ELEMENTARY SCHOOL ONE

TOWN, MARYLAND

Jonathan Cann

Advisor: Dr. Stephen Treado

Mechanical Option

BAE/MAE Integrated Program 2015

Top Photo Courtesy of NARPAC

Lower Photo Courtesy of www.janneyschool.org

Main Entrance – North Facade
Courtesy of NARPAC, Inc.

Elementary School One
Town, Maryland

BUILDING STATISTICS
Size: *84,400 GSF*
Height: *3 stories above*
Occupancy: *Educational*
Completion: *August 2011*
Cost: *$25 Million*
Delivery Method: *Mod.Design Build*

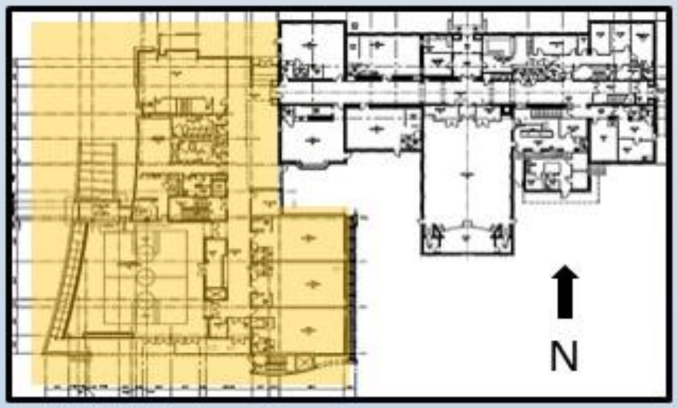
PROJECT TEAM
Owner: *Elementary School One*
Architect: *Devrouax & Purnell*
Civil: *Delon Hampton*
M.E.P. (sponsor): *JVP Engineers*
Structural: *Restl Designers*

HISTORICAL INFORMATION
- Existing structure was built in 1925
- Listed on the National register of Historic Places.
- Façade of the existing building is protected.

ARCHITECTURAL
- 3 story existing brick building with a 3 story addition mixed brick and glass façade
- Administrative offices, cafeteria, multipurpose room, classrooms, library and underground parking garage
- The addition's façade transitions from historic brick to modern glazing.
- LEED 2007 Gold Certification

STRUCTURAL
- Existing building has load bearing brick.
- Addition 4" metal studs supported by steel beams.
- Roof is 3" metal deck with 4" rigid insulation.

Isometric Rendering - Northwest
Courtesy of Devrouax and Purnell Architects



First floor plan with the addition highlighted

MECHANICAL
- 3 dedicated outside air RTUs with heat wheels that serve the most of the building through VAV boxes. These spaces are conditioned by 3 air cooled VRF systems.
- Cafeteria and multipurpose room are served by two RTU each.
- Finned tube radiators and cabinet heaters for extra heating.

LIGHTING/ELECTRICAL
- 480V, 3 phase service from the main switch gear that distributes the power, emergency and standby branches.
- There are 11 transformers that serve several high voltage and low voltage branches.
- Oil generator on roof for backup power.
- Lighting mostly recessed fluorescent and compact fluorescent lamps.

Jonathan Cann | Mechanical | Dr. Treado
www.engr.psu.edu/ae/thesis/portfolios/2015/jac5850

Table of Contents

Executive Summary

Elementary School One underwent modernization in 2010, renovating the existing building and adding an addition to the west side of the building. The existing building was built in 1925 and is currently listed on the National Register of Historic Places. The addition adds four floors with three above grade. The addition includes classrooms, a multipurpose room, and a library.

The mechanical system installed was a VRF system with air-cooled condensers that condition most spaces. Those spaces are also served by three DOAS units ducted to VAV boxes in each space. The rest of the spaces are conditioned by rooftop packed units and split system AHUs.

Proposed Alternative

The proposed alternative is to have water-cooled VRF units with a ground coupled heat pump. The goal of this design is to increase building efficiency and reduce operating cost. A combination of Trace 700 modeling and hand calculations determined the building loads and energy consumption. The alternative system reduces the yearly energy consumption cost by $35,431.19 and reduces emission by 21%. The initial cost difference is an increase of $566,215.69 with the 10% Federal Rebate. The payback period with the rebate is 15.98 years and 19.58 years without. The alternative system is recommended, especially for a long-term owner such as the school district. This system will be saving money on the utility bill for a long time.

Construction Breadth

The impact of the alternative system on the construction cost, schedule, and site operations was investigated. It was found that the initial cost was increased by $566,215.69. The installation of the ground coupled system was 80 days more than the original system, but the schedule would only be impacted for 25 days due to the location of installation. The site layout was only temporarily affected for those 25 days where portables had to be relocated.

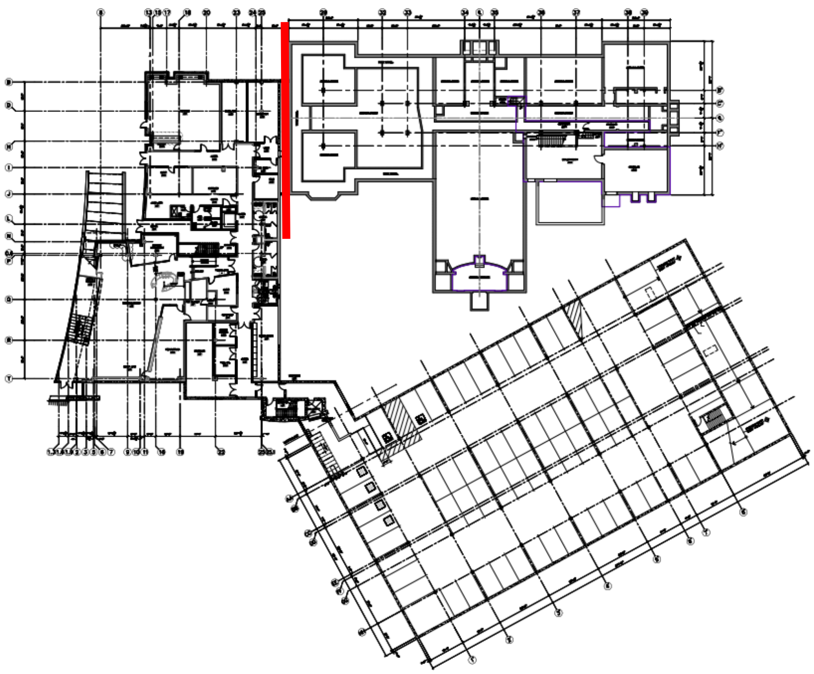
Acoustical Breadth

The acoustical comfort of the multipurpose room and cafeteria were investigated using Dynasonic Software. The multipurpose room is served by two RTUs and the noise criteria was much greater than comfortable level, NC->65. The multipurpose RTUs needed acoustical treatment of 2 in duct lining and two duct silencers to reduce to under NC-45. The cost of these treatments total to $16,157. The cafeteria NC levels were only slightly over the preferred level, NC-52 to NC-45. The recommended treatment for the cafeteria is two duct silencers coming to a cost of $4000. The cafeteria doesn't need the treatment because the rooms are not learning spaces.

Building Overview

Building Name: Elementary School One
Location and Site: Town, Maryland
Dates of Construction: 2010 – August 2011
Size: 84,400 sq. ft.
Number of Stories: 3 above and 1 below grade

Figure 1- Building Layout



The red line separates the existing building and the addition. The existing is on the right and the addition is on the left.

Mechanical Systems Summary

Elementary School One modernization involved a renovation of the existing building and an addition on the west side. All new mechanical systems were applied to both the existing building and the addition. The mechanical system has three dedicated outside air RTUs that supply VAV boxes in each space. Each space then exhausts air back to the RTUs for heat wheel. There are three air-cooled VRF systems that condition these spaces with dedicated outside area.

Two RTUs serve the cafeteria and two serve the multipurpose room. There are also baseboard radiators and cabinet heaters in some of the spaces near the exterior. In the administrative section of the existing building, an AHU conditions the spaces with its own outside air intake. There are small AHUs that serve the computer room and telecom room, but they were not included in my analysis because of the insignificant impact.

The figures below show the areas each unit serves.

Blue- RTU-1 and 2 serve cafeteria
Orange- RTU-3 and 4 DOAS serve the existing building (heat wheel)
Purple- RTU-5 DOAS serve the addition (heat wheel)
Green- RTU-6 and 7 serve the multipurpose room
Red- AHU serves administrative offices

Figure 2- Basement Block Layout

Figure 3- First Floor Block Layout

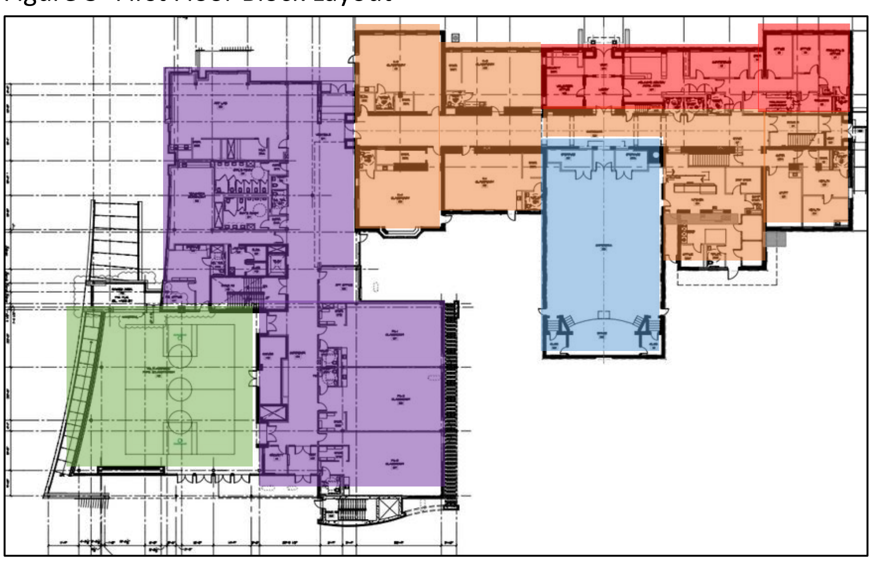


Figure 4- Second Floor Block Layout

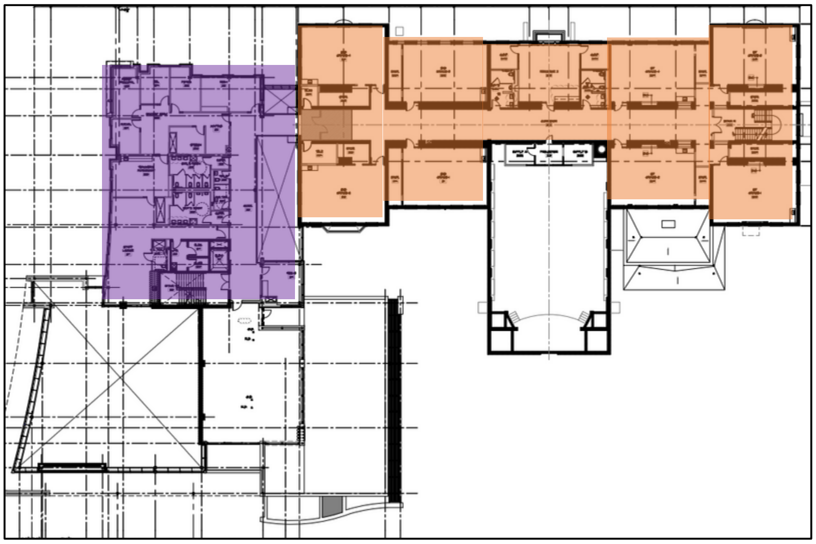
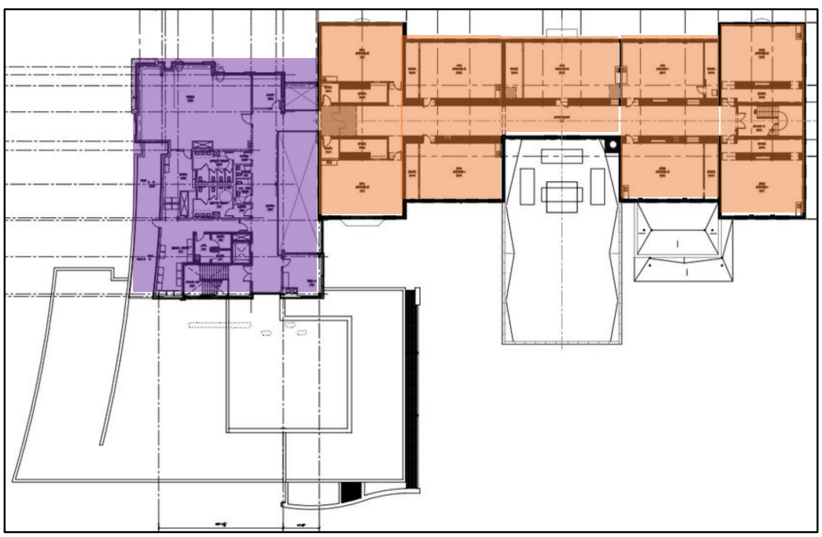


Figure 5- Third Floor Block Layout



Design Conditions

The outdoor design conditions are based on ASHRAE Handbook weather information from Baltimore, Maryland. The indoor design conditions are based on the owner's needs and the engineer's input. The relative humidity of the space will be controlled to maintain between 48% and 55% RH. Table 1 below summarizes the design temperatures for the building systems. Weather based on Baltimore, Maryland data.

Table 1- Outdoor and Indoor design conditions

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

Ventilation Requirements

The designed ventilation rates were based on ASHRAE Standard 62.1. Most of the spaces are served by the dedicated outside air units which have a set minimum flow rate to ensure compliance. The other spaces, cafeteria and multipurpose room, are served by packaged rooftop units that will provide mixed air to the spaces. In Appendix A, the detailed outdoor air calculations for each space can be found. Table 2 below is a summary of the ventilation rates for each unit.

Table 2: RTU Ventilation Summary

Unit	Supply CFM	Required OA CFM	Design OA CFM	OA%
RTU-1,2	15,000	2,876	5,000	33.3%
RTU-3	9,180	4,327	9,180	100%
RTU-4	5,600	2,881	5,600	100%
RTU-5	8,575	3,573	8,575	100%
RTU-6,7	16,000	3,552	5,000	31.3%

Mechanical Equipment

Air Handling Units

The rooftop units and air conditioning units combine to serve all the spaces in the building. RTU-3, 4 and 5 in Table 3 are dedicated outside area units. The DOAS units serve the spaces using VAV boxes. There are 59 VAV boxes in the building ranging from 75 cfm to 600 cfm. RTU-1, 2, 6 and 7 are packaged units that condition and provide OA to the space. These spaces are provided with extra heating from 10 electric unit heaters and electric baseboards. The AC units, Table 4, serve individual spaces that needed different loads and schedules. The AC units are a part of a split system with air cooled condensing units, Table 5.

Table 3- RTU Operation

Rooftop Unit Schedule			
Unit No.	**Area Served**	**Supply CFM**	**Total Load (MBH)**
RTU-1	Cafeteria	1625	227
RTU-2	Cafeteria	1625	227
RTU-3	Exist. Bldg.	7475	350
RTU-4	Exist. Bldg.	5175	236.9
RTU-5	Addition	8350	538
RTU-6	Multi-purpose	2250	235
RTU-7	Multi-purpose	2250	235

Table 4: ACU Operation

AC Unit Schedules			
Unit No.	**Area Served**	**CFM**	**Capacity (MBH)**
AC-1	Admin	2200	81.77
AC-2	Computer Rm	1000	30
AC-3	Telecom	800	24

Table 5: Condensing units for AC Units

Air Cooled Condensing Units Schedules		
Unit No.	**Serving**	**Capacity (MBH)**
ACCU-1	AC-1	95.9
ACCU-2	AC-2	30
ACCU-3	AC-3	24

VRF Operations

There are three variable refrigerant flow systems that condition the spaces served by the DOAS. The VRF units have cooling and heating capacities seen in Table 6. The VRF is air-cooled to three condensing units on the roof, Table 7. The spaces served by the DOAS can receive conditioned outside air from the DOAS units and then the VRF can supply any further conditioning. There are 13 cabinet heaters that serve vestibules, corridors and stairwells if extra heating is needed.

Table 6- Capacities of VRF Units

AC Unit Schedules (VRF)		
CFM	**Cooling (MBH)**	**Heating (MBH)**
230	7.5	8.5
300	9.6	10.9
420	12.3	13.6
550	19	21
185	7.5	8.5

Table 7- Condensing Units for VRF Operation

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

Boilers

The two mechanical rooms located in the bottom floor each have a 399,000 BTUH natural gas boiler. The boilers provide the building with hot water for domestic use. The boiler summary is in Table 8.

Table 8- Boiler Operation

Domestic Water Heater Schedule			
Unit No.	**Location**	**Type**	**BTUH Input**
WH-1	New Boiler Rm	Gas	399,000
WH-2	Ex. Boiler Rm	Gas	399,000

Mechanical System Schematics and Operation

Air Side

The building is served by seven rooftop air handling units. The schematic design for the packaged RTUs (1, 2, 6 & 7) can be seen in Figure 6 below. These units have supply fans and return fans with VFD control. The fan speed and the damper control will vary depending on the response from the BAS system. The BAS system will determine the flow based on the space, outside and return air temperatures and humidity. These units must maintain a 30% mixture of outdoor air when the spaces are occupied.

The outside air enters the RTU due to the downstream supply fan and a temperature sensor indicates the OA temperature. The OA will be mixed with some amount of return air unless in economizer mode. This air next goes through a filter with a differential pressure sensor on both sides to indicate filter status. The air is then conditioned and dehumidified by the cooling coil, dependent on the space's need. The cooling coil is followed by a freeze stat to prevent any damage. The air goes through the supply fan and is then conditioned by the heating coil if it is needed. The supply air temperature is censored along with the space's temperature and CO2 concentration. The return air is pulled by the exhaust fan. As the RA enters the unit, a smoke detector and RA temperature sensor monitor the air. A percentage of the return air can be mixed with the OA using the RA dampers or exhausted out.

The rooftop units 3, 4, & 5 (Figure 7) are a part of a designated outside air system (DOAS). These units have supply and exhaust fans that are both VFD. The units supply 100% OA to the spaces they serve. To make this unit more efficient, a heat wheel is used to transfer heat from the exhaust to the supply air depending on the season. The energy wheel itself has dampers for bypass if less heat transfer is needed. The air goes through a similar path as the unit above: filter, coiling cool, heating coil, and the space. These DOAS units have the same sensors as listed for previous units. The DOAS unit supplies the spaces through VAV boxes that has dampers. The VAV box changes the flow with the damper and can also reheat the air with the electric duct heater. The return air is pulled from each space and exhausted outside. The DOAS system has a set minimum OA flow rate which is controlled by the unit itself.

