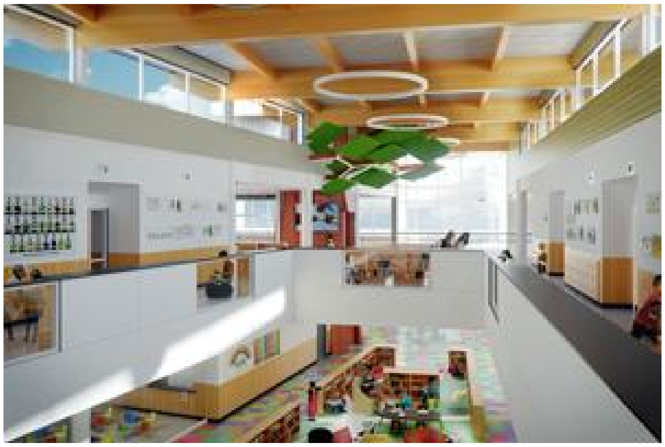

Phoenixville Early Learning Center and Elementary School

Senior Thesis Final Report

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Consultant: Dr. William Bahnfleth
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Sponsored by:

Barton Associates Consulting Engineers

PHOENIXVILLE EARLY LEARNING CENTER AND ELEMENTARY SCHOOL

Phoenixville, PA	152,000 SF (GROSS)	Two Stories	$80 Million (Overall)

Learning Studio

Learning Stairs Atrium

First Floor Media Center

CPEP: https://www.engr.psu.edu/ae/thesis/portfolios/2016/noa5100/index.htm

DESIGN TEAM:

Owner: Phoenixville Area School District
Architect: SCHRADERGROUP architecture LLC
MEPFP: Barton Associates Inc
Structural: SCHRADERGROUP architecture LLC
Civil: T&M Associates
Landscape Architecture: T&M Associates

Building Systems

Architectural

Function: Education, including; classrooms, offices, cafeteria, gymnasium, media center, art studio

Façade: Prefinished cementitious siding product system with lapped and stacked assemblies. As well as a sand blasted CMU Veneer.

Structural

Lateral System: Braced Framing with reinforced CMU Shear Walls, Moment Frames may be used if brace frames cannot be accommodated.

Foundation: Concrete Piers will be used and sized on specific loads.

Floor System: 3-1/2” Normal Weight Concrete topping on 2” 20 GA composited metal floor deck. Slab is reinforced with #4 rebar at 16” spacing.

Mechanical

Heating: Three High Efficiency Condensing Boilers provide heating for the water to serve 88 water source heat pumps. Condenser water units circulate water from heat pumps to boiler and cooling tower.

Cooling: One Cooling Tower provides chilled water to the rest of the building and uses a flat plate heat ex changer to condense water.

Ventilation: Water Source Heat Pumps are found in every class room as well as 10 Energy Recovery Ventilator Units on the roof.

Electrical/ Lighting

Supply: Building is serviced by a 277/480V, 3-phase, 4-wire, 1600A Underground service from a utility transformer.

Lighting: Primarily is 277V fluorescent lamp fixtures. They will be long-life T8. Exterior Lights, downlights, and accent fixtures will be LED.

Contents

Acknowledgements:

I would like to thank the AE faculty for their help and guidance over the past five years. I would especially like to thank the team at Barton Associates for their guidance and support over the past two years. Thank you as well to the architects at SCHRADERgroup Architecture LLC, and the Phoenixville School District for letting me use their building.

Thank You to my fellow comrades in the AE Class of 2016.

Thank you most importantly to my family, who have been there every step of the way.

"Keep your head up kid." – Don Cherry

Executive Summary:

Over the past two semesters there has been comprehensive analysis done on the Phoenixville Early Learning Center to determine how it meets codes, compares to other buildings in energy usage, and an in depth review of the schematics of the mechanical system within the building. These previous reports can be found on my website. This report consists of a multifaceted study on the Early Learning Center and how various systems perform better or worse on the same building. It should be noted the purpose of these studies is not to imply insufficiency of the current design, however, they are to be evaluated for educational purposes.

In the depth analysis three different systems are brought to the fore front, comparing the current water-source heat pump system with the following systems; geothermal heat pump system, centralized air handling unit, and variable refrigerant flow (VRF) with a DOAS ventilation system. Lifecycle cost analysis, feasibility, operating cost, space utilization, construction cost and energy usage studies were completed on the previously mentioned systems on a basis to provide educational insight on how the equipment would perform within the building. At the end of the analysis the geothermal heat pump system was chosen for recommendation to the board of the Phoenixville School Board.

The geothermal heat pump system had a discounted payback of 11.37 years as compared to the baseline, water-source heat pump system. The life cycle cost of the geothermal heat pump system is $7,444,722. An area around the site was chosen for a vertical well field orientation to support roughly 67,000 feet of pipe, or about 200 wells at 400 feet deep, to pump 600 gpm of ethylene glycol through the geothermal heat exchanger. This design proved to add an additional 42 days to the construction schedule and an added cost of 1.54 million dollars.

Despite low costs of rooftop air handling units, when compared to the water-source heat pump system the units did not payback. Similarly, the VRF system also did not pay back. The VRF system had the best response to mitigating mechanical space within the building however, fell short in the energy efficiency and cost categories.

Breadth analysis consisted of evaluating various building systems that will be influenced by the change in mechanical systems. The breadths confirmed scheduling and cost impacts on construction of a geothermal heat pump system increased the construction time and also increased construction costs. Extra crews as well as equipment needed to be brought onto the site to drill bore holes and construct the geothermal well field.

