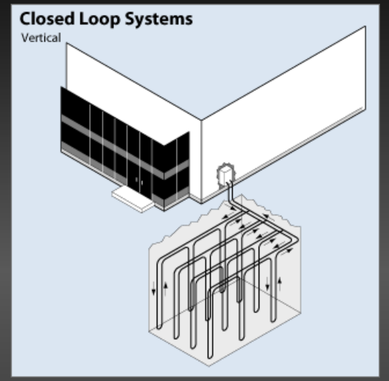


www.kochergeowelldrilling.com

Pipe & Flow Design

480 GPM

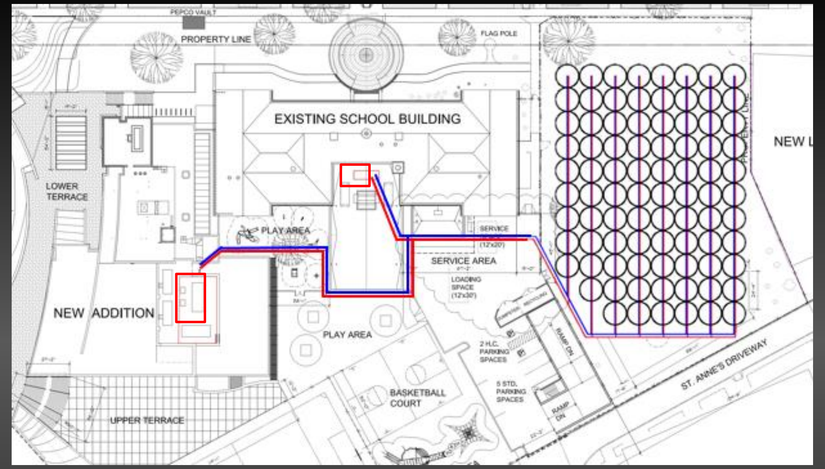
2.9 GPM/ton design

6” header pipe

2” row pipe

1” well U-tube

5” bore diameter



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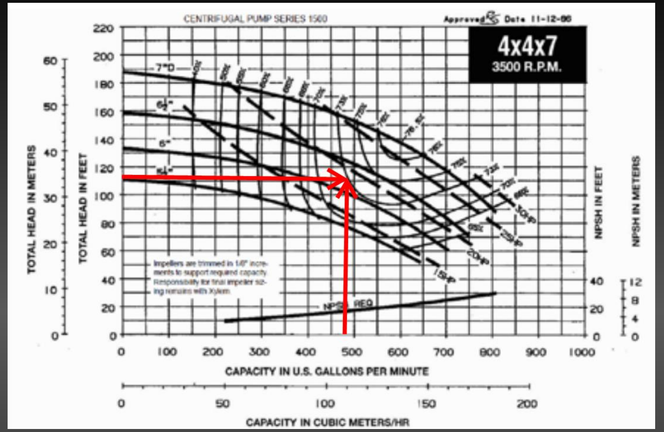
Well Pump Selection

Table 22- Head Loss	
Friction Loss	6.8 ft
Fixture Loss	109 ft
Velocity Loss	0.4 ft
Total head loss	116.2 ft

www.goulds.com

Size	Head	Flow Rate	RPM	HP	Manufacturer	Model
4x4x7	116.2 ft	480 gpm	3500	20	Goulds	AC-135.3F



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Water-Cooled VRF Unit Selection

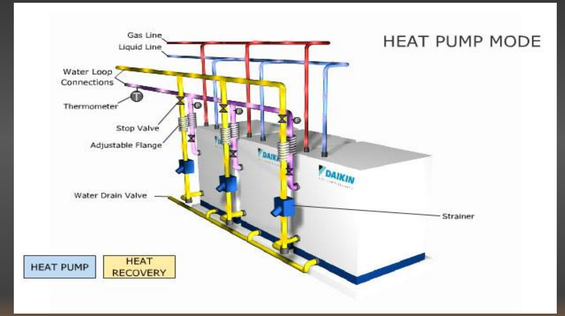
Unified heat pump and heat recovery

Units in series to reach needed capacity

Self heat recovery between modules

	Daikin	VRV-WIII Series				
	Unit	21 ton	18 ton	12 ton	7 ton	6 ton
Cooling	Capacity (Btu/h)	252,000	216,000	144,000	84,000	72,000
	EER	15.0	15.3	15.3	15.0	15.3
Heating	Capacity (Btu/h)	283,500	243,000	162,000	94,000	81,000
	COP	4.7	5.3	5.3	4.7	5.3

	Units
CU-VRF-1	(3)x 21 ton + 12 ton
CU-VRF-2	(2)x 21 ton + 7 ton
CU-VRF-3	21 ton + 18 ton + 6 ton