Figure 6- Schematic of Packaged RTUs
RTUs- 1, 2, 6 & 7

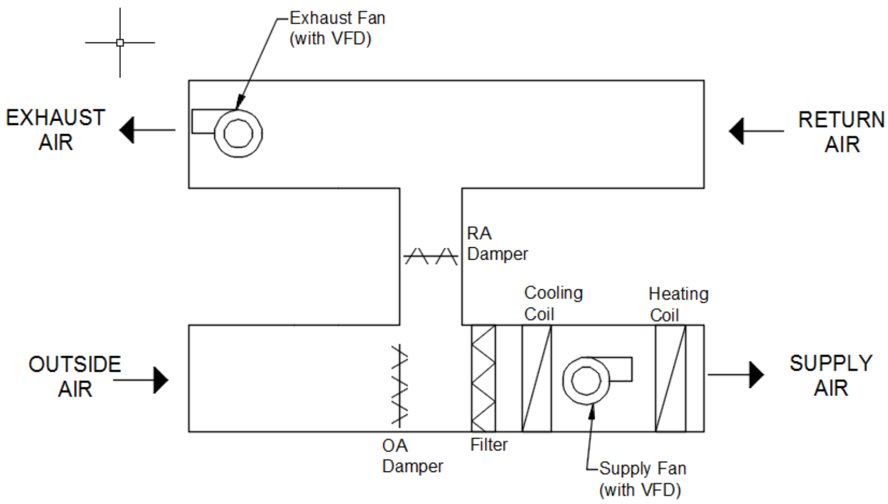
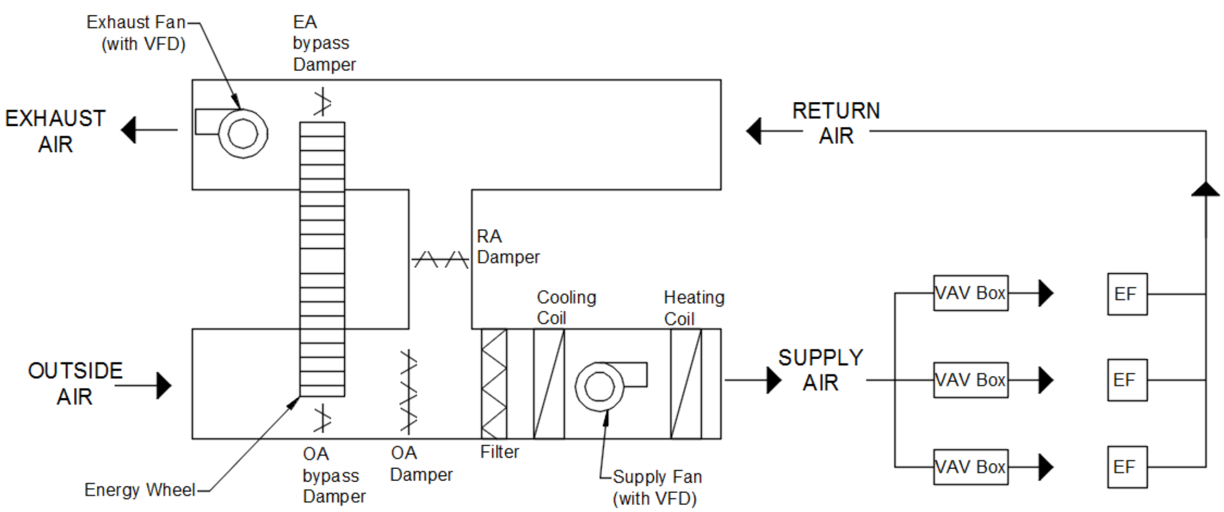


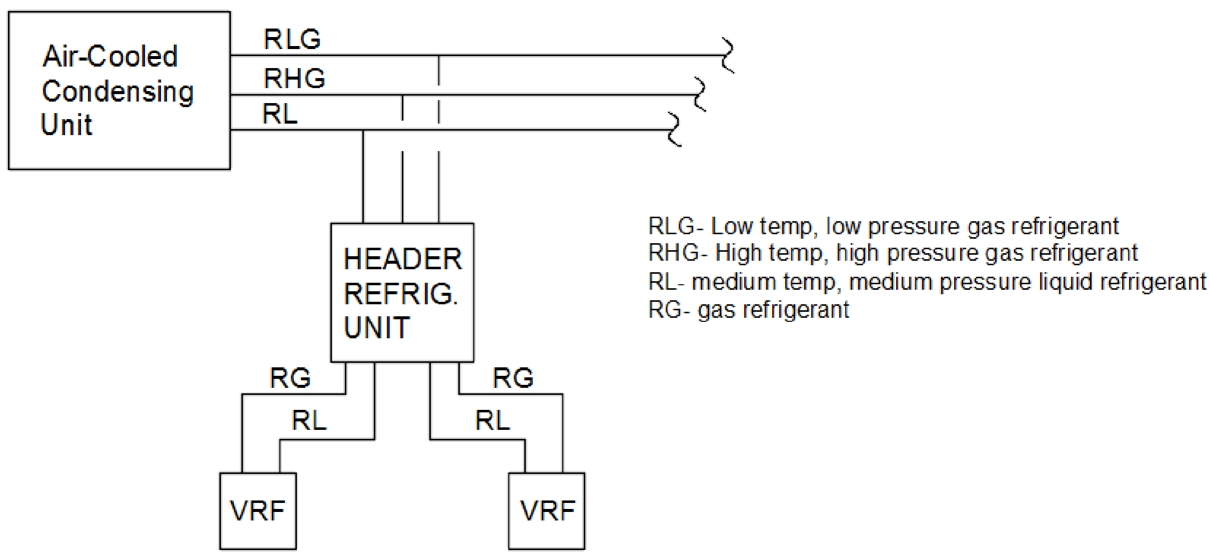
Figure 7- Schematic of DOAS RTUs
RTUs- 3, 4 & 5



Refrigerant Side

There are three separate variable refrigerant flow systems that serve the building using R-410a as the refrigerant. The schematic can be seen below in Figure 8. The VRF system consists of an air-cooled condensing unit that serves several header units that distribute the refrigerant to the VRF boxes which condition the air in each space. The condensing units are on the rooftop and transfer heat to the outside air. Three refrigerant pipes go from the condensing unit to the header units. The three pipes have the refrigerant with different enthalpy as seen below. The header unit controls the flow of refrigerant to the individual space boxes. The flow is controlled by the temperature in each space. The boxes in each space are basically fan coil units. The fan pulls in air from the space, conditions the air with the coils and supplies that air back to the space. The VRF units have a self-monitoring system that can be controlled by the BAS system.

Figure 8- VRF System Schematic
Variable Refrigerant Flow System



Existing System Evaluation

ASHRAE 62.1 Evaluation

Section 5 – Systems and Equipment

5.1- Ventilation Air Distribution

Section 5.1.1 requires that air balancing of the ventilation system must provide the means to adjust to achieve at least the minimum ventilation airflow required for the space. Most spaces are supplied a dedicated outside air system that reaches a VAV box for each space. The branches going to the VAV boxes and the diffusers have a balancing damper, which both allow each space to get the appropriate OA flow. The RTUs that serve the cafeteria and multipurpose room have OA intake balancing within the unit. The administrative space that is served by its own AHU has a motorized damper to control the outside air intake to the unit.

Section 5.1.2 states when ceiling or floor plenum is used to reticulate return air and to distribute ventilation that the system must provide at least the minimum required ventilation airflow. This section does not apply to Elementary School One because the mechanical systems do not use a plenum.

Section 5.1.3 states that air balance testing requirements be documented. In specification 15950, it states that all air systems must be balanced with accordance to Associated Air Balance Council (AABC), National Environmental Balancing Bureau (NEBB), and Sheet Metal and Air Conditioning Contractor's National Association (SMACNA).

5.2- Exhaust Duct Location

Section 5.2 states that all harmful contaminants that are exhausted must be negatively pressured and not leak into any spaces that the duct passes through. All spaces that require exhaust such as bathrooms, storage, etc. have a negatively pressured duct that leads to an energy wheel and is not mixed with supply air.

5.3- Ventilation System Controls

Section 5.3 requires the ventilation system to be controlled manually or automatically to maintain at least the minimum outside air requirement. The mechanical ventilation system is controlled by VAV boxes, manual balancing dampers, air flow sensors and thermostats. The VAV boxes in each space have a minimum airflow setting and the airflow can be increased depending on the sensors' data sent to the RTUs. All controls are located on an interface with BAS and ATC.

5.4- Airstream Surfaces

Section 5.4 requires that all airstream surfaces must resist mold growth and erosion. In specification 15815, all ducts and airstream surfaces comply with ASTM, UL or SMACNA standards. All ducts are made of sheet metal and the duct accessories comply with the standards above.

5.5- Outdoor Air Intakes

Section 5.5 requires the outdoor air intakes to be a certain distance from potential outdoor contaminant sources. All outdoor air intakes meet the required distance and coverage from rain, snow and birds. All RTUs have parallel outside air intake and exhaust which are pointed away from the adjacent RTUs. This allows for the Class 4 air exhaust not to containment the supply air.

5.6- Local Capture of Contaminants

Section 5.6 states that non-combustion equipment discharge shall be directly ducted outdoors. The Elementary School does not have non-combustion equipment on site so this section does not apply.

5.7- Combustion Air

Section 5.7 requires fuel-burning appliances to be provided with sufficient air for combustion and if the appliance is vented that the vent goes directly outdoors. The fuel-burning appliances are the boilers in the basement and the generator on the roof. The mechanical room with boilers has exhaust that directly goes outside. The generator on the roof is open to the environment so no ventilation or exhaust is required.

5.8- Particulate Matter Removal

Section 5.8 states that filters or air cleaners must have a rating of MERV of at least 8 and should be located upstream of coils or other devices that may have wet surfaces. Each RTU has a 2" thick pre-filter and a 4" thick MERV 13 filter. Having these filters in series exceeds the requirement for this section.

5.9- Dehumidification Systems

Section 5.9.1 requires occupied spaces to be 65% RH or less. The design supply air for the mechanical systems range from 48% to 53% RH and this meets the requirement.

Section 5.9.2 requires the outdoor air shall be equal to or greater than the exhaust airflow. From the airflow calculations given, the outside air equals the exhaust airflow. The fan speeds may have been changed by maintenance when installed to pressurize the building.

5.10- Drain Pans

Section 5.10 requires all drain pans for condensate producing equipment to have a slope at least 0.125 in/ft and the drain outlet at the lowest point. The specification 15738 states that drain pan installation must follow these requirements for the RTUs. Some of the units on the roof have drain pans within the unit with an outlet at the lowest point which also complies. Condensate drain pans are installed by factory for the VRF units that connect into the storm water system.

5.11- Finned-Tube Coils and Heat Exchangers

Section 5.11.1 states that drain pans for cooling coils and heat exchangers that produce condensate must follow the drain pan requirements from section 5.10. There is a heat exchanger in the mechanical room for the boilers and the heat exchanger has a drain pain that complies with section 5.10.

Section 5.11.2 requires certain spacing of finned-tube coils for cleaning. This section does not apply to this building.

5.12- Humidifiers and Water Spray Systems

Section 5.12 states that water in contact with ventilation air must be at least potable and obstructions must be downstream at the required distance. Elementary School One does not have humidifiers or water spray systems so this section does not apply.

5.13- Access for Inspection, Cleaning and Maintenance

Section 5.13 requires that all equipment must have enough space to access panels for maintenance and cleaning. Most of the dampers, controls, VAVs and VRFs are in spaces with drop down ceilings for easy access. The RTUs and other equipment are spaced appropriately to comply with this section. Specification 15183 requires that all VRF piping above accessible ceilings be installed to allow sufficient space.

5.14- Building Envelope and Interior Surfaces

Section 5.14.1 requires the building envelope to have some water barrier or vapor retarder. The existing building is has load bearing brick which acts as a water barrier due to its thickness and ability to dry. The addition is a combination of glass curtain wall and face brick with vapor barrier and waterproof sealants. Both of these types of envelope meet the requirements of this section.

Section 5.14.2 states that any duct or pipe on interior surfaces that may produce condensation needs to have insulation. All cold surfaces in the building have insulation so it complies.

5.15- Building with Attached parking Garages

Section 5.15 requires the attached parking garage to have a lower pressure than adjacent occupied space or an airlock vestibule between spaces. The school meets both requirements. There is a vestibule that separates the underground parking garage from the entrance into the building. The parking garage has direct exhaust and is open to the outside on the ramp going down to the garage.

5.16- Air Classification and Recirculation

Section 5.16 requires certain air classifications cannot be used again or recirculated to other spaces depending on that space's air classification. Elementary School One's ventilation system brings air into a space and exhausts it directly out. There is no mixing of air classifications or reuse besides lesser Class air entering Class 4 air spaces like bathrooms. Which are negatively pressured so hallway air will be pulled in, and therefore comply with this section.

5.17- Requirements for Building Containing ETS Areas and ETS-free Areas

There are no ETS areas in Elementary School One so the section does not apply.

Section 6 – Procedures

6.1- General

Section 6.1 requires the ventilation system must be designed using Ventilation Rate Procedure, IAQ Procedure or Natural Ventilation Procedure. Elementary School One used the ventilation rate procedure to reach acceptable ventilation airflow.

6.2- Ventilation Rate Procedure

Sections 6.2.11 and 6.2.12 require filtration systems to be at least MERV of 6 and all AHUs exceed this requirement. The calculations for ventilation rate are described in this section. The calculation for ASHRAE 2013 compared to the designed values can be seen in Appendix A.

The design calculations were based on IMC 2006 and they were compared to ASHRAE 2013. Most of the designed outside airflow complies with the newer standard except two spaces. The music room and science classroom both are not supplied with enough outside air. This may be due to the change in requirements over the years or classification of the space.

ASHRAE 62.1 Summary

Elementary School One complies with the majority of these standards and exceeds many of them. The only area of this building that does not comply with the new code is the ventilation rate for two of the spaces. This may be due to the change of the standards through the years. Not many modifications will be needed to reach the modern standards, but the building can be improved.

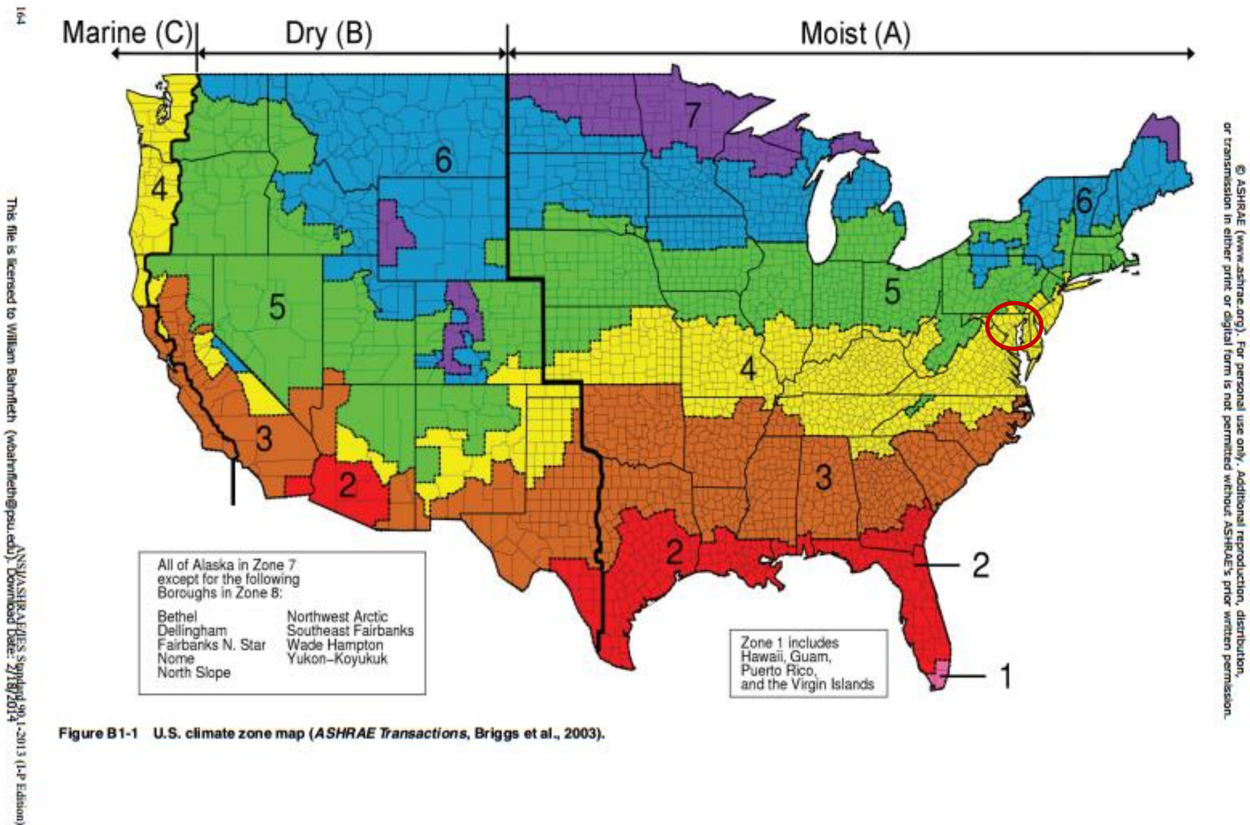
ASHRAE 90.1 Evaluation

Section 5 – Building Envelope

5.1- General

Section 5.1.4 states how to determine the climate of the site. Elementary School One falls in climate zone 4A, which can be seen in the image below. Zone 4A is an area that is middle temperature and moist. These factors affected the original design.

Figure 9- The Climate Zone map from ASHRAE 90.1



5.2 Compliance Paths

The building construction complies with Section 5.5 by the method of Prescriptive Building Envelope Option. To comply, vertical fenestration area cannot exceed 40% of the gross wall area and the skylight fenestration cannot exceed 5% of the gross roof area. Elementary School One meets both of these requires therefore can use this option.

5.4 Mandatory Provisions

Section 5.4.3 requires the building to have a continuous air barrier to prevent air leakage. The building meets this requirement.

5.5 Prescriptive Building Envelope Option

Elementary School One is nonresidential conditioned space and must comply with climate zone 4A requirements. They can be seen in the table to the right and the building meets the requirements.

Table 9- Building Envelope Requirements for climate zone 4 (A,B,C) from ASHRAE 90.1

Table 5.5-4 Building Envelope Re

Opaque Elements	Nonresidential Assembly Maximum	Nonresidential Insulation Min. R-Value	
Roofs			
Insulation Entirely above Deck	U-0.032	R-30 c.i.	
Metal Building[a]	U-0.037	R-19 + R-11 Ls or R-25 + R-8 Ls	
Attic and Other	U-0.021	R-49	
Walls, above Grade			
Mass	U-0.104	R-9.5 c.i.	
Metal Building	U-0.060	R-0 + R-15.8 c.i.	
Steel Framed	U-0.064	R-13 + R-7.5 c.i.	
Wood Framed and Other	U-0.064	R-13 + R-3.8 c.i. or R-20	
Wall, below Grade			
Below Grade Wall	C-0.119	R-7.5 c.i.	
Floors			
Mass	U-0.057	R-14.6 c.i.	
Steel Joist	U-0.038	R-30	
Wood Framed and Other	U-0.033	R-30	
Slab-on-Grade Floors			
Unheated	F-0.520	R-15 for 24 in.	
Heated	F-0.843	R-20 for 24 in.	
Opaque Doors			
Swinging	U-0.500		
Nonswinging	U-0.500		
Fenestration	**Assembly Max. U**	**Assembly Max. SHGC**	**Assembly Min. VT/SHGC**
Vertical Fenestration, 0%–40% of Wall		(for all frame types)	
Nonmetal framing, all	U-0.35		
Metal framing, fixed	U-0.42		
Metal framing, operable	U-0.50	SHGC-0.40	1.10
Metal framing, entrance door	U-0.77		
Skylight, 0%–3% of Roof			
All types	U-0.50	SHGC-0.40	NR

Section 6– Heating, Ventilating, and Air Conditioning

6.1- General

The existing building modernization must comply with all parts in section 6.1.13 and the addition must comply with section 6.2. Elementary School One classifies as an addition and renovation. Some of the standards overlap, but must be treated separately.