Electrical load analysis of a VRF system on the building revealed the VRF terminal and rooftop units had less of an electrical load than the water-source heat pump system. Wires, ground wires and conduit was able to be re-sized after solving for the amps of each component of the VRF system.

Overall, the owner should be satisfied with a system that meets his needs of energy efficiency, classroom space, ease of maintenance and payback period. A geothermal well field was designed to meet the school's needs and stay in budget. Students as well as faculty and staff will have an enjoyable work environment for many years to come.

Building Overview:

The Phoenixville Early Learning Center and Elementary school is being built for a progressive school district that is looking to expand and address their growing student population. Phoenixville Early Learning Center is a 152,000 square foot educational building designed to hold 1,526 occupants.

The building is comprised of two stories above grade and will accommodate grades K-5. There are three wings to the building as well as one large common area and an outdoor learning amphitheater. Wings of the building, as shown in Figure 1 below, are filled with learning spaces comprised of group learning

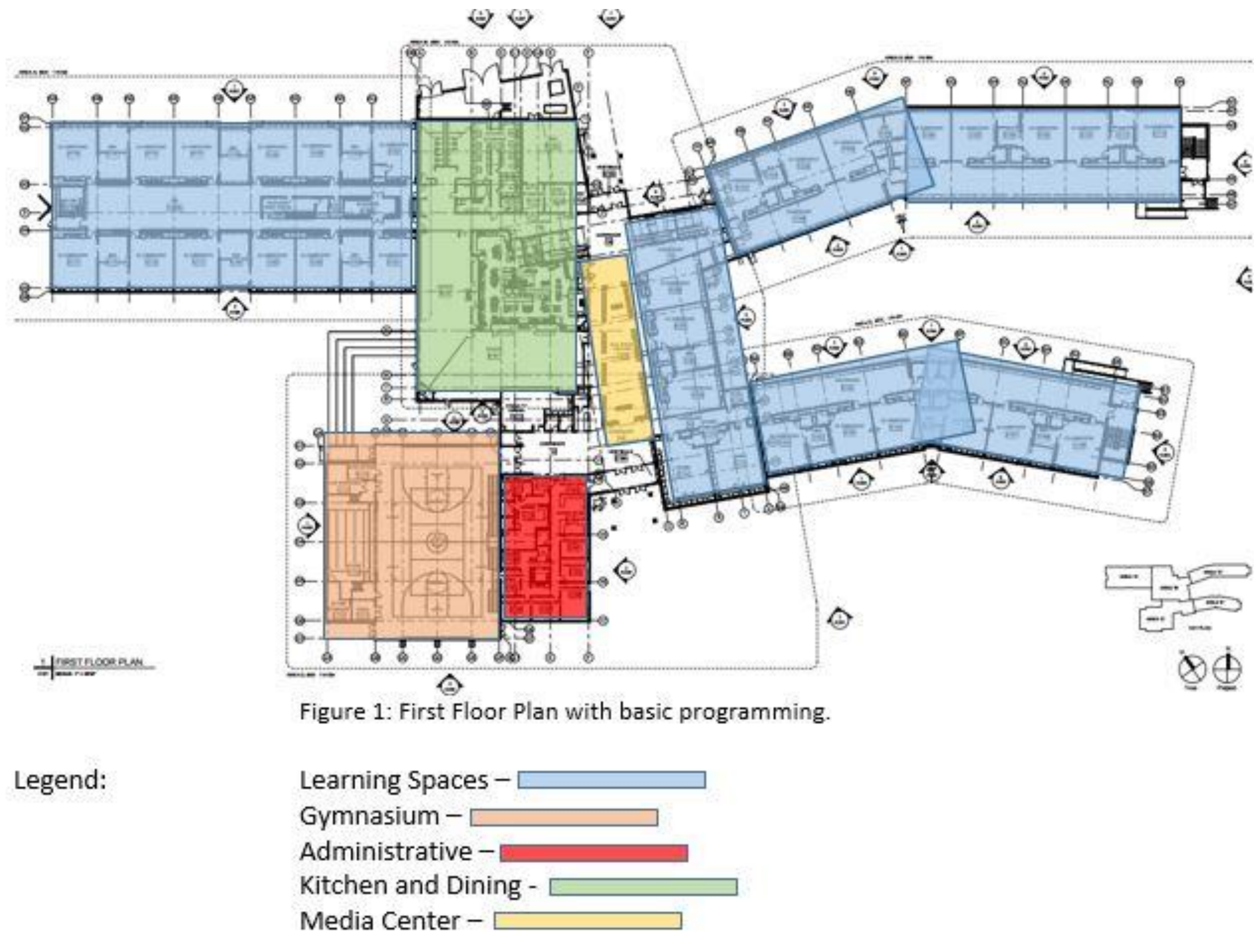


Figure 1: First Floor Plan with Basic Programming

areas as well as learning studios. Within the large common area there are administration spaces, the learning resource center, support spaces, a media center as well as a full size gymnasium as displayed in figure 1 above.

Figure 2 Learning Stairs Atrium,
Image used with permission from SCHRADERgroup Architecture

Architecturally, there are two main architectural areas that attract attention in the building. One of the areas is the Media Center which is on the first and second floor and displayed in Figure 3. The first floor is open to the second floor and the ceiling above, making the feeling of the space light and airy. Decorated throughout the space are bookshelves, with large reading chairs for comfort. In the second story there is a large "Learning Tree" that overhangs the Media Center. This tree is made from structural steel covered in fabric wrapped wood veneer panels on metal studs.