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Heat Exchanger Details

Ground Temperature 55ºF

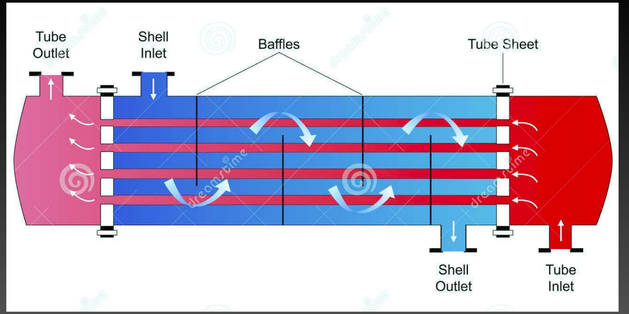
Ground Coupled Side

- 20% glycol / 80% water

VRF Side

- R140a

	Water			Refrigerant			Indoor Units Air	
	Tin	Tout	GPM	Tin	Tout	GPM	Supply	Return
Cooling	74°F	83°F	480	76°F	50°F	280	53-55°F	78-80°F
Heating	44°F	36°F	480	105°F	89°F	280	78-81°F	68-70°F



www.dreamstime.com

EA Credit 6

Refrigerant	Q (tons)	Refrigerant Impact per ton	Credit (<100)
R-410a	324	95.7	Yes

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Alternative System Energy Use

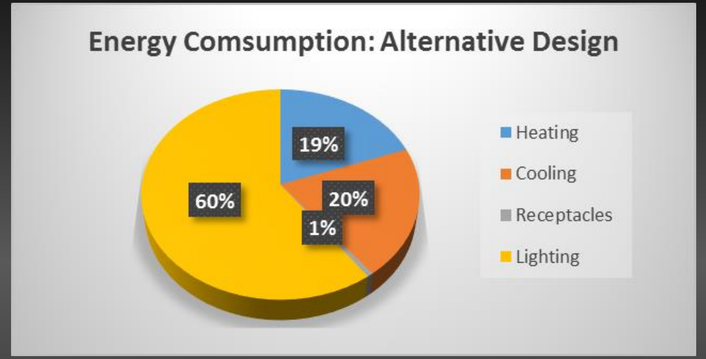

Table 25- Alternative Yearly Energy Consumption			
	Building	Building	Source
	kWh	kBtu/yr	kBtu/yr
Heating	185,431	632,320	1,896,960
Cooling	192,269	656,215	1,968,843
Lighting	572,805	1,954,985	5,865,541
Receptacle	6,173	21,069	63,213
Total	956,678	3,264,589	9,794,557
Cost	$131,064.90		

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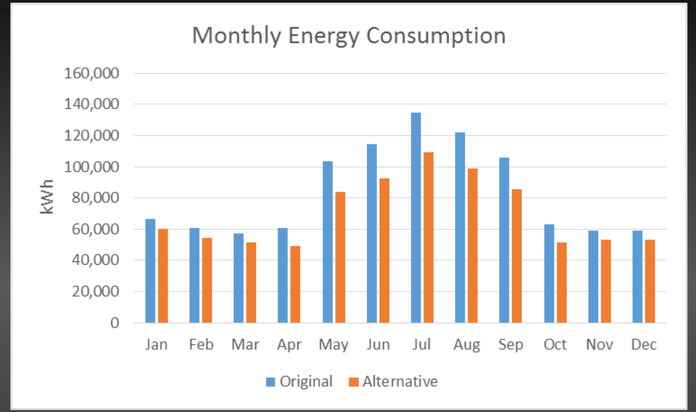
Energy & Emissions Comparison

Table 26- Yearly Energy Breakdown				
	Building (kWh)	Building (kBtu/yr)	Source (kBtu/yr)	Cost
Original System	1,215,300	4,147,823	12,444,711	$166,496.09
Alternative System	956,678	3,264,589	9,794,557	$131,064.90
Yearly Savings	**258,622**	**883,234**	**2,650,154**	**$35,431.19**

Emissions Comparison- 21.3% less

	CO2 (lbm/year)	SO2 (gm/year)	NOx (gm/year)
Original Design	1,626,597.0	14,638.5	2,801.8
Alternative Design	1,280,231.0	11,521.4	2,205.2



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Payback Period

Federal Tax Rebate

- 10 % of initial material and labor cost
- EER ≥ 14.1
- COP ≥ 3.3

Without rebate Payback Period = 19.53 years

Table 28- Payback Period		
	Cost	
Original System	$56,348.44	
Alternative System	$692,071.26	
With 10% Rebate	$622,564.13	
System Difference	$566,215.69	
Yearly Energy Savings	$35,431.19	
Payback Period	**15.98**	**Years**
	191.77	Months

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maps.google.com

Cost Comparison

	Mechanical Cost	Total Construction Cost
Original Design	$3,461,864	$20,969,617
Alternative Design	$4,028,079	$21,535,833
Percent Increase	**16.4%**	**2.7%**

Original Building cost is based on 2015 using inflation from 2010.