6.2- Compliance Paths

Elementary School One uses the compliance path defined in section 6.4 (Mandatory Provisions) and section 6.5 (Prescriptive Path).

6.4- Mandatory Provisions

The buildings equipment must meet the minimum performance specified in the tables in Appendix B. Elementary School One complies with the requirements. Specification section 15088 complies with the pipe insulation and section 15086 meets the duct insulation requirement.

6.5- Prescriptive path

All cooling systems over 54,000 BTU/h must have an economizer. All RTUs have an economizer that serves Elementary School One. The dedicated outside air units utilize a heat wheel.

Section 7– Service Water Heating

The service water for heating is supplied from the five boilers in the mechanical room in the basement. There is a recirculation and heat exchanger to conserve energy. Complying with section 7.4.3, all equipment and piping are properly insulated. The water temperature is controlled by the building's BAS interface.

Section 8– Power

Section 8.4.1 states the voltage drop for feeders must be at a maximum of 2% and a maximum drop of 3% for branch circuits. Elementary School One power distribution complies with this section. There is an oil generator on the roof that can run the emergency lightning if needed.

Section 9– Lighting

Most lighting fixtures are recessed fluorescent in the school and compact fluorescent lamps are used in the multipurpose room. The lighting throughout the building is controlled by time switches, photoelectric switches, stand-alone daylight-harvesting switching controls and indoor occupancy sensors. These controls help save energy while meeting the lighting power density for the spaces. Elementary School One complies with the lighting power densities in table 9.5.1, which is 0.87 W/sf for schools.

ASHRAE 90.1 Summary

ASHRAE Standard 90.1 establishes minimum requirements for energy efficiency. The standard involves the building envelope and the systems. Elementary School One meets the new standards of ASHRAE 90.1. The existing building envelope will have imperfections because of its age. Elementary School One when it was modernized earned LEED Gold so the systems are energy efficient. There is room for improvement because the design would not get LEED Gold by today's standards and there is new technology that can be applied.

LEED Evaluation

Elementary School One achieved LEED for Schools 2007 Gold Certification. The following is an evaluation of the mechanical systems LEED credits based on the current USGBC LEEDv4.

Energy & Atmosphere Credits

EA Prerequisite 1: Fundamental Commissioning and Verification (Complies)

The purpose of this prerequisite is to verify that the mechanical system is installed and operates as the design intended. Commissioning and verification were completed by a third party hired by the owner.

EA Prerequisite 2: Minimum Energy Performance (Complies)

The purpose of this prerequisite is to reduce the environmental and economic harms of excessive energy use by achieving a minimum level of energy efficiency for the building and its systems. The minimum energy cost savings of 5% is required for all new construction projects and the energy model from the designer has savings of 19.4%.

EA Prerequisite 3: Building-Level Energy Metering (Complies)
The purpose of this prerequisite is to ensure that energy usage by the building is documented. New electricity and natural gas meters were installed to accurately measure the building consumption.

EA Prerequisite 4: Fundamental Refrigerant Management (Complies)
The purpose of this prerequisite is to reduce stratospheric ozone depletion. The designed systems have zero use of CFC-Based refrigerants.

EA Credit 1: Enhanced Commissioning (0/6 pts)
The purpose of this credit is to further support the design, construction, and operation of a project that meets the owner's project requirements. No documentation of enhanced commissioning is available.

EA Credit 2: Optimize Energy Performance (7/16 pts)
The purpose of this credit is achieve increasing levels of energy performance beyond prerequisite standard. The energy model predicted energy cost savings of 19.4% from the baseline. The building falls under new construction, and 7 of 16 points are achieved.

EA Credit 3: Advanced Energy Metering (1/1 pts)
The purpose of this credit is to ensure that whole-building energy sources used by the building are documented to allow for possible energy savings in the future. New electricity and natural gas meters were installed for collecting energy usage data.

EA Credit 4: Demand Response (0/2 pts)
The purpose of this credit is to increase participation in demand response technologies and programs to reduce energy usage. This credit is new for LEEDv4 so no documentation is available for demand response.

EA Credit 5: Renewable Energy Production (0/3 pts)
The purpose of this credit is to reduce the environmental and economic harms associated with fossil fuel energy. There is no renewable energy production on site.

EA Credit 6: Enhanced Refrigerant Management (1/1 pts)
The purpose of this credit is to reduce ozone depletion and to support early compliance with the Montreal Protocol. The packaged AC units and split AC units both use R-140a as the refrigerant. To achieve this credit, the refrigerant impact per ton must be < 100. The school's systems meet the requirement and the data can be seen in Table 10.

Table 10- EA Credit 6 Data

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

EA Credit 7: Green Power and Carbon Offsets (0/2 pts)

The purpose of this credit is to encourage the reduction of greenhouse gas emissions through use of renewable energy, grid source technologies and carbon mitigation projects. No documentation was available on green power or carbon offsets.

Indoor Environmental Quality Credits

EQ Prerequisite 1: Minimum Indoor Air Quality Performance (Complies)

The design complies with this section by meeting the minimum ventilation requirements of ASHRAE 62.1 except for two spaces. This may be due to the design using an older version of standards. These spaces have operable windows which allow the spaces to comply. The calculations and analysis can be seen in Appendix A.

EQ Prerequisite 2: Environmental Tobacco Smoke Control (Complies)

The school does not allow smoking on site and the proper signage is posted around the facility. The school complies with the prerequisite.

EQ Prerequisite 3: Minimum Acoustic Performance (Complies)

The previous versions of LEED do not include this prerequisite. These new requirements state that the background noise level in learning spaces must be less than 40 dBA and require exterior treatment for schools near noisy areas. The addition of the school must comply, but the original building falls under the historic preservation exception.

EQ Credit 1: Enhanced Indoor Air Quality Strategies (1/2 pts)

The purpose of this credit is improved indoor air quality for the occupants. The design does have CO2 sensors in each occupied space, but does not design 30% OA increase of the requirement to achieve the 2 points in this section.

EQ Credit 4: Indoor Air Quality Assessment (0/2 pts)

The purpose of this credit is to establish better quality indoor air in the building after construction and during occupancy. No documentation was found on air testing or air flush outs. This credit was not in the previous versions of LEED.

EQ Credit 5: Thermal Comfort (1/1 pts)

The school complies with ASHRAE 55-2010. The set points for temperature, humidity and ventilation follow that standard. The thermal comfort satisfies 80% of the occupants by having thermostats and occupancy sensors in each space controlling the individual space fan coil unit.

EQ Credit 9: Acoustical Performance (2/2 pts)

The purpose of this credit is to provide learning spaces that promote occupants' well-being, productivity, and communications through acoustic design. An acoustical consultant was hired and verified that the spaces do meet School LEED Ratings. The problem spaces do not affect LEED rating because they are not learning spaces.

Existing System Analysis

Energy Sources

Elementary School One's energy sources are electricity and natural gas. Electricity provides power to most of the building and the natural gas provides power to the two water heaters. Both of these energy sources come from the city provider. Table 11 summarizes the utility rates.

Table 11- Average Utility Rates

Energy Source	Average Rate
Electricity	$0.131/kWH
Natural Gas	$1.044/therm

Annual Energy Use

Elementary School One consumes 4,147,823 kBtu/yr, which can be seen in Table 12 and Figure 8. Most of the energy consumed by the building is due to the lights. School only operates during normal school hours and during extracurricular activities after hours. The energy consumed cannot be decreased much because of the lighting requirements of ASHRAE. The second largest energy usage is mechanical cooling at 31%, followed by heating at 22%. The building's yearly emissions can be seen in Table 13.

Figure 8: Energy Consumption Pie Chart

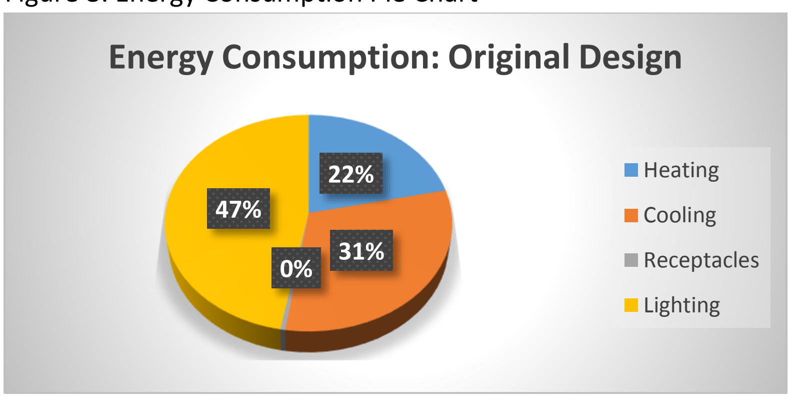


Table 12: Equipment energy consumption modeled in Trane.

	% 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

Table 13- Building Yearly Emissions

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

Mechanical System First Cost

The direct cost of construction is compared to the mechanical cost below in Table 14. The total mechanical cost for the entire project is $3,216,046, which is 16.5% of the total cost of construction. These costs are based on the values in 2010 when the school was built.

Table 14: Construction Cost Summary

		Estimated Direct Cost	Estimated Square Foot Cost	Percent of Construction
Existing Building Renovation (45,455 sqft)	Mechanical	$1,999,293	$43.98	10.3%
	Total	$7,963,236	$163.77	40.9%
New Addition (35,790 sqft)	Mechanical	$1,216,753	$34.00	6.25%
	Total	$11,517,383	$321.80	59.1%
Total Construction		$19,480,619	$239.78	100%

Proposal Overview

Alternatives Considered

Several ideas were considered for the redesign of the mechanical system of Elementary School One. During the decision process, many factors were considered including: construction cost, operating cost, maintainability, energy consumption and feasibility. The alternatives considered are listed below:

- Building Envelope Evaluation
  - Thermal Performance
  - Structural Impact
  - Architectural and Historic considerations
- Using chilled beam system instead of VRF system
- Changing VRF air-cooled to water-cooled
  - Ground coupled heat pump
- On-site renewable energy sources
  - Solar power
  - Wind power

The options considered have different impacts and feasibility due to the current system types and site location. Not all alternatives can be investigated because of time and information limitations. The alternative selected will have an impact on several disciplines and have educational value.

Proposed Alternatives

The following alternatives were chosen to compare cost and energy impact to the current design. Also, the alternatives were chosen for educational interest and benefit. The proposed investigations are not meant to imply faults in the original design, but are presented for the educational value. The semester schedule can be seen in Appendix C.

Depth

The proposed alternative that will be investigated is implementing a water-cooled VRF condenser looped with a heat exchanger to a ground coupled heat pump. This will change the VRF condensers from air-cooled to water–cooled. Heat exchangers will transfer the loads between the three condensing units and the ground coupled system. A closed loop ground coupled system has antifreeze and water mixture filled pipes that transfer loads between the building and the earth. The pipes will be in vertical wells to exchange heat with the constant temperature of the earth. The earth temperature becomes constant from 20 ft. to 30 ft. below the surface depending on the area and soil.

The alternative design will have an impact on the initial cost and energy consumption of the mechanical system. Water-cooled systems have higher initial cost, but are more energy efficient than air-cooled systems. The heat transfer properties of water are much better than those of air. The water-cooled has constant performance whereas with air-cooled the performance is dependent on the ambient air temperature. Also, the installation of the ground coupled system will be costly, but the system will be using a basically free energy sink, the earth.

Breadths

Construction

The construction of the ground coupled system will alter the coordination, schedule, cost, and site layout of the construction management team. An analysis of the impacts on coordination, schedule and cost will be performed. The geothermal system additional cost may include materials, installation, controls and more. The schedule may or may not be affected depending on the site coordination. These impacts will be investigated and evaluated throughout the construction process.

Acoustics

The spaces served by the packaged rooftop units, cafeteria and multi-purpose room, have not been acoustically addressed. These spaces are served by untreated ducts directly from the rooftop units and may produce high background noise levels. The high ceiling height and surface materials of the spaces may allow for poor acoustical characteristics such as reverberation time, absorption, and diffraction. An assessment of the spaces will be performed using software, and alternative solutions will be evaluated.

Masters Coursework

The integration of the ground coupled heat pump to the VRF system will involve knowledge gained from several master courses. Information learned in AE 557 (Centralized Cooling Production and Distribution Systems) will be used in the design and investigation of water-cooled condensers and ground coupled systems. AE 552 (Indoor Air Quality) content was used during the evaluation of current ventilation and mechanical systems. AE 557 (Centralized Heating Production and Distribution Systems) content will help in the energy consumption and life cycle cost analysis.

Tools and Methods

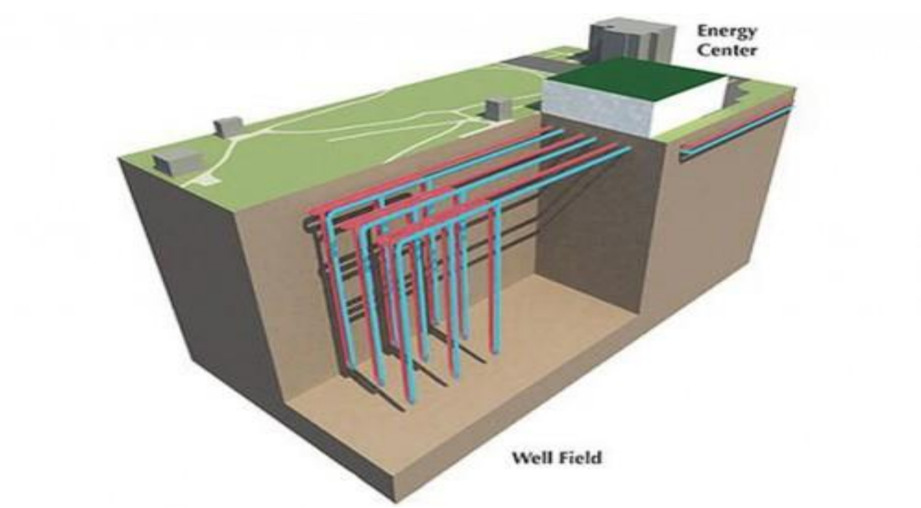
Load simulation and energy analysis will be done using Trace Trane 700, inputting the mechanical system, controls, site orientation, building envelope and materials. Trace Trane software was used to perform load and energy analysis of the current building state in Technical Report Two. There are limitations of input of mechanical systems and controls in the software which need to be accounted for in the conclusion. If time allows, other software will be used to perform the same analysis. The energy analysis will allow for the comparison of initial cost and long-term savings.

The acoustical analysis will be performed using the software Dynasonics AIM. The software input includes duct lengths, transitions, air velocity, and space properties. This will determine noise levels produced in the space compared to the recommended level. If software limitations are significant, then hand calculations can be done to conclude the analysis.

Proposal Analysis

Mechanical Investigation

The implementation of a ground coupled heat pump has many factors to balance to achieve the goal of meeting the building load. It must balance the efficiency of the system with material and labor costs. During the design process, a variety of options were investigated and one solution was chosen. The method of design was based on the ASHRAE Handbook.

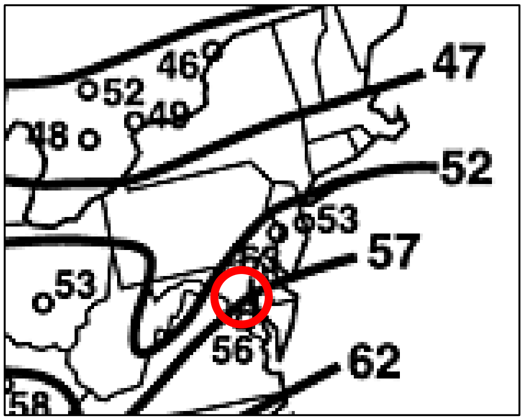


Courtesy of www.cleantechnica.com

Site Characteristics

The site characteristics that will affect the design of the ground coupled system are soil properties, material properties, ground temperature and site layout. Basing the design in the Baltimore area, Figure 11 shows the ground temperature at about 55°F. Figure 11 is a zoomed in region of the larger map found in Appendix D.

Figure 11-Ground Temperature Map (mean annual earth temperatures)



The soil type was obtained from the geotechnical report (Appendix D) from the actual site. The report shows that 30 ft deep is moist, very dense sand. The properties of this type of soil are found in a figure in Appendix XX. The summary of the soil properties can be seen in Table 15.

Table 15- Soil 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

Well Design

Next, the fluid, bore and pipe properties were determined. The fluid in the ground loop is water with 20% glycol to prevent freezing in the pipes that are closer to the surface. For the wells, 1 inch SDR 11 polyethylene U-tubes in 5in diameter bore were chosen. SDR 11 was chosen because it is one of the cheaper materials with the better thermal resistances. Grout is added around the U-tube to fill in the extra space in bore. The total bore thermal resistance is the U-tube resistance plus the grout resistance. In Table 16, the bore properties are shown.

Table 16- Well Properties

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

Calculating the needed length of well to meet the building cooling and heating loads was completed using the following two equations. These equations are a part of the method for geothermal heat pump design in the ASHRAE Handbook. In order to solve these equations, the variables must be solved for or obtained.

Equation 1: Required Bore Length for Cooling (ft)

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

Equation 2: Required Bore Length for Heating (ft)

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

The following equations are used to solve for the effective thermal resistance of the ground for annual pulse, monthly pulse and daily pulse. The values of the variables in the following equations are shown in Table 17 below.

Eq. 3: Time of Operation

$$\tau_1 = 3650 \text{ days}$$
$$\tau_2 = 3650 + 30 = 3680 \text{ days}$$
$$\tau_f = 3650 + 30 + 0.25 = 3680.25 \text{ days}$$

Eq. 4: Fourier Number

$$\mathrm{Fo}_f = 4\alpha\tau_f/d_b^2$$
$$\mathrm{Fo}_1 = 4\alpha(\tau_f - \tau_1)/d_b^2$$
$$\mathrm{Fo}_2 = 4\alpha(\tau_f - \tau_2)/d_b^2$$

Eq. 5: Thermal Resistance

$$R_{ga} = (G_f - G_1)/k_g$$
$$R_{gm} = (G_1 - G_2)/k_g$$
$$R_{gd} = G_2/k_g$$

Table 17- Thermal Resistance Calculation Variables

	Annual Pulse (1)	Monthly Pulse (2)	Daily Pulse (f)
Time of Operation (days)	3650	3680	3680.25
Diffusivity (ft^2/day)	0.91	0.91	0.91
Bore Diameter (ft)	0.42	0.42	0.42
Fourier Number, Fo	75,942	624	5.16
G-Factor	0.957	0.567	0.21
kg (Btu/h*ft*°F)	1.6	1.6	1.6
	Effective Thermal Resistance of the Ground (ft*hr*°F/Btu)		
	Rga	**Rgm**	**Rgd**
	0.2438	0.223	0.131

The ASHRAE Handbook recommends to start with the ground loop entering temperature for cooling to be 20°F above the ground temperature and for heating to be 10°F below the ground temperature. Using that recommendation as a starting point, temperatures were adjusted for the flows of both refrigerant and water sides of the heat exchanger. The ground loop temperatures for cooling mode are 74°F in and 83°F out of the heat exchanger. The temperatures for heating mode are 44°F in and 36°F out.