Figure 3 First Floor Media Center,
Image used with permission from SCHRADERgroup Architecture

The second main architectural feature area consists of two sets of "Learning Stairs" which forms a large atrium, as shown in Figure 2. These stairs are for students to sit on and read or do work. They have a view out through the exterior façade and is a main artery of the building.

There are a few features utilized with sustainability in mind. A Green Roof will be constructed over the dining area; this feature will be minimizing the heat island effect.
The green roof will be extensive and feature green roof plants that are low maintenance. Sunshades and light shelves have been added to all windows with a southern exposure, reducing peak loads in the rooms and allowing daylight to travel further into the building. Energy Recovery Units were utilized in the mechanical system to reclaim heat from existing air sources. High efficiency boilers were also used to minimize energy usage. Furthermore, high efficiency electronic plumbing fixtures were specified to reduce water usage. The project did not pursue LEED Certification, however earned a 90 point ENERGY STAR score.

Existing Mechanical Systems Overview:

To provide an energy efficient and comfortable design the engineers decided to install water-source heat pumps, energy recovery capability, condenser water pumps, a cooling tower and a high efficiency boiler plant. Heat pumps are located within small closet areas within close proximity to the space they are serving. Most of the large assembly spaces utilize equipment on the roof or in mechanical rooms. Ventilation is provided by energy recovery ventilator units (ERV) fitted with enthalpy heat wheels which are on the roof and ducted to water-source heat pumps. Fans on the rooftop draw air out of the building and exhaust areas such as toilet rooms and locker rooms.

Hot water in the building is distributed via a central location of boilers within the mechanical room. Cold water originates from the roof and is run thru the cooling tower which extracts heat from the condenser loop. Electric trace heating cable is used throughout the building, to prevent piping from freezing in winter months.

Electric unit heaters will also be used in places without ceilings. These spaces using electric unit heaters are “back of house” spaces.

Ventilation Requirements, ASHRAE Standard 62.1:

A comprehensive analysis was done comparing the current system with ASHRAE Standard 62.1 which addressed energy usage, ventilation and building envelope. Overall, the existing system proved to be in compliance with section 5. The Early Learning Center demonstrated the exhaust ducts, outdoor air intakes, and airstream surfaces are designed with the occupants in mind, prohibiting the growth of mold, dust collection and capturing quality air. Particulates that may pass into the system will promptly be caught in MERV-8 filters upstream of the units. Training of the proper maintenance and upkeep of the system will be crucial for the school district. However, with the all-inclusive equipment manuals and training program the Phoenixville School District will be able to keep and maintain the Early Learning Center for years to come.

The ventilation throughout the building was analyzed for the breathing zone and outdoor airflows. To calculate the breathing zone outdoor airflow the following equation was used;

$$V_{bz} = R_p \times P_z + R_a \times A_z \quad (6.2.2.1)$$

Where, Az =Zone floor area or the net occupiable floor area of the ventilation zone, square feet
Pz = Zone population, the number of people in the ventilation zone during typical usage
Rp = Outdoor airflow rate required per person as specified in Table 6.2.2.1
Ra = Outdoor airflow rate required per unit area as specified in Table 6.2.2.1
(Definitions taken from ASHRAE STD 62.1 – 2013 Section 6.2.2.1)

It was determined when performing the calculations, conservative estimates in terms of the areas were used. Similar rooms, and areas, were grouped together. This process gave a safety factor to account for building leakage. Table 1 below displays the outdoor ventilation requirements as well as the comparison to the designed outdoor air supply. As shown in the table, all but two of the ERV’s meet compliance with ASHRAE Standard 62.1 Section 6. This could have been skewed because of the grouping of rooms. There should be enough ventilation within the building to effectively provide safe occupancy.

To calculate the Primary Outdoor Air Fraction (Z_{pz}) we use the equation found in section 6.2.5.1 of ASHRAE Standard 62.1. The Primary Outdoor Air Fraction is the fraction of outdoor air needed in the zone to the total amount of airflow to the zone. The equation is the following:

$$Z_{pz} = \frac{V_{oz}}{V_{pz}}$$

Where, Z_{pz} = Primary Outdoor Air Fraction
V_{oz} = Zone Outdoor Air Flow
V_{pz} = Zone Primary Airflow, which included outdoor air as well as recirculated air

After finding the primary outdoor air fraction, refer to Table 6.2.5.2 of ASHRAE Standard 62.1 -2013 to find the System Ventilation Efficiency. Depending on the outdoor air fraction the ventilation efficiency will change. Now, knowing the Ventilation Efficiency the uncorrected outdoor intake (V_{ou}) can be calculated.

TABLE 6.2.5.2 System Ventilation Efficiency

Max (Z_P)	E_v
≤0.15	1.0
≤0.25	0.9
≤0.35	0.8
≤0.45	0.7
≤0.55	0.6
>0.55	Use Appendix A

1. "Max (Z_{pz})" refers to the largest value of Z_{pz}, calculated using Equation 6.2.5.1, among all the ventilation zones served by the system.
2. For values of Max (Z_{pz}) between 0.15 and 0.55, the corresponding value of E_v may be determined by interpolating the values in the table.
3. The values of E_v in this table are based on a 0.15 average outdoor air fraction for the system (i.e., the ratio of the uncorrected outdoor air intake [V_{ou}] to the total zone primary airflow for all the zones served by the air handler). For systems with higher values of the average outdoor air fraction, this table may result in unrealistically low values of E_v and the use of Normative Appendix A may yield more practical results.