Original		
Material	Condensers	$42,377.00
	Controls	$823.00
Labor	Condensers	$11,985.00
	Controls	$1,163.00
Total Cost		**$56,348.00**

Alternative		
Material	Pump	$19,200
	Antifreeze	$6,786
	Water	$14
	Controls	$1,475
	Investigation	$915
	Loop	$424,521
	Sub-total	$452,911
Labor	Pump	$1,842
	Controls	$2,952
	Investigation	$3,993
	Loop	$230,373
	Sub-total	$239,160
Total Cost		**$692,071**

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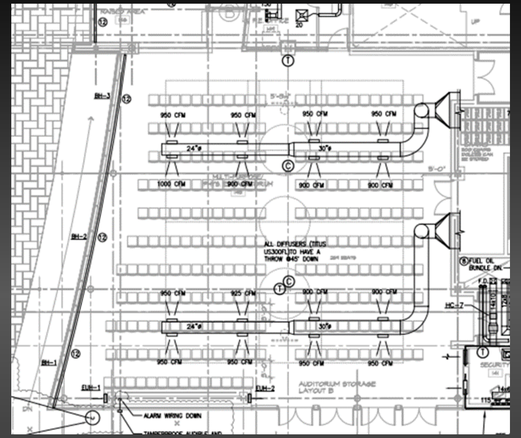


Multi-purpose Room Acoustical Treatment

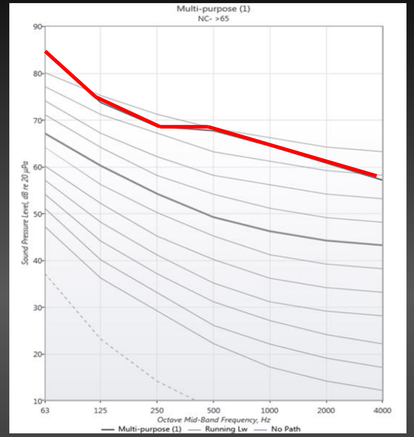
Before: NC > 65 After: NC – 39

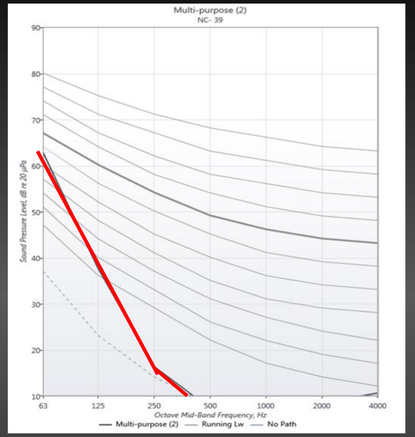
Added Treatment:
- 2” duct lining (60 ft each)
- One duct silencer each

Cost Breakdown
Duct lining = $11,457
Duct Silencers= $4,700

Total Cost = $16,157

Goal NC-45





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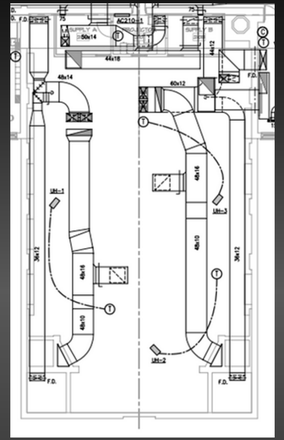
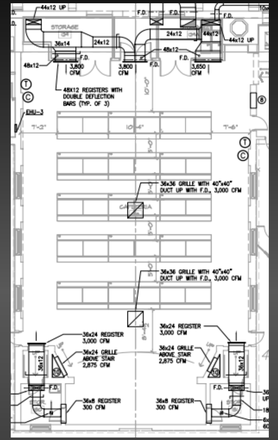




Cafeteria Acoustical Treatment

Before: NC - 52 After: NC – 41

Added Treatment:

- One duct silencer each (36”x12”x50”)

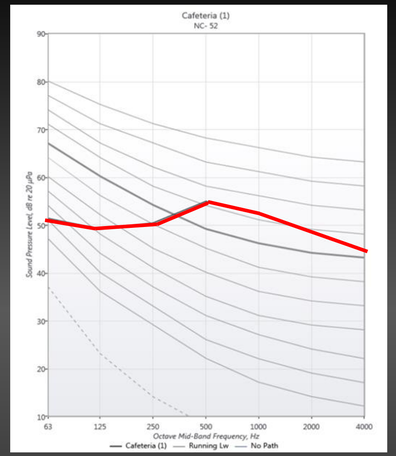
Cost Breakdown

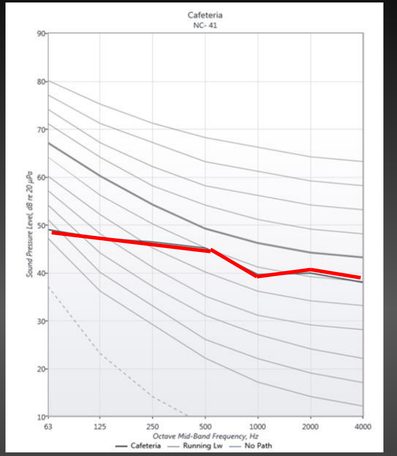
Duct Silencers= $4,000

Total Cost = $4,000

Not recommended extra cost

Goal NC-45





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Conclusion

System Initial Cost - $692,071.26

Monthly Savings - $2952.60

Payback Period of System – 15.98 years

EUI Reduction – 21.3%

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Acknowledgements

Penn State Faculty

JVP Engineers

Dr. Stephen Treado

All my peers that helped during the process

All my friends and family for their support

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Questions?

www.kumicm.com