The required well length for the ground coupled heat pump is determined using Equations 1 and 2. The remaining variables needed to solve the equations are listed below with their assumptions.

- Power input at design cooling load (or heating) was determined by summing the electrical power to operate the ground loop itself.
- The net annual average heat transfer to the ground is estimated at 1/8th of the block load (6).
- The short circuit heat loss factor is 1.04 based on 3 gpm/ton and 1 bore per loop.
- The temperature penalty for interference of adjacent bores is 2°F due to the 15 ft spacing of the bores and the grid elongated pattern.

Table 18 below displays all the variable values that went into Equations 1 and 2. The result of the calculation is that 33,689 ft length is needed to deliver the 167.5 tons of cooling. The system will need 85 wells for 400 ft depth. The system base bore length is 201 ft per ton. The over estimation of cooling and heating load will allow the system to operate at this capacity long term if the ground temperature increases 20- 30 years from now.

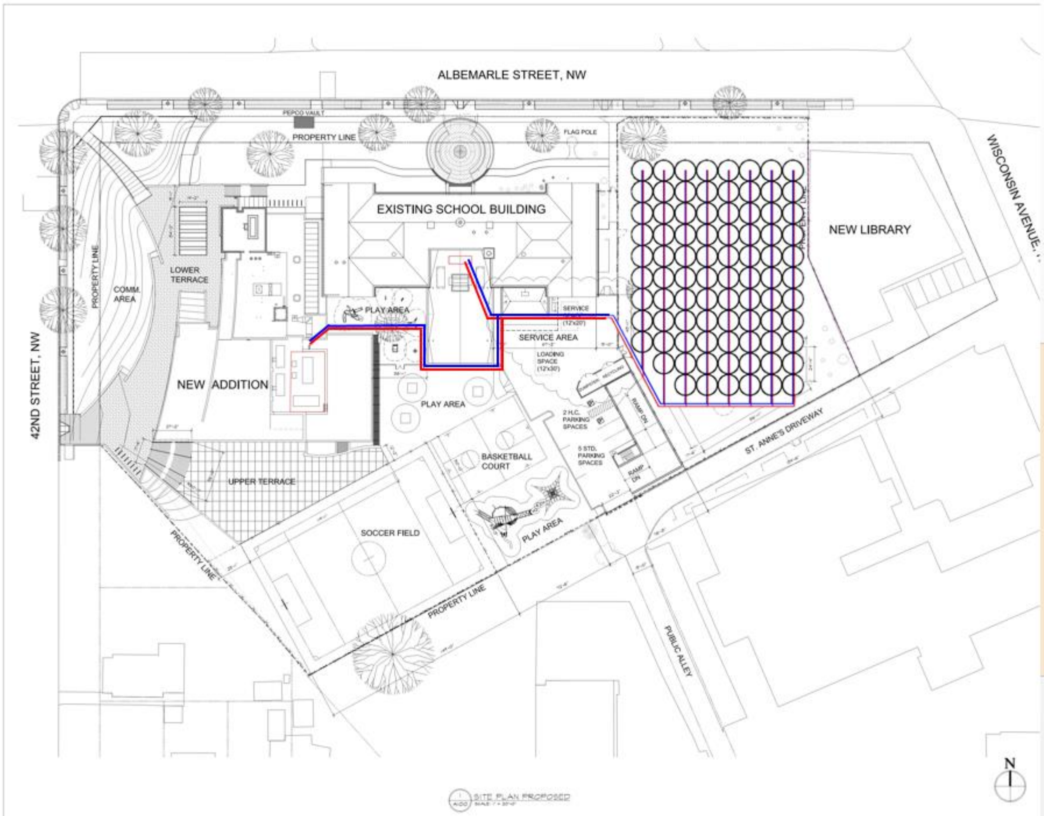
Table 18- Well Length Calculation

	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	

Ground Coupled Well Field Layout

Elementary School One’s biggest unoccupied field is the east field. The field area is 24,000 sqft and the area used by the well field is 19,125 sqft. The 85 wells are organized in 6 runs of 11 wells, 1 run of 10 wells and 1 run of 9 wells. The layout was due to the oddly shaped area. The main run has several turns to go around the underground garage and reach the rooftop units. In Figure 12, the piping layout shows a branch going to the existing building roof unit and another branch going around the cafeteria to the addition building roof units. The header pipes go from the field wells to the building mechanical room east of the cafeteria where the pump is located. The branch lines then go from the pump to the rooftop units.

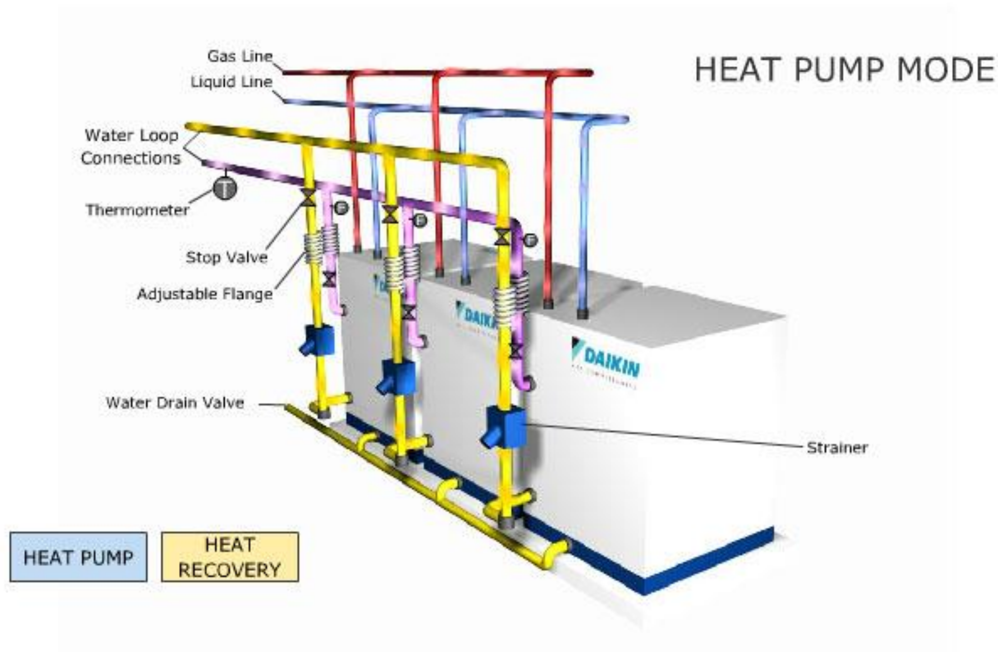
Figure 12- Well Field Layout



Mechanical Equipment

Water-Cooled VRF Units

The original design has three VRF air-cooled condensers with three separate VRF loops. Not changing the refrigerant side of the VRF system, water-cooled units must be selected to serve the three VRF systems. In order to achieve the capacity needed, several module heat pump units are going to replace the air-cooled condensers. Selecting from the Daikin series in Table 19, different combinations of these units are used to reach the loads. Table 20 shows the combination used to serve the VRF systems. The heat pump units will be arranged in parallel to maintain the effectiveness of the units. The layout of the CU-VRF-2 units is shown in Figure 13 (yellow lines are the unit clearances). The fluid properties about the heat exchanger are shown in Table 21.



Courtesy of www.daikin.com

Table 19- Heat Pump Unit Performance

	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

Table 20- Heat Pump Unit Combinations

	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

Figure 13- CU-VRF-2 Example Layout

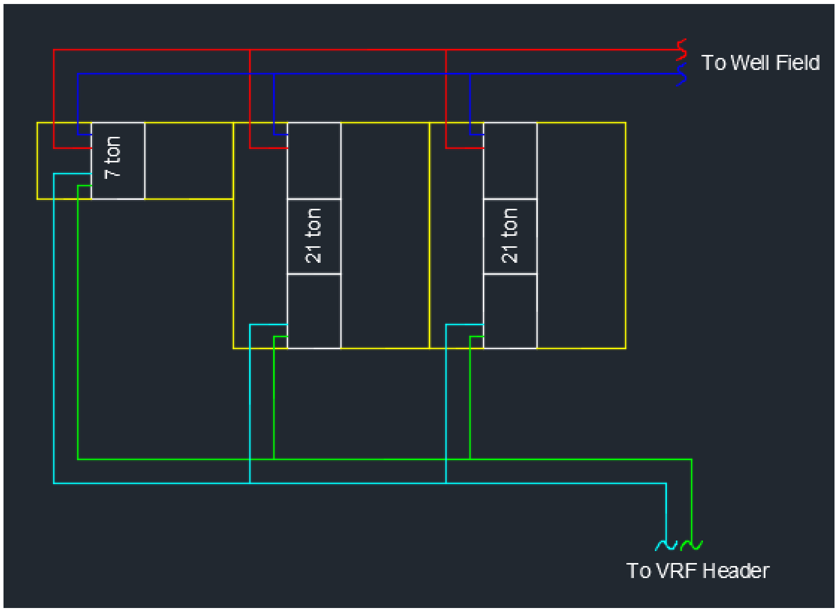


Table 21- Fluid Temperatures for the Heat Exchanger and Spaces

	Water			Refrigerant			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

Well Field Pump

The pump selection is based on flow rate, head loss, and efficiency. The flow rate is based on the ASHRAE recommended 3 gpm/ton, but the units selected above limit the water flow rate. The designed flow rate is 480 gpm, which gives 2.87 gpm/ton. The pump also was selected by the head loss of the ground coupled loop. The total head loss is summarized in Table 22 below. To meet the pump requirements, a 4x4x7 in-line mounted centrifugal pump was selected. The pump curve, Figure 14, was used to pick the most efficient pump for the given parameters. The selected pump characteristics are shown in Table 23.

Table 22- Head Loss

Friction Loss	6.8 ft
Fixture Loss	109 ft
Velocity Loss	0.4 ft
Total head loss	116.2 ft

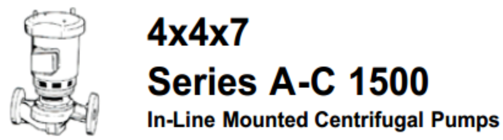


Figure 14- Pump Curve

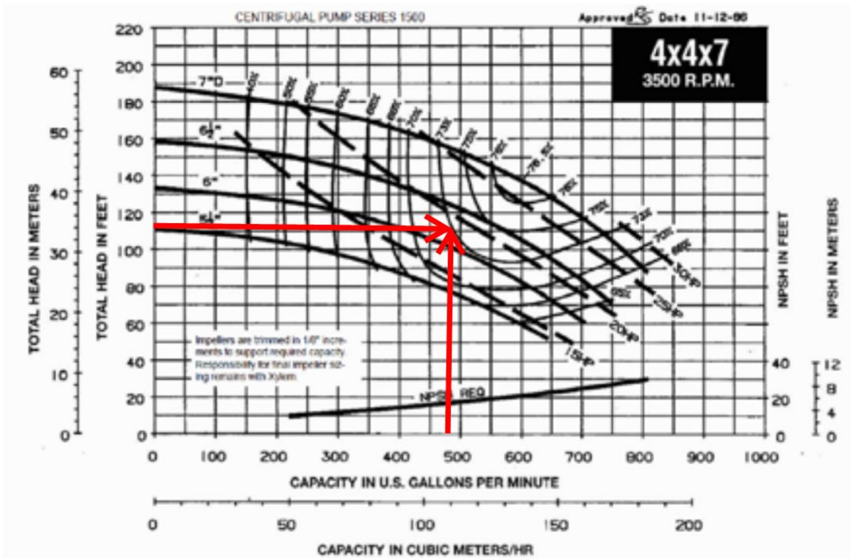


Table 23- Pump Characteristics

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

LEED Improvements

The alternative design would receive 10 points compared to the original design. EA Credit 2: optimize Energy Performance improved from 19.4% to 36.6% earning the school 14/16 pts. EA Credit 5: Renewable Energy Production improved from 0/3 pts to 3/3 pts due to the renewable energy produced from the ground coupled heat pump.

Energy and Cost Evaluation

Energy Comparison

The alternative system was proposed to improve the mechanical system's energy consumption and emissions. The original and alternative designs were modeled in Trace 700. During the making of the model, limitations were found with the program's modeling capability. Trace could model the cooling mode of the ground coupled heat pump, but could not model the heating mode directly. A combination of modeling and hand calculations were used to determine the heating capacity of the ground coupled heat pump system.

The operation schedule was assumed to be 8 am to 5 pm during the weekdays only. The cooling mode operated from April through October, 7 months. The heating mode operated from November through March, 5 months. The ground coupled heat pump was sized to meet both cooling and heating loads of the building. The heating load of the building will not change with the change of system, only the energy the system uses to meet that same load. The calculated heating energy savings for the ground coupled heat pump was the heat load minus the pump energy. The yearly building energy consumption for each system is in Table 24 and Table 25. The yearly energy savings of the alternative compared to the original is $35,431.19 (Table 26). The decrease in energy consumption is due to the use of a renewable energy source, the earth. The original, air-cooled system used fan energy to transfer the heat to the air. Air-cooled systems are not as efficient as water-cooled because water has a better heat transfer coefficient. Also, efficiency of the air-cooled depends on the air temperature, which changes greatly during the year compared to the nearly constant temperature of the ground.

Table 24- Original Yearly Energy Consumption

	Building	**Building**	**Source**
	kWh	kBtu/yr	kBtu/yr
Heating	262,015	894,258	2,683,041
Cooling	374,307	1,277,511	3,832,916
Lighting	572,805	1,954,985	5,865,541
Receptacle	6,173	21,069	63,213
Total	1,215,300	4,147,823	12,444,711
Cost	**$166,496.09**		

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**		

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**

The alternative design building energy consumption breakdown is shown in Figure 15. The biggest consumption of energy is the building lighting at 60%. Lighting energy is hard to reduce because there is a minimum watt/sqft requirement for different types of spaces. The next largest energy consumer is cooling at 20%, followed by heating at 19%. The monthly energy consumption comparison can be seen in Figure 16. During cooling months, the average energy reduction is 81%. During the heating months, the average reduction of energy used is 89%. The environmental impact of emissions is a very important concern with new construction. The reduction of the alternative design is 21.3% (Table 27), which will improve the LEED score and could have government incentives. The original building emissions and energy usage were very good compared to most buildings, but the reduction of the alternative design made a big improvement.

Figure 15- Pie Chart of Building Energy Consumption

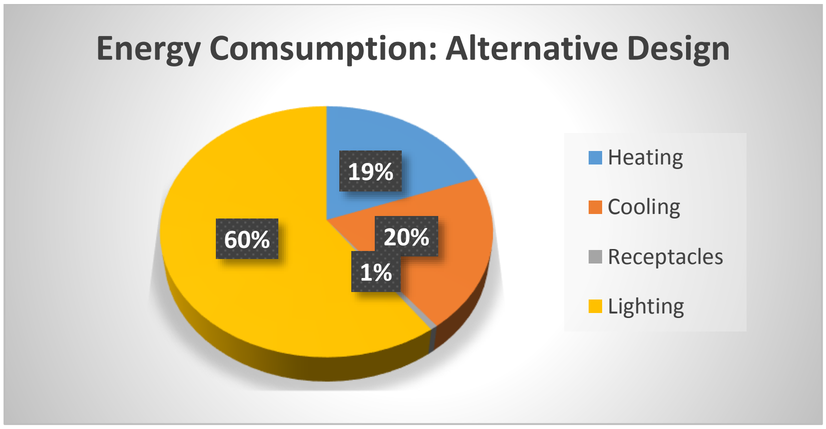


Figure 16- Monthly Energy Consumption Comparison

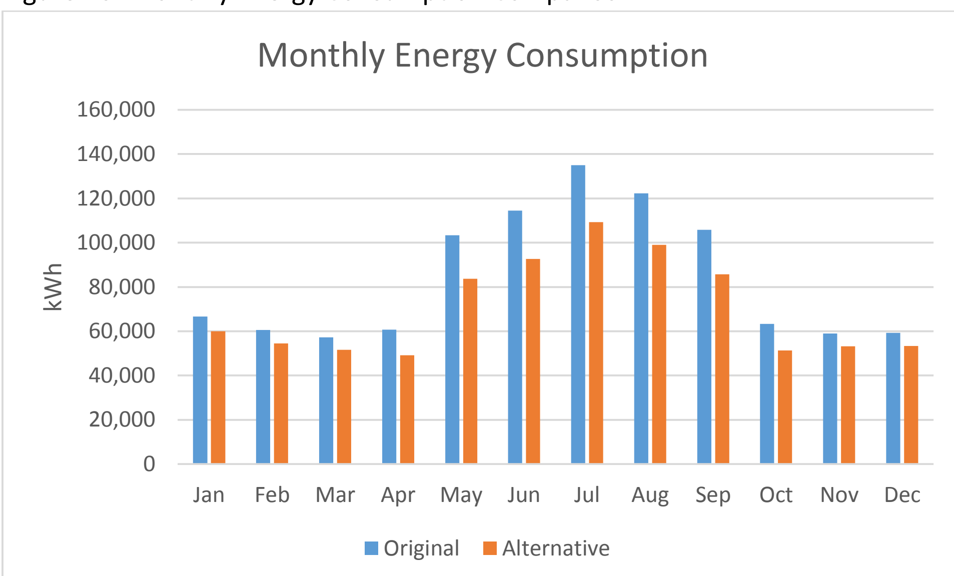


Table 27- Environmental Emissions Impact Comparison

	CO_2 (lbm/year)	SO_2 (gm/year)	NO_x (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
Reduction	21.29%	21.29%	21.29%

Cost Comparison

The alternative design has a very high initial cost compared to the original system. A ground coupled initial cost is significant due to the material for 85x 400ft wells and the labor to drill the bores. Owners who will have the building for a long period of time, like a school district, can see the long term benefit of installing such an expensive system. The cost of the original system and the cost of the alternative system are shown in Table 28. The difference in initial cost is $566,215.69 with the 10% Federal Rebate. The qualifications for the Federal Rebate is that a closed loop system must have an EER ≥ 14.1 and a COP ≥ 3.3. All of the heat pump units selected meet this requirement which allows the school to apply for the 10% rebate. The initial cost is a big difference, but the payback period is 15.98 years. Without the Federal Rebate, the payback period would be 19.53 years, which is still worth the initial investment for a long term owner like a school district.

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

Proposed Alternative Conclusion

Construction Breadth

A cost, site, and schedule investigation was done to determine the impacts on the construction of the ground coupled heat pump. Original building cost from 2010 was corrected with inflation to compare the cost impacts for construction in 2015. The original construction schedule was not available, but the impact of the added work was analyzed.