Figure 4: System Ventilation Efficency, ASHRAE Std 62.1, 6.2.5.2

Uncorrected outdoor intake is the amount of intake air that needs to be brought into the building, including all zones based on people, area and occupant diversity. The equation to calculate uncorrected outdoor intake and occupant diversity is the following:

$$V_{ou} = D\sum_{All\ Zones} R_p P_z + \sum_{All\ Zones} R_a A_z$$

And:

$$D = \frac{P_s}{\sum_{All\ zones} P_z}$$

Where, D = Occupant Diversity
P_s = System Population

Lastly, to calculate the Outdoor Air Intake (V_{ot}), the uncorrected outdoor intake is compared to the overall efficiency of the system to provide accurate airflow. A summary and description of the outcomes is described below.

System Evaluation:

Within the Early Learning Center, there are ten ERV units that serve to distribute and condition air throughout the building. For the basis of my calculations, I used information given by SCHRADERGROUP architecture, as well as Barton Associates. In performing the calculations, I combined similar spaces to have less zones and less complexity. Total occupancy in the building is calculated at 2685 occupants and to distribute air to these occupants a multi-zone system was used. Air distribution configurations used a ceiling supply of warm air and a floor return. According to Table 6.2.2.2 of ASHRAE Standard 62.1 – 2013 the effectiveness of this system is 100 percent effective, or, $E_z = 1$.
Details of the calculations including rooms included in the zones, zone square footage, primary airflow rates, as well as population values can be found in Appendix A. All calculations were independently performed for this report but a procedure provided by Barton Associates, which is based off of the ASHRAE model, was utilized. Primary airflow rates as well as areas for each room were taken from drawings provided by SCHRADERGROUP architecture and Barton Associates. Occupant diversity in the Early Learning Center was designed at 100%, therefore a diversity value of 100% was also used in these calculations.

System Evaluation: Power and Lighting

When the electricity comes into the building it first goes through a PECO Utility Transformer to drop the voltage to 277 and 408 volts. The electricity is then sent into the 2000 amp switchboard where it is distributed to panels across the building. Two other transformers are required to step the voltage down to 120/208 volts for usage in classrooms and offices. Electrical drawings were configured to the detail of the National Electric Code, as well as the 2009 International Electrical Code and comply with all power requirements.

All lighting systems are to comply with sections 9.4, 9.5 and 9.7. These sections discuss controls, testing, lighting power densities, and submittals. Interior lighting controls are based on occupancy sensors with local manual overrides conserving energy when people are out of the space. Lighting power density levels comply with Table 9.5.1. As a school building, the lighting power density needed to be below 0.87 W/〖ft〗^2. The Early Learning Center complies with this code as most of their fixtures are florescent, which produces a very low lighting power density.

Table 1: Outdoor Airflow Ventilation Rates

ERV OUTDOOR VENTILATION ASHRAE STD 62.1 COMPLIANCE				
ERV	Zones Served	Required OA (CFM)	Design OA (CFM)	Compliance?
ERV-1	15, 16, 28,29	6085	8915	Yes
ERV-2	18, 19, 30, 31	5125	6480	Yes
ERV-3	3, 21, 22	5320	6155	Yes
ERV-4	1, 2, 20	5290	6125	Yes
ERV-5	7, 8, 25	5520	3775	No
ERV-6	13	3100	5000	Yes
ERV-7	12	480	600	Yes
ERV-8	14, 27	1204	600	No
ERV-9	4, 5, 6, 9, 23, 24	2356	3870	Yes
ERV-10	10, 24, 26	3090	4375	Yes
Total	31	37570	45895	
Notes				
1. When adding CFM values were rounded to the nearest factor of 5.				
2. Zone 24 was split evenly between zones served.				

Design Heating and Cooling Loads:

The design heating and cooling loads were calculated from an energy model created in Trane Trace 700. This program takes into account room size, window size, population, location, wall construction, ceiling construction, number of floors and countless other variables to formulate the loads for the building over a given year. The systems modeled in trace were water-source heat pumps served from boiler and cooling tower plants. After analyzing data, the total building load over the given year is 326.5 tons cooling and 219 tons heating. Table 2 below shows the airflow and heating/cooling capacity requirements for each ERV system.

Table 2: Heating/ Cooling Loads and Airflow

Model System Design Loads					
		Airflow (CFM)		Total Capacity (Tons)	
	Sq Ft	Supply	Exhaust	Heating	Cooling
ERV -1	27605	22394	10258	42.5	54.9
ERV -2	19080	25187	7553	48.3	62.4
ERV -3	12808	19751	6196	37.4	49.8
ERV -4	23263	11174	7060	23.6	30.6
ERV -5	8940	3591	2950	6.55	11.4
ERV -6	10980	11226	2351	18.3	27.8
ERV -7	6255	5925	0	2.9	12.1
ERV -8	6600	6539	90	3.9	12.9
ERV -9	9870	5471	84	3.2	12.9
ERV -10	24415	21369	6748	32.3	51.7
Total	149816	132627	43290	218.95	326.5

Results were produced through multiple iterations. The first iteration had produced results that were too low compared to the professional energy model that was provided by Barton Associates, the mechanical engineers. Multiple attempts and sequences were used to provide a more accurate energy model. There were two main changes that impacted the accuracy of the model. The first change was the supply air temperature. In the first couple of iterations the supply air temperature set point for the mechanical equipment was too high. Early models represented the supply air temperature was set to 57-59 degrees Fahrenheit however, it was reduced to 55-57 degrees in the later models. Reducing the supply air temperature was crucial to meeting the room loads and resulted in a higher cooling load. Similarly, window types within the building were also reconfigured. It was assumed in the first models high quality windows were to be used. Upon discussion with the mechanical designers, the window types were designed with the worst case scenario in mind. This design condition was put in place because when windows are replaced they have no control over what windows would be going in. Also, it was discussed, the mechanical system would rather be slightly oversized than be undersized and not be able to handle the load.