Cost Analysis

The cost of material and labor of the original system parts is $56,348. This price only includes the material and labor that was removed from the original design. The cost of material and labor of the alternative system is $692,071. The cost breakdown of material and labor for both systems is shown in Table 29. The initial cost difference of the systems is $635,723. The federal rebate for geothermal systems is 10% if the system meets the requirements. When the rebate is included in the initial cost, the system price difference is $566,215.69. The total cost of construction of the building in 2015 can be seen in Table 30. Mechanical cost increased the total cost of the building by 1.67%. In relations to the overall mechanical system cost, the increase of the alternative system is relatively reasonable. This could have allowed the school district to be convinced to increase the budget to provide for the alternative system.

Table 29- Construction Cost Breakdown

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**

Table 30- Total Construction Cost

	Original Design	**Alternative Design**
Mechanical	$3,461,864	$3,889,965
Total Construction	$20,969,617	$21,397,718
Percent Mechanical	16.51%	18.18%

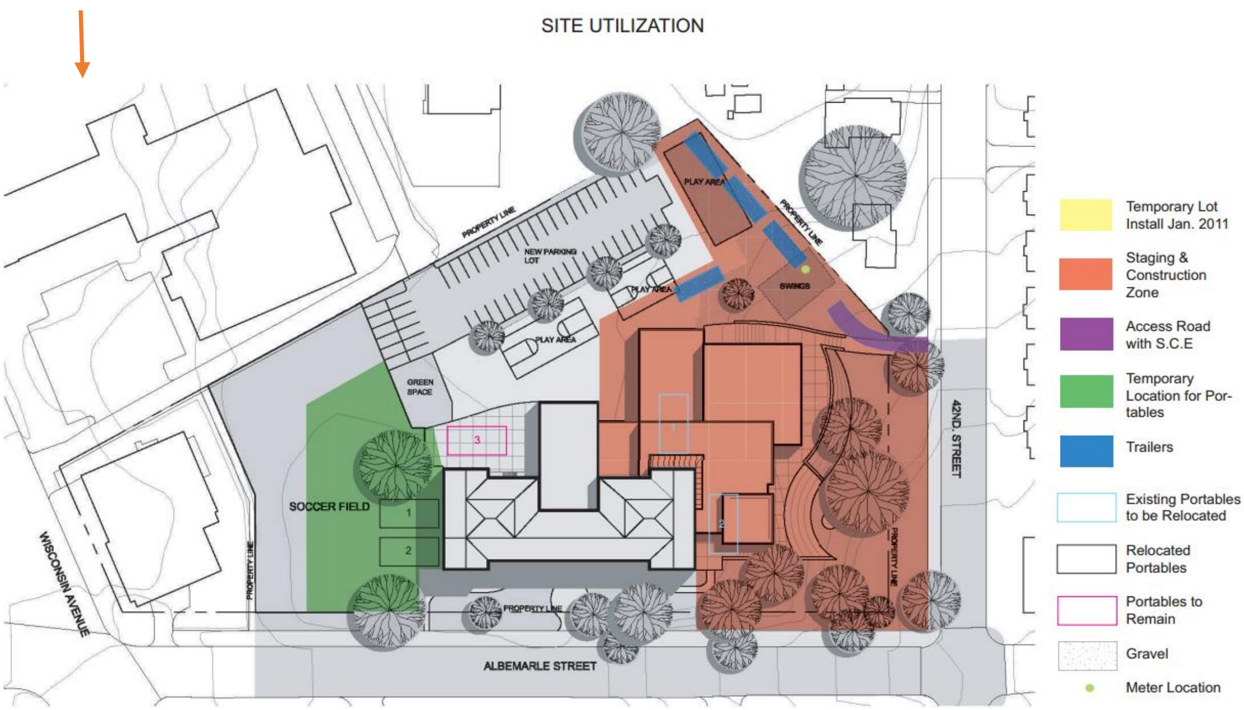
Schedule Impact

The ground coupled heat pump system will take approximately 90 days to install. The changes made to the original system were replacing the air-cooled units with water-cooled units. The original units took about 10 days to install the units, connections and controls. The alternative system will take about 90 days to install the pumps, units, pipes, fittings and wells. The 80 day difference should not affect the original schedule much because the east field is mostly not used during construction. The biggest impact on the schedule will be the excavation and installation of the pipes going to the rooftop heat pumps. That impact could push back the schedule by 5 days.

Site Impact

The original site layout has the temporary location of portables on the east field (soccer field), but this is where the ground coupled heat pump is going to be installed. Relocating the portables to the parking lot area will affect the original schedule by a maximum of 25 days. The drilling rig will need the area labeled 1 and 2 in Figure 17, to drill 24 wells. The drilling rig will have enough room to install the other 61 wells with the portables in the designated area.

Figure 17- Site Layout



Acoustical Breath

The spaces served by the packaged rooftop units, cafeteria and multi-purpose room have not been acoustically addressed. These spaces are served by untreated ducts directly from the rooftop units and may produce high background noise levels. The high ceiling height and surface materials of the spaces may allow for poor acoustical characteristics such as reverberation time, absorption, and diffraction. Using Dynasonics Software, an examination was done and an acoustical solution was found for both spaces.

Multipurpose Room

The multipurpose room is used as a gymnasium and auditorium. RTU-6 and RTU-7 condition the space and are located on the adjacent roof. The duct and diffuser layout can be seen in Figure 18. During the beginning of operation, occupants noticed the units produced a lot of noise and it was not comfortable to be in the space. When the original design was analyzed the noise criteria was NC- >65 (Figure 19) and the goal is to be NC-45. After implementing various acoustical treats, a solution was found. Adding 2 in duct lining to the ducts (total length 60 ft each) and a duct silencer to each unit's duct, the noise criteria dropped to NC-39 (Figure 20). The cost of the 2 in duct lining for material and labor is $11,457. The cost of the two duct silencers for material and labor is $4,700. The total cost of the acoustical treatment is $16,157. This cost is necessary for people to be comfortable in the space.

Figure 18- Multipurpose Room Mechanical Layout

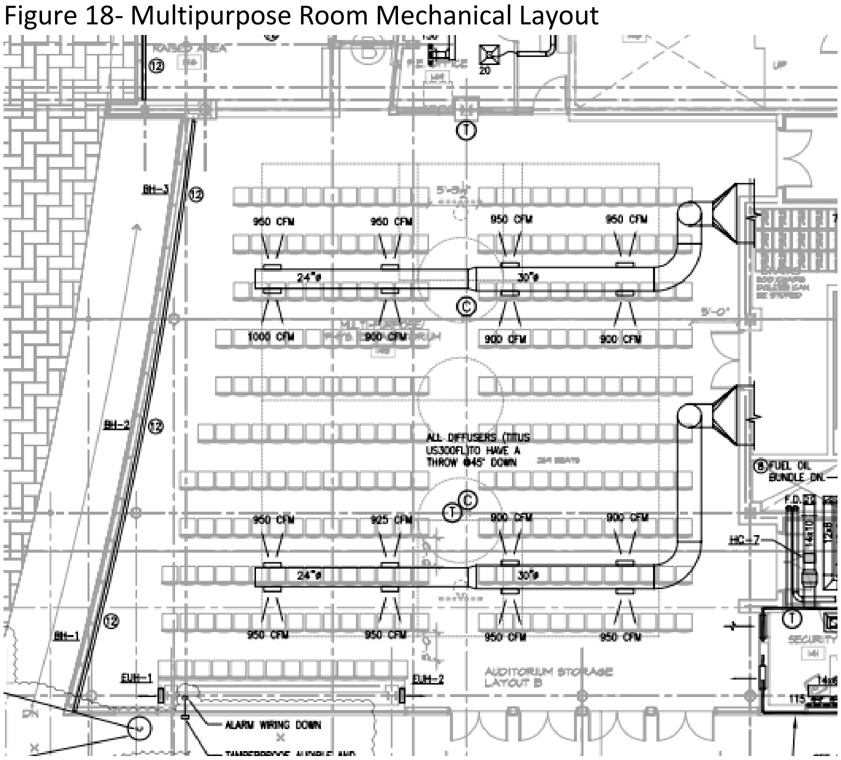


Figure 19- NC of Multipurpose Room before treatment

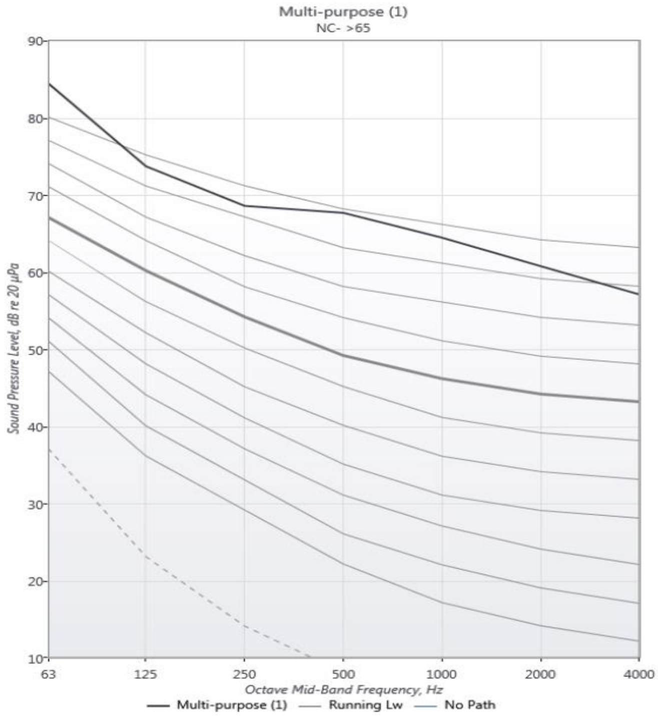
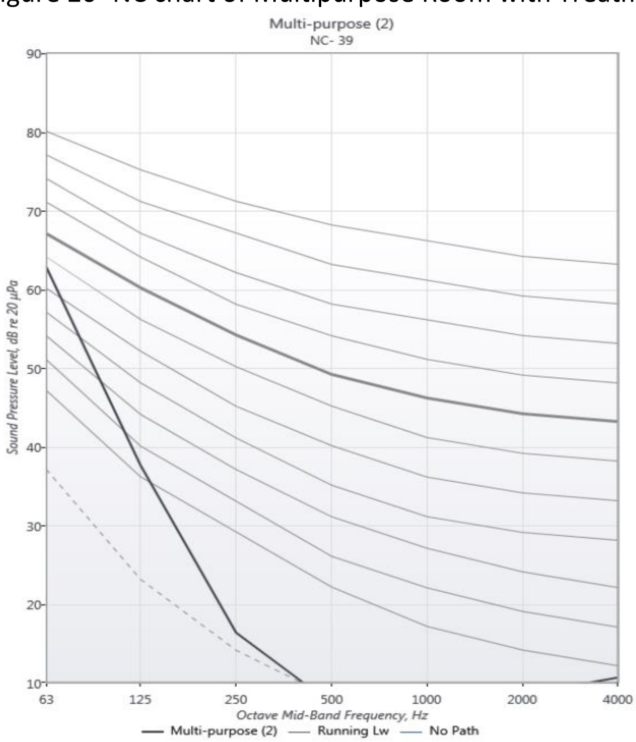


Figure 20- NC chart of Multipurpose Room with Treatment



Cafeteria

The cafeteria has RTU-1, and RTU-2 conditioning the space. The units are located on the cafeteria roof on the north end. The original design noise criteria is NC-52(Figure 22), which is very close to the NC-45 criteria. Adding a duct silencer to each unit's duct drops the noise to NC-41(Figure 23) meeting the goal. The cost of the two duct silencers is $4,000. The acoustical treatment is not nessary because it is not a learning space. It would be up to the owner/budget to implent the cafeteria treatment since without treatment the NC-52 is acceptable for the type of space.

Figure 21- Cafeteria Mechancial Layout

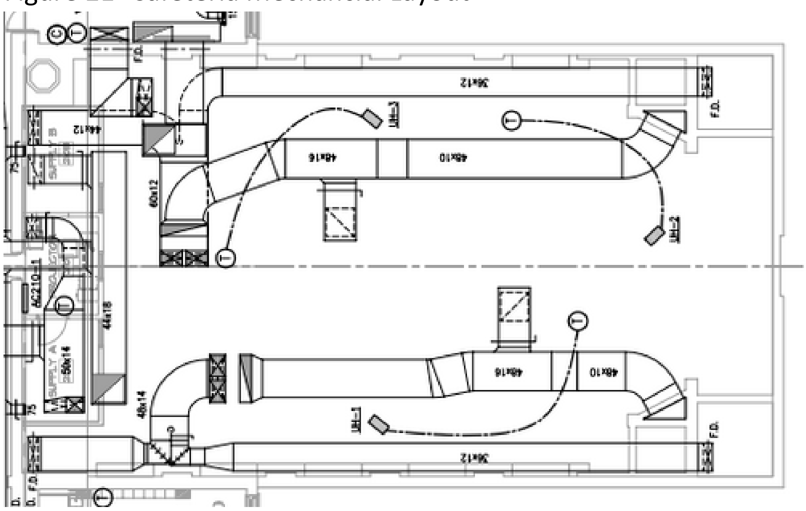


Figure 22- NC chart Cafeteria before treatment

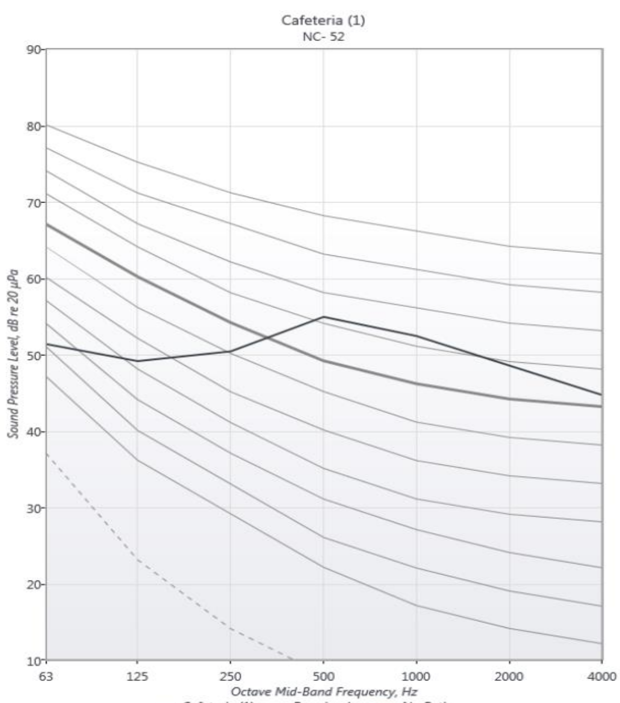
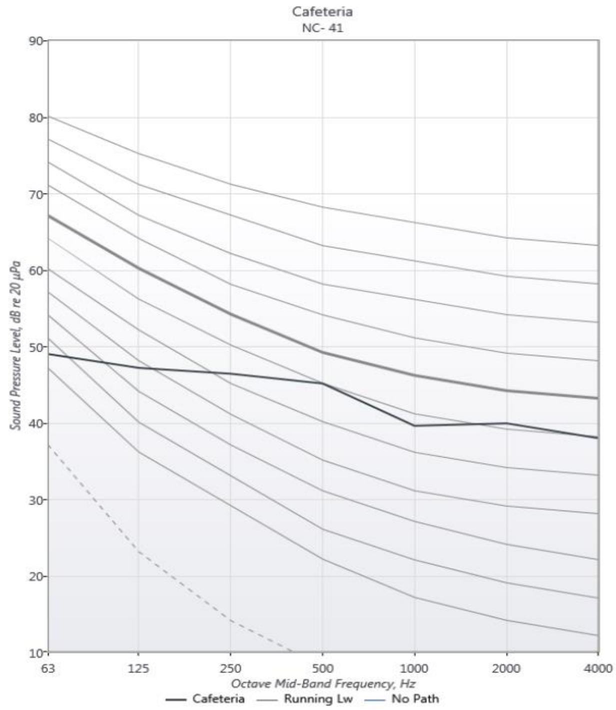


Figure 23- NC chart Cafeteria with treatment



Overall Proposed Alternative Evaluation

The main goals of Elementary School One modernization were to expand for more classrooms and improve comfort to allow for better learning while being energy efficient. One of the main difficulties in the design is to balance energy efficiency and initial cost of construction. The building's mechanical system provides comfortable learning spaces while meeting requirements of ventilation and conditioning.

Elementary School One's original design in 2010 received LEED for Schools 2007 Gold Certification. The original design is very energy efficient. The DOAS rooftop units combined with the VRF system provides thermal and acoustical comfort to the learning spaces. The combination of systems makes for a very energy efficient mechanical system.

The alternative design looks to improve on this great design. The alternative design changed the air-cooled VRF condensers with water-cooled units with ground coupled heat pump. A ground coupled heat pump will reduce visual and noise pollution. Also, the heat pump can reduce maintenance and operation cost. The initial cost of the ground coupled heat pump is much greater than the original design. The system initial cost difference is $566,215.69 with the 10% Federal Rebate. The yearly energy consumption reduction is $35,431.19 with 21% reduction in emissions. The payback period of the alternative system is 15.98 years.

Overall, the alternative mechanical system is recommended for Elementary School One, especially because the school district is a long-term owner. The payback period allows the investment in the system to pay off relatively quickly. The ground coupled heat pump reduces energy consumption, emissions and improves the efficiency and LEED points.

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Appendix

Appendix A

ASHRAE 62.1 Section 6 Ventilation Calculations

Existing Building

ASHRAE 62.1 2013 Section 6- Ventialtion Rate													
Existing Rooms		Designed Calculations			Ventilation Rate Factor								
Floor	Room	Area (sf)	# of People	Min OA (cfm)	Space Type	Rp	Occupant Density	Pz	Ra	Az	Required OA	Meets ASHRAE	Difference
1st	Cafeteria	3550	249	4980	Multiuse	7.5	100	355	0.06	3550	2876	YES	
1st	RM 123	210	2	40	Office	5	5	1	0.06	210	18	YES	
1st	RM 124	201	2	40	Office	5	5	1	0.06	201	17	YES	
1st	RM 101	780	30	450	Class	10	35	27	0.12	780	367	YES	
1st	RM 102	623	30	450	Class	10	35	22	0.12	623	293	YES	
1st	RM 125	294	3	60	Office	5	5	1	0.06	294	25	YES	
1st	CORR	1861	0	186	Corridor	0	0	0	0.06	1861	112	YES	
1st	RM 132	647	30	450	Class	10	35	23	0.12	647	304	YES	
1st	RM 133	688	30	450	Class	10	35	24	0.12	688	323	YES	
2nd	CONF	200	10	200	Conference	5	50	10	0.06	200	62	YES	
2nd	RM 201	706	30	450	Class	10	35	25	0.12	706	332	YES	
2nd	RM 202	706	30	450	Class	10	35	25	0.12	706	332	YES	
2nd	RM 203	494	4	80	Office	5	5	2	0.06	494	42	YES	
2nd	RM204	704	30	450	Class	10	35	25	0.12	704	331	YES	
2nd	RM 205	704	30	450	Class	10	35	25	0.12	704	331	YES	
2nd	CORR	1884	0	188	Corridor	0	0	0	0.06	1884	113	YES	
2nd	RM 208	704	30	450	Class	10	35	25	0.12	704	331	YES	
2nd	RM 209	704	30	450	Class	10	35	25	0.12	704	331	YES	
2nd	RM 211	707	30	450	Class	10	35	25	0.12	707	332	YES	
2nd	RM 212	706	30	450	Class	10	35	25	0.12	706	332	YES	
3rd	RM 301	706	30	450	Class	10	35	25	0.12	706	332	YES	
3rd	RM 302	708	30	450	Class	10	35	25	0.12	708	333	YES	
3rd	RM 303	940	30	450	Class	10	35	33	0.12	940	442	YES	
3rd	RM 304	703	30	450	Class	10	35	25	0.12	703	330	YES	
3rd	RM 305	704	30	450	Class	10	35	25	0.12	704	331	YES	
3rd	RM 307	700	30	450	Class	10	35	25	0.12	700	329	YES	
3rd	RM 308	705	30	450	Class	10	35	25	0.12	705	331	YES	
3rd	RM 309	707	30	450	Class	10	35	25	0.12	707	332	YES	
3rd	RM 310	706	30	450	Class	10	35	25	0.12	706	332	YES	
3rd	CORR	2004	0	200	Corridor	0	0	0	0.06	2004	120	YES	

Building Addition

ASHRAE 62.1 2013 Section 6- Ventialtion Rate													
Addition Rooms		Designed Calculations			Ventilation Rate Factor								
Floor	Room	Area (sf)	# of People	Min OA (cfm)	Space Type	Rp	Occupant Density	Pz	Ra	Az	Required OA	Meets ASHRAE	Difference
1st	AFT 136	203	2	40	Office	5	5	1	0.06	203	17	YES	
1st	ART LAB 135	1016	30	450	Art Class	10	20	20	0.18	1016	386	YES	
1st	CORR 144	2810	0	281	Corridor	0	0	0	0.06	2810	169	YES	
1st	PE OFFICE149	280	2	40	Office	5	5	1	0.06	280	24	YES	
1st	PK CLASS 137	1007	30	450	Class PK	10	25	25	0.12	1007	373	YES	
1st	PK CLASS 138	1007	30	450	Class PK	10	25	25	0.12	1007	373	YES	
1st	PK CLASS 139	1007	30	450	Class PK	10	25	25	0.12	1007	373	YES	
1st	STORAGE 147	128	0	19	Storage	5	2	0	0.06	128	9	YES	
1st	TEACHER 152	548	4	80	Office	5	5	3	0.06	548	47	YES	
1st	SECURITY 141	97	1	20	Office	5	5	0	0.06	97	8	YES	
1st	MULTIPURPOSE	4015	269	4035	Multiuse	7.5	100	402	0.06	4015	3252	YES	
2nd	SPEECH 230	132	1	20	Office	5	5	1	0.06	132	11	YES	
2nd	ASSIST 233	191	2	40	Office	5	5	1	0.06	191	16	YES	
2nd	CORR 216	940	0	94	Corridor	0	0	0	0.06	940	56	YES	
2nd	ESL 234	132	1	20	Office	5	5	1	0.06	132	11	YES	
2nd	PSYCH	156	2	40	Office	5	5	1	0.06	156	13	YES	
2nd	RES 213	263	2	40	Office	5	5	1	0.06	263	22	YES	
2nd	RES 214	251	2	40	Office	5	5	1	0.06	251	21	YES	
2nd	SOCIAL 229	135	1	20	Office	5	5	1	0.06	135	11	YES	
2nd	STAFF LOUGE 217	746	22	440	Breakroom	5	50	37	0.12	746	276	YES	
2nd	STUDENT SERV 23	350	3	60	Office	5	5	2	0.06	350	30	YES	
2nd	TEACHER 228	380	3	60	Office	5	5	2	0.06	380	32	YES	
3rd	BOOK STOR 314	501	0	75	Storage	5	2	1	0.06	501	35	YES	
3rd	CONF 326	150	8	160	Conference	5	50	8	0.06	150	47	YES	
3rd	CORR 327	935	0	94	Corridor	0	0	0	0.06	935	56	YES	
3rd	MUSIC 325	1240	30	450	Music	10	35	43	0.06	1240	508	NO	58.4
3rd	RES 312	251	2	40	Office	5	5	1	0.06	251	21	YES	
3rd	STORAGE 324	235	0	35	Storage	5	2	0	0.06	235	16	YES	
Basemen	AV CLOSET L17	198	2	40	Storage	5	2	0	0.06	198	14	YES	
Basemen	BOOK STOR L13	500	0	75	Storage	5	2	1	0.06	500	35	YES	
Basemen	CONF L20	180	6	120	Conferenc	5	50	9	0.06	180	56	YES	
Basemen	CONF L33	300	10	200	Conferenc	5	50	15	0.06	300	93	YES	
Basemen	CORR L07	1100	0	110	Corridor	0	0	0	0.06	1100	66	YES	
Basemen	CUST L31	337	3	45	Storage	5	2	1	0.06	337	24	YES	
Basemen	HEAD END L19	110	1	20	Storage	5	2	0	0.06	110	8	YES	
Basemen	MEDIA L18A	514	4	80	Office	5	5	3	0.06	514	44	YES	
Basemen	OFFICE L23	320	3	45	Office	5	5	2	0.06	320	27	YES	
Basemen	READING RM L21	3110	63	945	Libraries	5	10	31	0.12	3110	529	YES	
Basemen	STORAGE L32	303	0	45	Storage	5	2	1	0.06	303	21	YES	
Basemen	SCIENCE L01	1205	30	450	Class	10	35	42	0.12	1205	566	NO	116.35

Appendix B

ASHRAE Requirements

TABLE 6.8.1-1 Electrically Operated Unitary Air Conditioners and Condensing Units—Minimum Efficiency Requirements

Equipment Type	Size Category	Heating Section Type	Subcategory or Rating Condition	Minimum Efficiency	Test Procedure[a]
Air conditioners, air cooled	<65,000 Btu/h[b]	All	Split system	13.0 SEER	AHRI 210/240
			Single package	13.0 SEER (before 1/20/15) 14 SEER (as of 1/1/2015)	
Through the wall, air cooled	≤30,000 Btu/h[b]	All	Split system	12.0 SEER	
			Single package	12.0 SEER	
Small duct high velocity, air cooled	<65,000 Btu/h[b]	All	Split System	11.0 SEER	
Air conditioners, air cooled	≥65,000 Btu/h and <135,000 Btu/h	Electric resistance (or none)	Split system and single package	11.2 EER 11.4 IEER (before 1/1/2016) 12.9 IEER (as of 1/1/2016)	AHRI 340/360
		All other	Split system and single package	11.0 EER 11.2 IEER (before 1/1/2016) 12.7 IEER (as of 1/1/2016)	
	≥135,000 Btu/h and <240,000 Btu/h	Electric resistance (or none)	Split system and single package	11.0 EER 11.2 IEER (before 1/1/2016) 12.4 IEER (as of 1/1/2016)	
		All other	Split system and single package	10.8 EER 11.0 IEER (before 1/1/2016) 12.2 IEER (as of 1/1/2016)	
	≥240,000 Btu/h and <760,000 Btu/h	Electric resistance (or none)	Split system and single package	10.0 EER 10.1 IEER (before 1/1/2016) 11.6 IEER (as of 1/1/2016)	
		All other	Split system and single package	9.8 EER 9.9 IEER (before 1/1/2016) 11.4 IEER (as of 1/1/2016)	
	≥760,000 Btu/h	Electric resistance (or none)	Split system and single package	9.7 EER 9.8 IEER (before 1/1/2016) 11.2 IEER (as of 1/1/2016)	
		All other	Split system and single package	9.5 EER 9.6 IEER (before 1/1/2016) 11.0 IEER (as of 1/1/2016)	

a. Section 12 contains a complete specification of the referenced test procedure, including the referenced year version of the test procedure.
b. Single-phase, air-cooled air conditioners <65,000 Btu/h are regulated by NAECA. SEER values are those set by NAECA.

ANSI/ASHRAE/IES Standard 90.1-2013 (I-P Edition) 63

TABLE 6.8.1-6 Gas- and Oil-Fired Boilers—Minimum Efficiency Requirements

Equipment Type[a]	Subcategory or Rating Condition	Size Category (Input)	Minimum Efficiency	Efficiency as of 3/2/2020	Test Procedure
Boilers, hot water	Gas fired	<300,000 Btu/h[f,g]	82% AFUE	82% AFUE	10 CFR Part 430
		≥300,000 Btu/h and ≤2,500,000 Btu/h[d]	80% E_t	80% E_t	10 CFR Part 431
		>2,500,000 Btu/h[a]	82% E_c	82% E_c	
	Oil fired[e]	<300,000 Btu/h[g]	84% AFUE	84% AFUE	10 CFR Part 430
		≥300,000 Btu/h and ≤2,500,000 Btu/h[d]	82% E_t	82% E_t	10 CFR Part 431
		>2,500,000 Btu/h[a]	84% E_c	84% E_c	
Boilers, steam	Gas fired	<300,000 Btu/h[f]	80% AFUE	80% AFUE	10 CFR Part 430
	Gas fired—all, except natural draft	≥300,000 Btu/h and ≤2,500,000 Btu/h[d]	79% E_t	79% E_t	10 CFR Part 431
		>2,500,000 Btu/h[a]	79% E_t	79% E_t	
	Gas fired—natural draft	≥300,000 Btu/h and ≤2,500,000 Btu/h[d]	77% E_t	79% E_t	
		>2,500,000 Btu/h[a]	77% E_t	79% E_t	
	Oil fired[e]	<300,000 Btu/h	82% AFUE	82% AFUE	10 CFR Part 430
		≥300,000 Btu/h and ≤2,500,000 Btu/h[d]	81% E_t	81% E_t	10 CFR Part 431
		>2,500,000 Btu/h[a]	81% E_t	81% E_t	

a. These requirements apply to boilers with rated input of 8,000,000 Btu/h or less that are not packaged boilers and to all packaged boilers. Minimum efficiency requirements for boilers cover all capacities of packaged boilers.
b. E_c = combustion efficiency (100% less flue losses). See reference document for detailed information.
c. E_t = thermal efficiency. See reference document for detailed information.
d. Maximum capacity—minimum and maximum ratings as provided for and allowed by the unit's controls.
e. Includes oil-fired (residual).
f. Boilers shall not be equipped with a constant burning pilot light.
g. A boiler not equipped with a tankless domestic water heating coil shall be equipped with an automatic means for adjusting the temperature of the water such that an incremental change in inferred heat load produces a corresponding incremental change in the temperature of the water supplied.

TABLE 6.8.1-9 Electrically Operated Variable-Refrigerant-Flow Air Conditioners—Minimum Efficiency Requirements

Equipment Type	Size Category	Heating Section Type	Subcategory or Rating Condition	Minimum Efficiency	Test Procedure
VRF air conditioners, air cooled	<65,000 Btu/h	All	VRF multisplit system	13.0 SEER	AHRI 1230
	≥65,000 Btu/h and <135,000 Btu/h	Electric resistance (or none)	VRF multisplit system	11.2 EER 12.5 IEER	
	≥135,000 Btu/h and <240,000 Btu/h	Electric resistance (or none)	VRF multisplit system	11.0 EER 12.3 IEER	
	≥240,000 Btu/h	Electric resistance (or none)	VRF multisplit system	10.0 EER 11.1 IEER	

TABLE 6.8.1-10 Electrically Operated Variable-Refrigerant-Flow Air-to-Air and Applied Heat Pumps—Minimum Efficiency Requirements

Equipment Type	Size Category	Heating Section Type	Subcategory or Rating Condition	Minimum Efficiency	Test Procedure
VRF air cooled (cooling mode)	<65,000 Btu/h	All	VRF multisplit system	13.0 SEER	AHRI 1230
	≥65,000 Btu/h and <135,000 Btu/h	Electric resistance (or none)	VRF multisplit system	11.0 EER 12.3 IEER	
	≥65,000 Btu/h and <135,000 Btu/h	Electric resistance (or none)	VRF multisplit system with heat recovery	10.8 EER 12.1 IEER	
	≥135,000 Btu/h and <240,000 Btu/h	Electric resistance (or none)	VRF multisplit system	10.6 EER 11.8 IEER	
	≥135,000 Btu/h and <240,000 Btu/h	Electric resistance (or none)	VRF multisplit system with heat recovery	10.4 EER 11.6 IEER	
	≥240,000 Btu/h	Electric resistance (or none)	VRF multisplit system	9.5 EER 10.6 IEER	
	≥240,000 Btu/h	Electric resistance (or none)	VRF multisplit system with heat recovery	9.3 EER 10.4 IEER	
VRF water source (cooling mode)	<65,000 Btu/h	All	VRF multisplit systems 86°F entering water	12.0 EER	AHRI 1230
	<65,000 Btu/h	All	VRF multisplit systems with heat recovery 86°F entering water	11.8 EER	
	≥65,000 Btu/h and <135,000 Btu/h	All	VRF multisplit system 86°F entering water	12.0 EER	
	≥65,000 Btu/h and <135,000 Btu/h	All	VRF multisplit system with heat recovery 86°F entering water	11.8 EER	
	≥135,000 Btu/h	All	VRF multisplit system 86°F entering water	10.0 EER	
	≥135,000 Btu/h	All	VRF multisplit system with heat recovery 86°F entering water	9.8 EER	
VRF groundwater source (cooling mode)	<135,000 Btu/h	All	VRF multisplit system 59°F entering water	16.2 EER	AHRI 1230
	<135,000 Btu/h	All	VRF multisplit system with heat recovery 59°F entering water	16.0 EER	
	≥135,000 Btu/h	All	VRF multisplit system 59°F entering water	13.8 EER	
	≥135,000 Btu/h	All	VRF multisplit system with heat recovery 59°F entering water	13.6 EER	

TABLE 6.8.2-2 Minimum Duct Insulation R-Value,[a] Combined Heating and Cooling Supply Ducts and Return Ducts

Climate Zone	Duct Location						
	Exterior	Ventilated Attic	Unvented Attic Above Insulated Ceiling	Unvented Attic with Roof Insulation[a]	Unconditioned Space[b]	Indirectly Conditioned Space[c]	Buried
Supply Ducts							
1	R-6	R-6	R-8	R-3.5	R-3.5	None	R-3.5
2	R-6	R-6	R-6	R-3.5	R-3.5	None	R-3.5
3	R-6	R-6	R-6	R-3.5	R-3.5	None	R-3.5
4	R-6	R-6	R-6	R-3.5	R-3.5	None	R-3.5
5	R-6	R-6	R-6	R-1.9	R-3.5	None	R-3.5
6	R-8	R-6	R-6	R-1.9	R-3.5	None	R-3.5
7	R-8	R-6	R-6	R-1.9	R-3.5	None	R-3.5
8	R-8	R-8	R-8	R-1.9	R-6	None	R-6
Return Ducts							
1 to 8	R-3.5	R-3.5	R-3.5	None	None	None	None

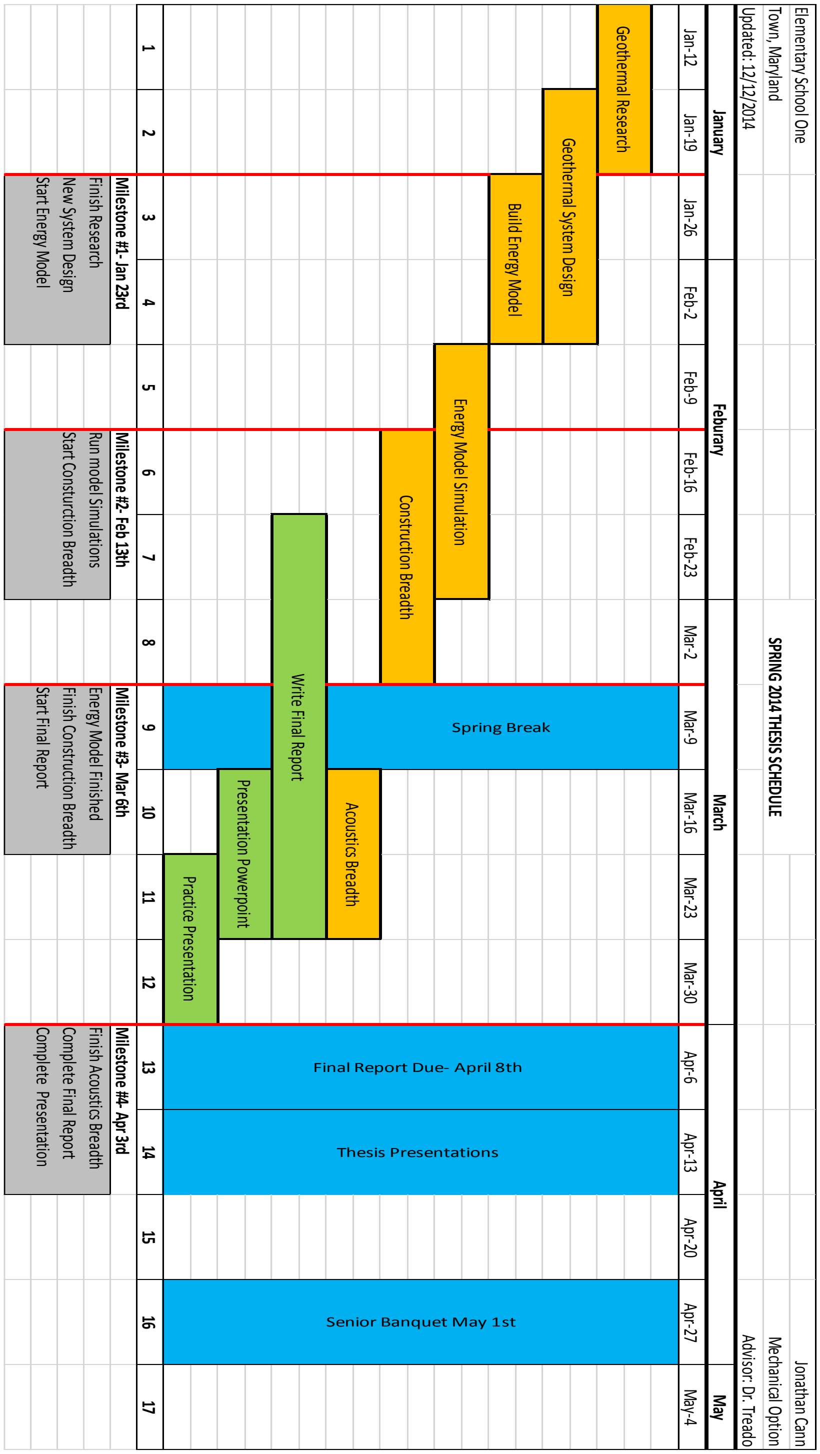
a. Insulation R-values, measured in (h·ft^2·°F)/Btu, are for the insulation as installed and do not include film resistance. The required minimum thicknesses do not consider water vapor transmission and possible surface condensation. Where exterior walls are used as plenum walls, wall insulation shall be as required by the most restrictive condition of Section 6.4.4.2 or Section 5. Insulation resistance measured on a horizontal plane in accordance with ASTM C518 at a mean temperature of 75°F at the installed thickness.

b. Includes crawlspaces, both ventilated and nonventilated.

c. Includes return air plenums with or without exposed roofs above.