A new comparison of the accepted mechanical designer's model and the created model showed a close resemblance. Table 3 on the next page displays Barton Associates' model, indicated with a "B", and the created model indicated with an "N".

Table 3: Energy Model Comparisons

Combined Model and Design Results						
			Airflow (CFM)		Total Capacity (Tons)	
		Sq Ft	Supply	Exhaust	Heating	Cooling
ERV -1	N	27605	22394	10258	42.5	54.9
	B	22505	28074	9360	51.6	67
ERV -2	N	19080	25187	7553	48.3	62.4
	B	17142	19056	6434	34.3	46.5
ERV -3	N	12808	19751	6196	37.4	49.8
	B	16286	12803	5987	23.7	32.3
ERV -4	N	23263	3591	2950	6.55	11.4
	B	16251	15294	5985	27.4	40.1
ERV -5	N	8940	11975	8314	234	525
	B	5308	9394	3775	17.9	25.3
ERV -6	N	10980	11226	2351	18.3	27.8
	B	9303	12458	4813	26.4	38.1
ERV -7	N	6255	5925	0	2.9	12.1
	B	3391	2474	400	3.9	5.6
ERV -8	N	6600	6539	90	3.9	12.9
	B	/	/	/	/	/
ERV -9	N	9870	5471	84	3.2	12.9
	B	4659	4063	540	5.9	9.6
ERV -10	N	24415	21369	6748	32.3	51.7
	B	26635	22534	6947	33.7	55.8
Heating Only	B	9153	610	610	5.1	0
Stair WSHP	B	768	2773	25	3.7	6.2
WSHP - 20	B	2618	1991	0	0	4.1
WSHP - 89	B	806	599	48	1.4	1.3
Totals	N	149816	132627	43290	219.0	326.5
	B	134825	132123	44924	235	331.9

Results from table three were then complied to find the percent accuracy of each column. Therefore, displayed below in Table 4 is the percent accuracy of the created model for each category.

Table 4: Accuracy of Generated Energy Model compared to Professional Model

Accuacy of Energy Model						
			Airflow (CFM)		Total Capacity (Tons)	
		Sq Ft	Supply	Exhaust	Heating	Cooling
% Accuracy		11.1	0.38	3.64	6.81	1.63

The accuracy of the model is very similar, which mean the results should prove to be able to provide a very good basis of design for future work including, sizing equipment and various design changes.

Design Objectives and Requirements:

The most important requirement for the mechanical system is it needs to be efficient. Efficient to save the school district energy, as well as manageable maintenance and the ability to be paid back within a 30 year time period. It has been discussed and decided not to pursue LEED accreditation which provided more flexibility for the mechanical designers because they did not have to bend boarders satisfying LEED points. Not pursuing LEED accreditation also saved the school district money by not paying LEED Accredited Professionals to perform analysis on the systems.

When analyzing efficiency and maintenance, it is of utmost importance to make the water source heat pumps accessible from the corridors. This was something the architect and mechanical designer worked on early in the process to achieve that goal. The door to the cabinets were put in the hallway for acoustical considerations and were also made large enough for easy access to all critical maintenance areas of the equipment. With this in mind, it is possible for maintenance personnel to tear out the unit, even while class is in session, and can replace it with another unit. Extra acoustical batt insulation was put inside the walls near the equipment closets to reduce noise. .

In the project it was determined mechanical space was an important factor in design. The school wanted to focus on enhancing usable space rather than shrinking classroom space because of the mechanical systems. Maintaining a larger use of learning space, as well as providing easy maintenance, makes for creative design solutions to be adapted for the mechanical systems of the Early Learning Center.

Cost was one of the greatest objectives and requirements put forth by the school district. As a public school district the cost of the school will mostly impact the taxpayers in the area. Staying on budget is crucial to success on the Early Learning Center Project. Therefore, providing a cost effective energy efficient system will be the crux of the design problem. The mechanical design team will assess where the line between energy efficient and cost effective belongs.

Energy Sources and Rates:

The two different energy sources used within the Early Learning Center are natural gas and electricity. Both of these services are piped directly from the street from existing infrastructure. Natural gas is primarily to serve the boilers to create hot water for the ERV and Water Source Heat Pumps.

Other possible energy sources which could be of use to investigate would be to provide a power generation on their campus with either steam, coal, nuclear. With the close proximity and sharing of parking, busing circles and campus greenery, there might be a savings of generating some of their own power for all of their buildings, reducing load on PECO and HESS during peak supply times.