Appendix C

Thesis Schedule



Appendix D

Geotechnical Report

ELEV. (ft)	SOIL DESCRIPTION Color, Moisture, Density, Plasticity, Size Proportions	STRA DEPTH (ft)
403.3	3 inches of **TOPSOIL**	0.3
398.5	Red brown, moist, loose to medium dense, fine to medium **SAND**, some clay, **(FILL)**	5.0
396.5	Dark brown, moist, loose, fine to medium **SAND**, some silt, trace roots, **(FILL)**	7.0
393.5	Red brown, moist, loose, fine to medium **SAND**, some clay, **(FILL)**	10.0
390.5	Yellow brown, moist, medium stiff, sandy lean **CLAY**, with gravel, **(CL)**	13.0
388.5	Brown, moist, very dense, **GRAVEL**, some fine to medium sand, **(GP)**	15.0
383.5	Yellow brown, moist, dense, fine to medium **SAND**, some clay, **(SC)**	20.0
377.0	Light brown, moist, hard, **SILT**, some clay, **(ML)**	26.5
373.5	Brown and gray, moist, very dense, **SAND**, some clay, micaceous, **(SC)**	30.0
	Bottom of Boring at 30.0 ft	

Cond	Blows/6"	No.	Type	Rec (in)
	3-7-7	1	DS	10
	2-3-2	2	DS	10
	3-3-3	3	DS	3
	3-3-3	4	DS	10
	2-3-4	5	DS	12
	34-35-27	6	DS	18
	10-14-17	7	DS	18
I/D	10-14-17	8	DS	15
	22-24-37	9	DS	18

DEPTH SCALE: 5, 10, 15, 20, 25, 30, 35, 40, 45

BORING & SAMPLE NOTES

1. No water encountered.
2. Drilled with Acker AD-II rig
3. Safety Hammer
4. Boring backfilled with auger cuttings

SAMPLER TYPE

DS - DRIVEN SPLIT SPOON
PT - PRESSED SHELBY TUBE
CA - CONTINUOUS FLIGHT AUGER
RC - ROCK CORE

SAMPLE CONDITIONS

D - DISINTEGRATED
I - INTACT
U - UNDISTURBED
L - LOST

GROUNDWATER DEPTH

AT COMPLETION Dry ft
AFTER ____ HRS. ____ ft
AFTER 24 HRS. ____ ft
CAVED AT 28.0 ft

BORING METHOD

HSA - HOLLOW STEM AUGERS
CFA - CONTINUOUS FLIGHT AUGERS
DC - DRIVING CASING
MD - MUD DRILLING

STANDARD PENETRATION TEST DRIVING 2" OD SAMPLER 1' WITH 140# HAMMER FALLING 30": COUNT MADE AT 6" INTERVALS

Average Annual Ground Temperature Map (3)

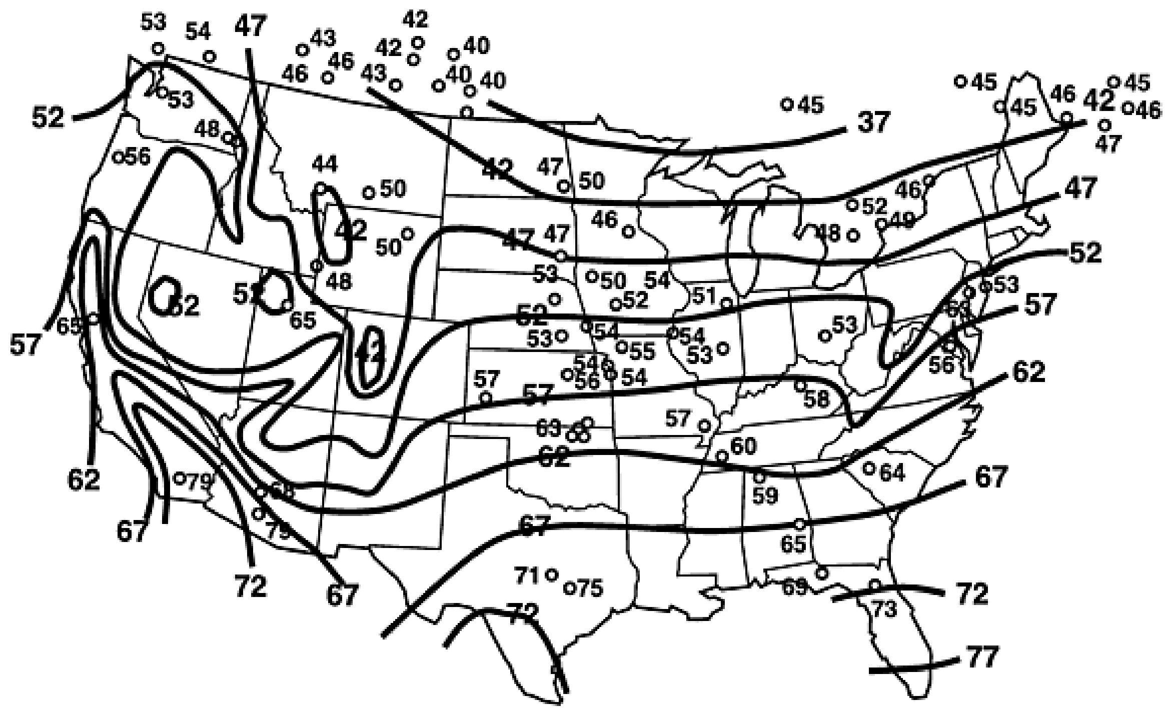


Figure 2. Mean annual earth temperature observations at individual stations, superimposed on well-water temperature contours.

Welll Design Properties (5)

Table 4 – Thermal Conductivity and Diffusivity of Sand and Clay Soils[5]

Soil Type	Dry Density (lb/ft³)	5% Moist		10% Moist		15% Moist		20% Moist	
		k	α	k	α	k	α	k	α
Coarse 100% Sand	120	1.2-1.9	0.96-1.5	1.4-2.0	0.93-1.3	1.6-1.2	0.91-1.2	-	
	100	0.8-1.4	0.77-1.3	1.2-1.5	0.96-1.2	1.3-1.6	0.89-1.1	1.4-1.7	0.84-1.0
	80	0.5-1.1	0.60-1.3	0.6-1.1	0.60-1.1	0.6-1.2	0.51-1.0	0.7-1.2	0.52-0.90
Fine Grain 100% Clay	120	0.6-0.8	0.48-0.64	0.6-0.8	0.4-0.53	0.8-1.1	0.46-0.63	-	-
	100	0.5-0.6	0.48-0.58	0.5-0.6	0.4-0.48	0.6-0.7	0.37-0.48	0.6-0.8	0.41-0.55
	80	0.3-0.5	0.36-0.6	0.35-0.5	0.35-0.5	0.4-0.55	0.34-0.47	0.4-0.6	0.30-0.45

Thermal Conductivity (k) - Btu/h•ft•F° and Thermal Diffusivity (α) - ft²/day
Coarse grain = 0.075 to 5 mm – Fine Grain less than 0.075 mm

Pipe Properties

Table 1 – Equivalent Diameters and Thermal Resistances for Polyethylene U-Tubes[2]

U-Tube Dia.	SDR or Schedule	Pipe (Bore) Thermal Resistance (h•ft•F°/Btu)			
		For Water Flows Above 2.0 US gpm	20% Prop. Glycol Flow 3.0 US gpm	20% Prop. Glycol Flow 5.0 US gpm	20% Prop. Glycol Flow 10.0 US gpm
¾ in. (0.15 ft)	SDR 11	0.09	0.12	NR	NR
	SDR 9	0.11	0.15	NR	NR
	Sch 40	0.10	0.14	NR	NR
1.0 in. (0.18 ft)	SDR 11	0.09	0.14	0.10	NR
	SDR 9	0.11	0.16	0.12	NR
	Sch 40	0.10	0.15	0.11	NR
1 1/4 in. (0.22 ft)	SDR 11	0.09	0.15	0.12	0.09
	SDR 9	0.11	0.17	0.15	0.11
	Sch 40	0.09	0.15	0.12	0.09
1 1/2 in. (0.25 ft)	SDR 11	0.09[1]	0.16	0.15	0.09
	SDR 9	0.11[1]	0.18	0.17	0.11
	Sch 40	0.08[1]	0.14	0.14	0.08

Based on using borehole cuttings for backfilling around u-tube. Use **Table 2** corrections for other conditions.
[1] Water flow must be at least 3.0 US gpm to avoid laminar flow for these cases.

Table 2 – Thermal Resistance Adjustments For Other Borehole Backfills or Grouts[3]

(Add value to Base Resistances in)

Natural Soil Cond.	0.9 Btu/h•ft•F°		1.3 Btu/h•ft•F°			1.7 Btu/h•ft•F°	
Backfill or Grout Conductivity	0.5 Btu/h•ft•F°	2.0 Btu/h•ft•F°	0.5 Btu/h•ft•F°	1.0 Btu/h•ft•F°	2.0 Btu/h•ft•F°	0.5 Btu/h•ft•F°	1.0 Btu/h•ft•F°
4 in. Bore							
¾ in. U-tube	0.11 (NR)	-0.05	0.14 (NR)	0.03	-0.02	0.17 (NR)	0.05
1 in U-tube	0.07	-0.03	0.09	0.02	-0.02	0.13 (NR)	0.04
5 in. Bore							
¾ in. U-tube	0.14 (NR)	-0.06	0.18 (NR)	0.04	-0.04	0.21 (NR)	0.06
1 in U-tube	0.11 (NR)	-0.04	0.14 (NR)	0.03	-0.02	0.16 (NR)	0.05
1 1/4 in U-tube	0.06	-0.03	0.09	0.02	-0.02	0.12 (NR)	0.04
6 in. Bore							
¾ in. U-tube	0.18 (NR)	-0.07	0.21 (NR)	0.04	-0.05	0.24 (NR)	0.07
1 in U-tube	0.14 (NR)	-0.06	0.17 (NR)	0.03	-0.04	0.21 (NR)	0.06
1 1/4 in U-tube	0.09	-0.04	0.12 (NR)	0.03	-0.02	0.15 (NR)	0.05
1 1/2 in U-tube	0.07	-0.03	0.09	0.02	-0.02	0.11 (NR)	0.04

(NR) Not Recommended
Air Gaps add 0.2 t o0.4 h•ft•F°/Btu to Bore Resistance
Note some adjustments are negative, which indicates a thermal enhancement and a lower net thermal resistance compared to natural backfills.

Appendix E

Federal Rebate

SEC. 105. ENERGY CREDIT FOR GEOTHERMAL HEAT PUMP SYSTEMS.

(a) In General- Subparagraph (A) of section 48(a)(3), as amended by this Act, is amended by striking `or' at the end of clause (v), by inserting `or' at the end of clause (vi), and by adding at the end the following new clause:

> `(vii) equipment which uses the ground or ground water as a thermal energy source to heat a structure or as a thermal energy sink to cool a structure, but only with respect to periods ending before January 1, 2017,'.

(b) Effective Date- The amendments made by this section shall apply to periods after the date of the enactment of this Act, in taxable years ending after such date, under rules similar to the rules of section 48(m) of the Internal Revenue Code of 1986 (as in effect on the day before the date of the enactment of the Revenue Reconciliation Act of 1990).

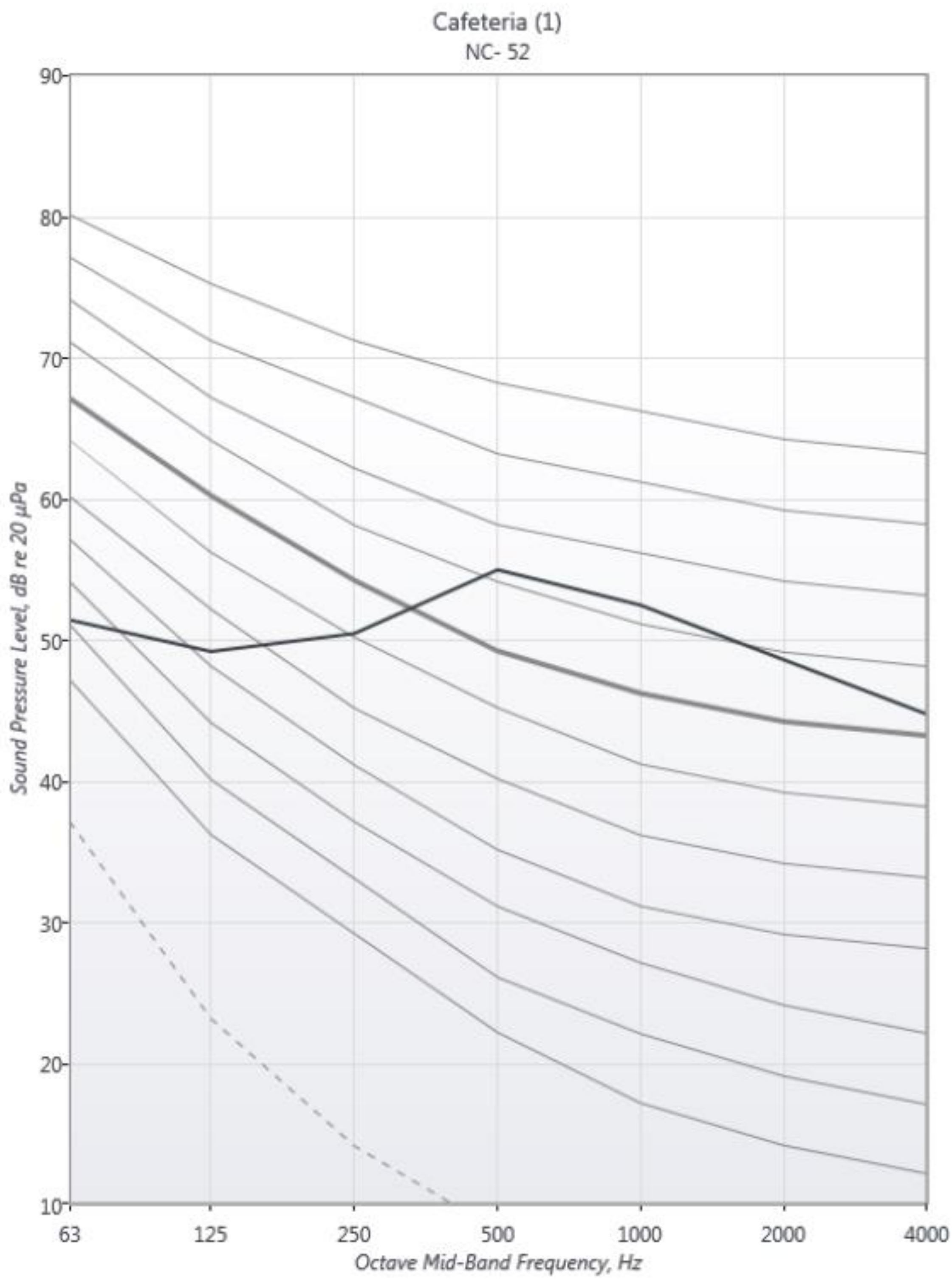
Appendix F

Acoustical Output From Dynasonics

Cafeteria Before Treatment

Cafeteria (1)
Calculation Summary

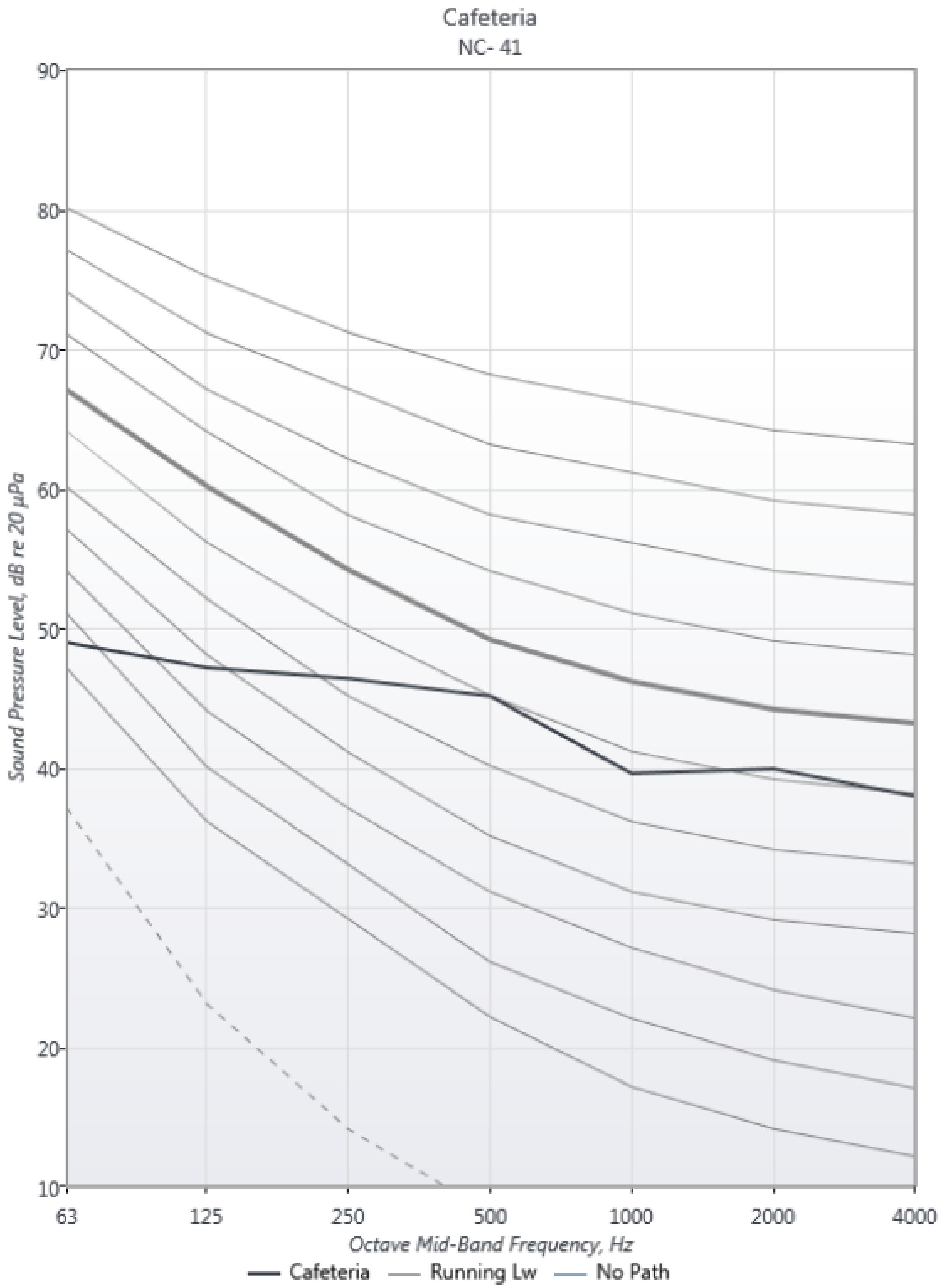
	Element	Properties	NC	63	125	250	500	1K	2K	4K	dB(A)
				Octave Midband Frequency, Hz							
30	**Cafeteria (1)**	**Criteria: NC-45**	**52**	**51**	**49**	**50**	**55**	**52**	**48**	**45**	**57**
31	**Supply Path (1)**	**Criteria: NC-45**									
32	Air Handling Unit - Ducted Inlet			92	83	81	81	79	75	71	
33	Rectangular Duct	36"x14"x10' (0")		-3	-2	-1	0	0	0	0	
34	Rectangular Elbow Radius	36"x14" (0")		0	-1	-2	-3	-3	-3	-3	
				50	48	45	42	37	32	26	
35	Rectangular Duct	36"x14"x6' (0")		-2	-1	-1	0	0	0	0	
36	Rectangular Duct	24"x12"x5' (0")		-2	-1	-1	0	0	0	0	
37	Room Correction (Classic Diffuse)	68'x46'x20'		-10	-10	-10	-10	-10	-10	-10	
38	Rectangular Duct	36"x12"x50' (0")		-15	-10	-7	-2	-2	-2	-2	
39	Rectangular Elbow Radius	36"x12" (0")		0	-1	-2	-3	-3	-3	-3	
				51	50	48	45	41	36	30	
40	Rectangular Duct	36"x12"x6' (0")		-2	-1	-1	0	0	0	0	
41	Rectangular Duct	18"x6"x5' (0")		-2	-1	-1	0	0	0	0	
42	Room Correction (Classic Diffuse)	68'x46'x20'		-10	-10	-10	-10	-10	-10	-10	
43	**SUM**		**49**	**48**	**46**	**47**	**52**	**49**	**45**	**42**	**54**
44	**Supply Path (1 (1))**	**Criteria: NC-45**									
45	Air Handling Unit - Ducted Inlet			92	83	81	81	79	75	71	
46	Rectangular Duct	36"x14"x10' (0")		-3	-2	-1	0	0	0	0	
47	Rectangular Elbow Radius	36"x14" (0")		0	-1	-2	-3	-3	-3	-3	
				50	48	45	42	37	32	26	
48	Rectangular Duct	36"x14"x6' (0")		-2	-1	-1	0	0	0	0	
49	Rectangular Duct	24"x12"x5' (0")		-2	-1	-1	0	0	0	0	
50	Room Correction (Classic Diffuse)	68'x46'x20'		-10	-10	-10	-10	-10	-10	-10	
51	Rectangular Duct	36"x12"x50' (0")		-15	-10	-7	-2	-2	-2	-2	
52	Rectangular Elbow Radius	36"x12" (0")		0	-1	-2	-3	-3	-3	-3	
				51	50	48	45	41	36	30	
53	Rectangular Duct	36"x12"x6' (0")		-2	-1	-1	0	0	0	0	
54	Rectangular Duct	18"x6"x5' (0")		-2	-1	-1	0	0	0	0	
55	Room Correction (Classic Diffuse)	68'x46'x20'		-10	-10	-10	-10	-10	-10	-10	
56	**SUM**		**49**	**48**	**46**	**47**	**52**	**49**	**45**	**42**	**54**


Cafeteria (1)
NC- 52
90
80
70
60
50
40
30
20
10
Sound Pressure Level, dB re 20 μPa
63
125
250
500
1000
2000
4000
Octave Mid-Band Frequency, Hz

Cafeteria After Treatment

Cafeteria
Calculation Summary

	Element	Properties	NC	63	125	250	500	1K	2K	4K	dB(A)
				Octave Midband Frequency, Hz							
1	**Cafeteria**	**Criteria: NC-45**	**41**	**49**	**47**	**46**	**45**	**39**	**40**	**38**	**47**
2	**Supply Path (1)**	**Criteria: NC-45**									
3	Air Handling Unit - Ducted Inlet			92	83	81	81	79	75	71	
4	Rectangular Duct	36"x14"x10' (0")		-3	-2	-1	0	0	0	0	
5	Rectangular Elbow Radius	36"x14" (0")		0	-1	-2	-3	-3	-3	-3	
				50	48	45	42	37	32	26	
6	PF55	36"x14"x36"		-3	-3	-5	-11	-15	-12	-11	
	Generated Noise			74	68	62	57	55	60	59	
7	Rectangular Duct	36"x14"x6' (0")		-2	-1	-1	0	0	0	0	
8	Rectangular Duct	24"x12"x5' (0")		-2	-1	-1	0	0	0	0	
9	Room Correction (Classic Diffuse)	68'x46'x20'		-10	-10	-10	-10	-10	-10	-10	
10	Rectangular Duct	36"x12"x50' (0")		-15	-10	-7	-2	-2	-2	-2	
11	Rectangular Elbow Radius	36"x12" (0")		0	-1	-2	-3	-3	-3	-3	
				51	50	48	45	41	36	30	
12	Rectangular Duct	36"x12"x6' (0")		-2	-1	-1	0	0	0	0	
13	Rectangular Duct	18"x6"x5' (0")		-2	-1	-1	0	0	0	0	
14	Room Correction (Classic Diffuse)	68'x46'x20'		-10	-10	-10	-10	-10	-10	-10	
15	**SUM**		**38**	**46**	**44**	**43**	**42**	**36**	**37**	**35**	**44**
16	**Supply Path (1 (1))**	**Criteria: NC-45**									
17	Air Handling Unit - Ducted Inlet			92	83	81	81	79	75	71	
18	Rectangular Duct	36"x14"x10' (0")		-3	-2	-1	0	0	0	0	
19	Rectangular Elbow Radius	36"x14" (0")		0	-1	-2	-3	-3	-3	-3	
				50	48	45	42	37	32	26	
20	PF55	36"x14"x36"		-3	-3	-5	-11	-15	-12	-11	
	Generated Noise			74	68	62	57	55	60	59	
21	Rectangular Duct	36"x14"x6' (0")		-2	-1	-1	0	0	0	0	
22	Rectangular Duct	24"x12"x5' (0")		-2	-1	-1	0	0	0	0	
23	Room Correction (Classic Diffuse)	68'x46'x20'		-10	-10	-10	-10	-10	-10	-10	
24	Rectangular Duct	36"x12"x50' (0")		-15	-10	-7	-2	-2	-2	-2	
25	Rectangular Elbow Radius	36"x12" (0")		0	-1	-2	-3	-3	-3	-3	
				51	50	48	45	41	36	30	
26	Rectangular Duct	36"x12"x6' (0")		-2	-1	-1	0	0	0	0	
27	Rectangular Duct	18"x6"x5' (0")		-2	-1	-1	0	0	0	0	
28	Room Correction (Classic Diffuse)	68'x46'x20'		-10	-10	-10	-10	-10	-10	-10	
29	**SUM**		**38**	**46**	**44**	**43**	**42**	**36**	**37**	**35**	**44**

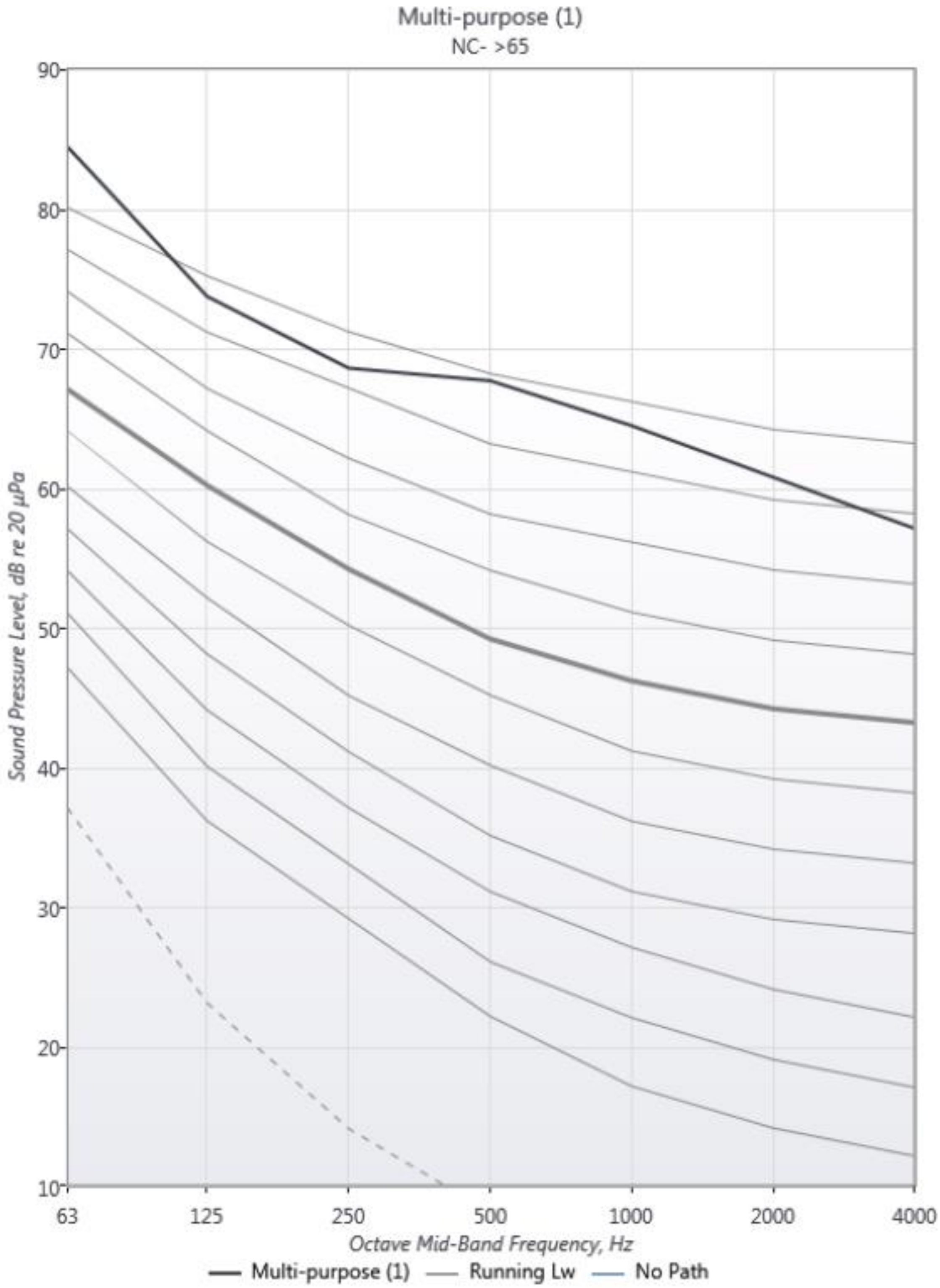

Cafeteria
NC- 41
Sound Pressure Level, dB re 20 µPa
90
80
70
60
50
40
30
20
10
63
125
250
500
1000
2000
4000
Octave Mid-Band Frequency, Hz
Cafeteria
Running Lw
No Path

Multipurpose Room Before Treatment

Multi-purpose (1)

Calculation Summary

	Element	Properties	NC	63	125	250	500	1K	2K	4K	dB(A)
				Octave Midband Frequency, Hz							
68	**Multi-purpose (1)**	**Criteria: NC-45**	**>65**	**84**	**74**	**68**	**68**	**64**	**61**	**57**	**70**
69	**Supply Path (1)**	**Criteria: NC-45**									
70	Air Handling Unit - Ducted Inlet			92	83	81	81	79	75	71	
71	Circular Elbow Radius	30" (0")		0	-1	-3	-3	-3	-3	-3	
				49	46	42	37	31	24	16	
72	Circular Elbow Radius	30" (0")		0	-1	-3	-3	-3	-3	-3	
				49	46	42	37	31	24	16	
73	Circular Duct	30"x30' (0")		-1	-1	-1	-1	-2	-2	-2	
74	Circular Duct	24"x30' (0")		-1	-1	-1	-1	-2	-2	-2	
75	Room Correction (Classic Diffuse)	83'7.2"x59'3.6"x25'		-9	-9	-8	-9	-9	-8	-8	
76	**SUM**		**>65**	**81**	**71**	**65**	**65**	**61**	**58**	**54**	**67**
77	**Supply Path (1 (2))**	**Criteria: NC-45**									
78	Air Handling Unit - Ducted Inlet			92	83	81	81	79	75	71	
79	Circular Elbow Radius	30" (0")		0	-1	-3	-3	-3	-3	-3	
				49	46	42	37	31	24	16	
80	Circular Elbow Radius	30" (0")		0	-1	-3	-3	-3	-3	-3	
				49	46	42	37	31	24	16	
81	Circular Duct	30"x30' (0")		-1	-1	-1	-1	-2	-2	-2	
82	Circular Duct	24"x30' (0")		-1	-1	-1	-1	-2	-2	-2	
83	Room Correction (Classic Diffuse)	83'7.2"x59'3.6"x25'		-9	-9	-8	-9	-9	-8	-8	
84	**SUM**		**>65**	**81**	**71**	**65**	**65**	**61**	**58**	**54**	**67**

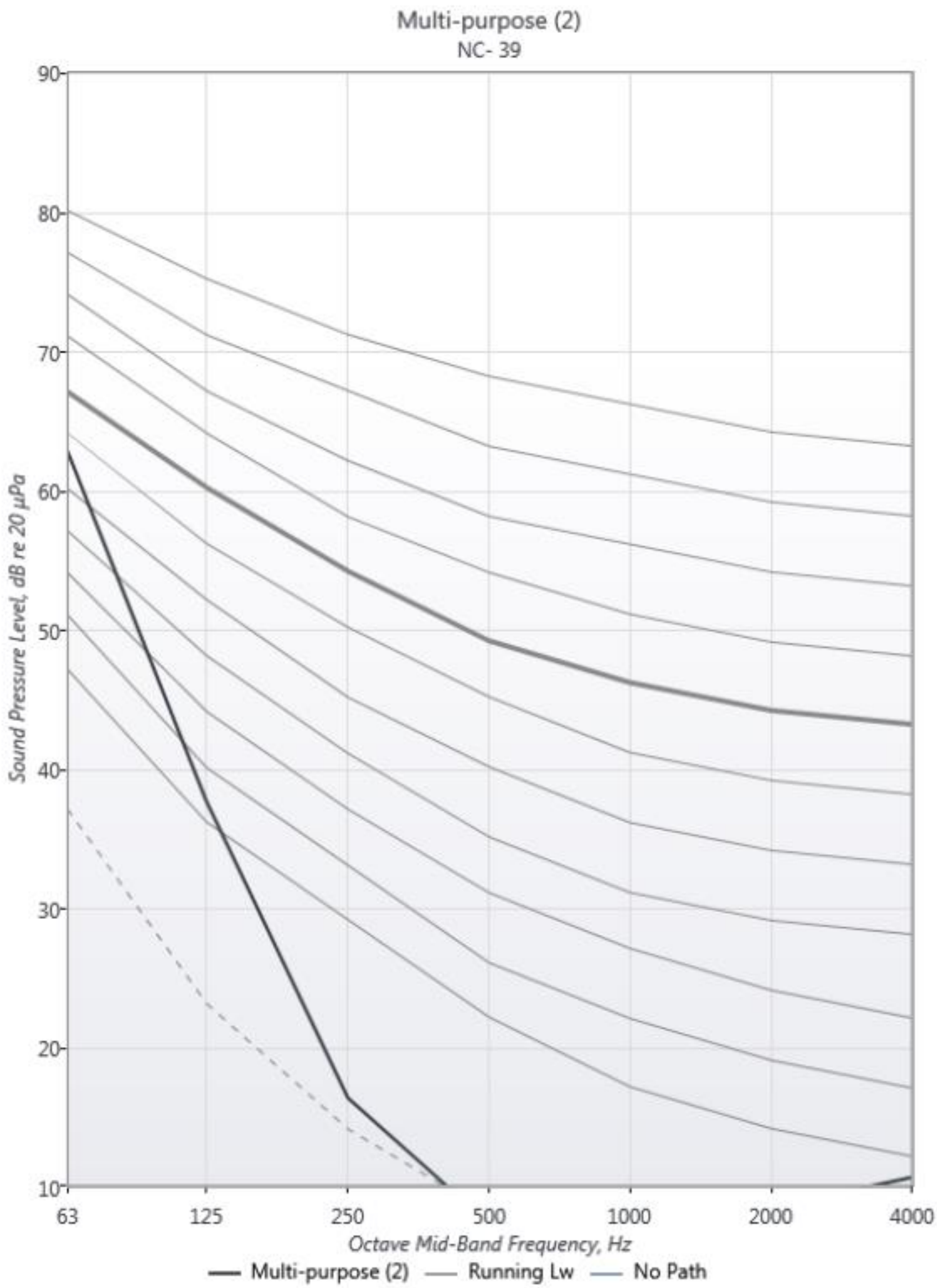

Multi-purpose (1)
NC- >65
Sound Pressure Level, dB re 20 µPa
90
80
70
60
50
40
30
20
10
63
125
250
500
1000
2000
4000
Octave Mid-Band Frequency, Hz
Multi-purpose (1)
Running Lw
No Path

Multipurpose Room After Treatment

Multi-purpose (2)

Calculation Summary

Element		Properties	NC	63	125	250	500	1K	2K	4K	dB(A)
				Octave Midband Frequency, Hz							
85	**Multi-purpose (2)**	**Criteria: NC-45**	**39**	**63**	**38**	**16**	**7**	**6**	**8**	**11**	**37**
86	**Supply Path (1)**	**Criteria: NC-45**									
87	Air Handling Unit - Ducted Inlet			92	83	81	81	79	75	71	
88	Circular Elbow Radius	30" (0")		0	-1	-3	-3	-3	-3	-3	
				49	46	42	37	31	24	16	
89	Circular Elbow Radius	30" (0")		0	-1	-3	-3	-3	-3	-3	
				49	46	42	37	31	24	16	
90	Circular Duct	30"x30' (2")		-6	-11	-27	-40	-40	-29	-21	
91	ST-A-EB	30"x72"		-9	-16	-30	-36	-36	-27	-22	
	Generated Noise			56	55	52	53	52	51	41	
92	Circular Duct	24"x30' (2")		-8	-14	-30	-40	-40	-37	-25	
93	Room Correction (Classic Diffuse)	83'7.2"x59'3.6"x25'		-9	-9	-8	-9	-9	-8	-8	
94	**SUM**		**35**	**60**	**35**	**13**	**4**	**3**	**5**	**8**	**34**
95	**Supply Path (1 (2))**	**Criteria: NC-45**									
96	Air Handling Unit - Ducted Inlet			92	83	81	81	79	75	71	
97	Circular Elbow Radius	30" (0")		0	-1	-3	-3	-3	-3	-3	
				49	46	42	37	31	24	16	
98	Circular Elbow Radius	30" (0")		0	-1	-3	-3	-3	-3	-3	
				49	46	42	37	31	24	16	
99	Circular Duct	30"x30' (2")		-6	-11	-27	-40	-40	-29	-21	
100	ST-A-EB	30"x72"		-9	-16	-30	-36	-36	-27	-22	
	Generated Noise			56	55	52	53	52	51	41	
101	Circular Duct	24"x30' (2")		-8	-14	-30	-40	-40	-37	-25	
102	Room Correction (Classic Diffuse)	83'7.2"x59'3.6"x25'		-9	-9	-8	-9	-9	-8	-8	
103	**SUM**		**35**	**60**	**35**	**13**	**4**	**3**	**5**	**8**	**34**


Multi-purpose (2)
NC- 39
Sound Pressure Level, dB re 20 µPa
90
80
70
60
50
40
30
20
10
63
125
250
500
1000
2000
4000
Octave Mid-Band Frequency, Hz
Multi-purpose (2)
Running Lw
No Path

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