Energy Rates:

Rates for electrical and natural gas change varying on the time of year and current economic conditions. The electric rates used for the Early Learning Center reflect prices for the Phoenixville Area School District from PECO Billing for distribution charges. PECO tariffs for billing were not able to be recovered, therefore the following costs are straight costs and have not been taxed. It is also important to note electric generation charges were not provided. From the information given by the school district, \$0.08/KWh and \$4.96/KW were utilized for the analysis. The school district also provided rates from Hess Billing for their price of natural gas without including any transmission charges. Rates given by the school district were representative of the commodity price for August and September. Therefore, since the price changes based on season a yearly average would be best represented and $8.9/MMBTU was used for the analysis. It is also important to note, since there are almost 100 water source heat pumps within the building, this is a large amount of water and the school district needs to pay for water usage since it is located on the Borough of Phoenixville water supply. Water use charges were not provided so an assumption of $5/1000 gallon rate was utilized in Table 5.

Table 5: Energy Rates assumed for Project.

Energy Rates		
Source	Rate	Units
Natural Gas	$8.90	/MMBTU
Electric	$0.08	/KWh

Annual Operating Cost:

Operating costs for the systems were calculated using Trane Trace 700 results and simple algebra. In the modeled case the annual utility costs of natural gas and electric were able to be distinguished. The results are shown below in Table 6: Annual Electric and Natural Gas Cost.

Table 6: Annual Electric and Natural Gas Cost

Annual Fuel Cost ($)	
Electric	73,723.92
Natural Gas	8,066.59

Based on provided values from the mechanical engineer annual utility costs are able to be compared. Below is Table 7, showing the Annual Utility costs of the model and the designed cost.

Table 7: Annual Utility Cost Comparison

Annual Utility Cost ($)		
Modeled	Designed	% Difference
81,790.51	107,572	(23.97)

As shown in the table above, the designed values for annual utility cost is about 24 percent higher than the modeled cost. The difference could be the result of a simplified model and varied assumptions for consumption of different system components such as the lighting or electrical components.

Emissions:

Emissions given off were primarily because of the natural gas boilers. The model created was able to analyze the CO2, SO2 and NOX being emitted off of the Early Learning Center. With a 90 point Energy Star home the environmental impact of the building is still very large, especially with the CO2 emissions. Table 8 below shows the actual emissions values given off by the building.

Table 8: Emissions Impact

Environmental Impact Analysis		
CO2	1113250	lbm/yr
SO2	8599	gm/yr
NOX	1665	gm/yr

Site, Cost and other factors that influenced design:

The main issue of wanting, or not wanting a geothermal system was a main factor that influenced design. There were two distinct groups from the owner; one that did want geothermal heat pumps and one group that did not want geothermal pumps. After a site analysis, it was determined the geothermal well would need to be placed 400 – 500 feet away from the school because of the Astroturf fields causing the need for a higher head and more pump power which would increase cost. The aforementioned is studied and analyzed later as a depth topic.

In the start of construction it is becoming evident there will be a plethora of RFI's and change orders. This is occurring because of coordination issues with the structural and mechanical systems. The structural system was not designed or modeled in Revit at the time the mechanical system was designed and is leading to a large amount of clashes with different systems.

Climate:

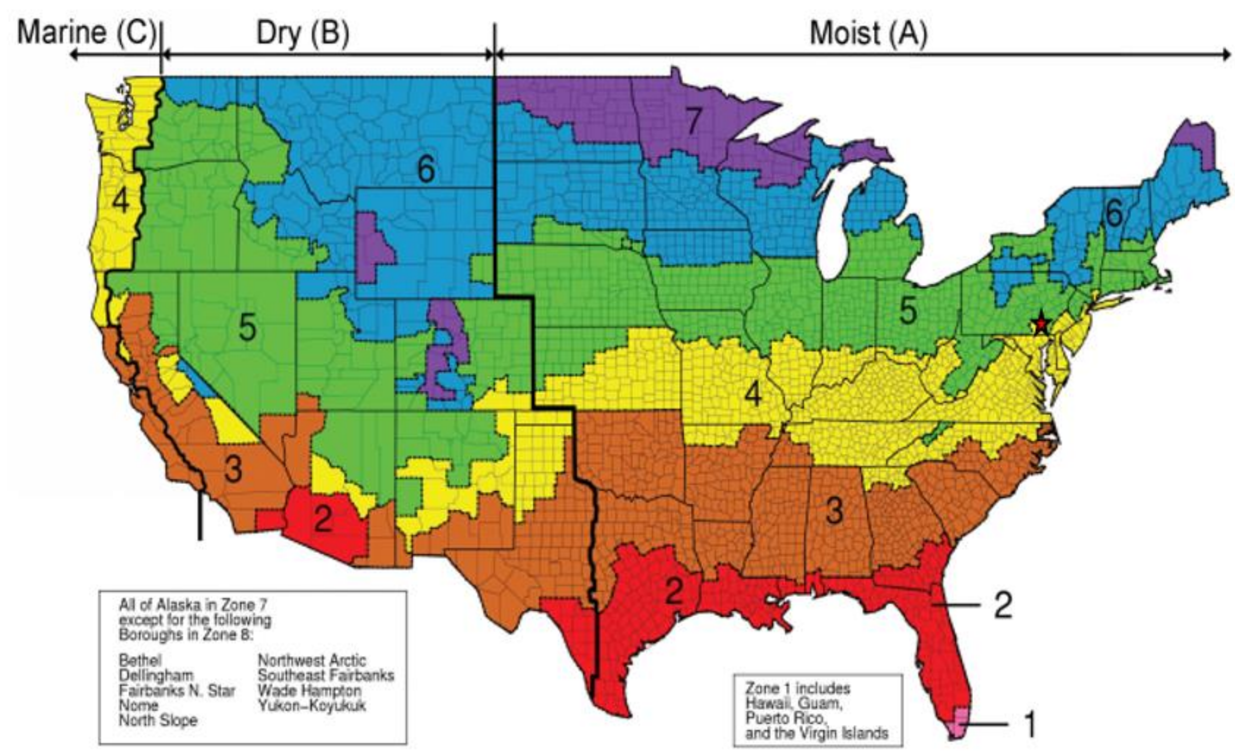


Figure 5: United States Climate Zone Map, ASHRAE Std 90.1- 2013

From analyzing the United States Climate Zone Map, the Phoenixville Early Learning Center is in Zone 5A, indicated in Figure 5 by the star. Zone 4A categorizes the location as a warm and humid location. In Zone 4A most of the precipitation comes in the winter months and humid summers. The Zone generally has less than 4500 Cooling Degree Days and between 3600 and 5400 Heating Degree Days.

Design Conditions:

Below the design conditions for the outdoor and indoor design conditions are discussed. These design conditions are the basis of temperatures and seasonal fluctuations of what the mechanical system needs to be designed to accommodate.

Outdoor Design Conditions:

The outdoor Conditions for the area of Phoenixville Early Learning Center and Elementary School are a direct reflection of the climate. As previously explained in Technical Report 1, the Early Learning Center is located in climate zone 5A, which designates the location as Cool-Humid with between 5400 and 7200 heating degree days. The specific temperatures used in the design for this building are shown in the table below. Temperatures were taken from ASHRAE Standard 169.

Table 9: Outdoor Design Conditions; Phoenixville, PA

Weather Design Condtions, Phoenixville, PA		
Season	Dry Bulb (°F)	Wet Bulb (°F)
Winter	11	/
Summer	91	74

Indoor Design Conditions:

The indoor Design Requirements were to keep the indoor air temperature and relative humidity levels to consistent states throughout the summer and winter months. During the summer months the temperatures would be higher because the temperature difference coming from the outdoors makes the interior space feel cooler. Similarly, in the winter the indoor temperature is lowered to save energy however, the occupants will still feel warm because they are coming from a cold outside temperature.

Table 10: Indoor Design Set Points

Conditioned Spaces (°F)			
Season	DB	WB	RH
Summer	79	68.2	\
Winter	70	\	30

Heating and Cooling Loads Comparison:

Heating Loads:

Heating Loads for the Early Learning Center and Elementary School are compared in the table below. Loads from the model and the mechanical engineers were computed using built Trane Trace 700 models. Both models included the different zones from the ERV units and comparatively showed similar results. Heating the water is two 166 ton high efficiency boilers, with one boiler on standby for emergencies.

Table 11: Comparison of Heating Loads

Heating Load Comparison (Tons)			
	Modeled	Designed	% Difference
ERV-1	42.5	52	18.3
ERV-2	48.3	34	-42.1
ERV-3	37.4	24	-55.8
ERV-4	23.6	27	12.6
ERV-5	6.55	18	63.6
ERV-6	18.3	26	29.6
ERV-7	2.9	4	27.5
ERV-8	3.9	/	/
ERV-9	3.2	6	46.7
ERV-10	32.3	34	5
Heating Only	/	5	/
Stair WSHP	/	4	/
WSHP-89	/	1.5	/
Total	218.95	235	6.829787234
/ = signifies the value was not represented			

Cooling Loads:

Similar to the heating loads, cooling loads for the elementary school were calculated using Trane Trace 700. Results of the calculations show similar performances of each models. Cooling for the building is derived from the 950 GPM Cooling Tower on the roof. After water is processed through the cooling tower pumps distribute the cooled water throughout the building.

Table 12: Comparison of Cooling Loads

Cooling Load Comparison (Tons)			
	Modeled	Designed	% Difference
ERV-1	44	67	34
ERV-2	42	46	9
ERV-3	36	32	11
ERV-4	30	40	25
ERV-5	44	26	41
ERV-6	23	38	39
ERV-7	7	6	14
ERV-8	8	/	/
ERV-9	13	10	23
ERV-10	40	56	29
WSHP-20	/	4	/
Stair WSHP	/	6	/
WSHP-89	/	2	/
Total	288	332	13
/ = signifies the value was not represented			

Existing Mechanical System:

The existing mechanical system is comprised of many systems working simultaneously together. The mechanical system has a main face of a Water source heat pump system fed from Energy Recovery Units which are heated and cooled with a boiler and cooling tower, which also utilizes a flat plate heat exchanger. These components heat and cool water as well as air to provide a sustainable and comfortable working environment for the occupants of the building.

Air-Side Components:

Intake air for the Early Learning Center is brought in through the ten Energy Recover Ventilators (ERV) on the roof. ERV units send air through the duct systems to reach terminal Water Source Heat Pump (WSHP) units located in closets in the classrooms as well as seven Rooftop Water Source heat pumps (RTWSHP) on the roof. When the air reaches one of these terminal WSHP units the air is conditioned again to ensure the proper temperature and comfort level for that particular room. This is one of the advantages of having terminal WSHP units because if a room on the south side of the building is experiencing a large solar gain they can lower the temperature on the unit, whereas a classroom on the north side of the building might need to turn the temperature up because they are not receiving the solar gain.

Energy Recovery Ventilator (ERV) – Air is brought into the building through these units which positively pressurize and feed the building. If all WSHP's are indexed to unoccupied mode the ERV unit serving those zones will de-energize and shut down with all dampers closing. ERV units are built with an energy wheel which mixes outdoor air and return air. By mixing the air by use of a rotating energy wheel outdoor air is able to be heated with the excess energy in the return air.

Table 13: Energy Recovery Ventilator Unit Schedule

Major Equipment: Energy Recovery Ventilators				
	OA CFM	EA CFM	OA FAN HP	EA FAN HP
ERV-1	8915	8470	10	10
ERV-2	6480	5845	7.5	5
ERV-3	6155	5945	5	5
ERV-4	6125	5600	5	5
ERV-5	3775	3050	3	1.5
ERV-6	5000	4500	3	3
ERV-7	600	550	1/3	1/3
ERV-8	600	550	1/3	1/3
ERV-9	3870	3870	3	3
ERV-10	4375	4155	5	5

Water Source Heat Pumps (WSHP) – RTWSHP's and terminal WSHP's for the classrooms function the same but vary in size. WSHP's take air and push them through heating and cooling coils. These coils are filled with water as a source to transmit energy which is fed from the boiler and cooling tower (*See Water Side Components).* With the large amount of WSHP's the all tonnages are represented in table 10 below.

Table 14: Water Source Heat Pumps Unit Schedule

Main Units: Water Source Heat Pumps								
		Fan Data					Cooling	
		CFM		ESP	HP	Heating (Tons)	Tons	
Unit	Tonnage	Total	OA				Total	Sense
WSHP-1	3	910	420	0.5	1/3	3.95	2.95	1.88
WSHP-7	4	1370	870	0.5	1/2	5.16	3.85	2.57
WSHP-14	3/4	255	40	0.5	1/8	0.92	0.7	0.5
WSHP-17	1.5	515	345	0.5	1/8	1.98	1.48	1
WSHP-22	2.0	760	155	0.5	1/3	2.75	2.08	1.44
WSHP-46	3.0	1140	420	0.5	1/2	4.07	3.04	2.1
WSHP-73	4.0	1670	490	0.5	1/2	5.51	4.33	3.09
RTWSHP-1	6.0	2430	600	1.25	1	7.45	6.17	5
RTWSHP-2	10.0	4305	600	1.5	5	12.4	8.72	9.29
RTWSHP-3	20.0	6500	2500	0.75	5	27.3	15.58	16.28
RTWSHP-6	15.0	6100	2665	0.87	5	16.88	9.98	10.69
RTWSHP-7	12.5	5500	1100	0.87	3	16.74	9.48	10.06

Fan units – There are several rooftop fans that draw outdoor air into the building for a DOAS system and help push the air to where it needs to go throughout the building.

Table 15: Fan Unit Schedule

Major Units: Fans				
Unit	CFM	ESP	HP(WATTS)	SONES
F-1	5355	1.25	2	15.5
F-2	600	0.8	1/4	8.2
F-3	500	0.5	0.067	7.4
F-4	500	0.5	0.067	7.4

Water-Side Components:

The water-side components are crucial to the success of the building's comfort. Water-side components control the temperature of the air that is being blown into the spaces because the air is first blown over the heating and cooling coils. It is imperative these coils be filled with the correct temperature water to provide steady, comfortable air. Temperatures of water are changed through the boiler where the water is heated to a gas state. This gas then condenses and goes to the cooling tower, where the cooling tower can cool the reuse water. Water from the cooling tower and the boiler are sent to ERV's and WSHP's to condition the air before it is delivered to the occupants. Water is constantly circulating and will progress back to either the cooling tower or the boiler to be reconditioned.

Boiler – A boiler heats water by burning natural gas. Water is pushed through multiple fins over the fire converting the water to steam and is pushed to the condensing tank where is cooled back into water and assumes the temperature it will be distributed through the building. Water leaving the boiler is at 140°F.

Table 16: Boiler Schedule

Major Equipment: Boilers						
	Gas Boiler					Boiler Motor HP
	Tons		GPM	LWT	Boiler HP	
Unit	Input	Output				
B-1	166.7	160	190	140	57.4	1.18
B-2	166.7	160	190	140	57.4	1.18
B-3	166.7	160	190	140	57.4	1.18

Cooling Tower – In the cooling tower energy is removed to cool the water. Energy is removed by evaporation. Water enters the cooling tower at 98.8 °F and leaves at 85°F

Table 17: Cooling Tower Schedule

Major Equipment: Cooling Tower						
Unit	Type	GPM	EWT	LWT	Tower WPD (PSI)	Fan HP
CT-1	Induced Draft	950	98.8	85	4.33	25

Plate-Frame Heat Exchanger (HX) – The HX can condense or heat the water depending on the supply and temperature of the water given. In the case of the elementary school it does perform both heating and cooling.

Table 18: Plate-Frame Heat Exchanger

Major Equipment: Plate-Frame Heat Exchanger								
Unit	Cooling Tower					Condenser Water		
	Tons	EWT	LWT	GPM	WPD	EWT	LWT	GPM	WPD
HX-1	541967	85	98.8	950	10.2	101.6	87	900	9.3

Pumps – Pumps control the supply of water to all of the heating coils in the rooftop units, the water source heat pumps and VAV boxes. These pumps are extremely important to the function of transporting liquid.

Table 19: Pump Schedule

Major Equipment: Pumps							
Unit	Service	GPM	FT HD	% EFF	RPM	HP	Impeller Size
P-1	Condenser Water	900	80	84.5	1750	30	9-7/8"
P-2	Condenser Water	900	80	84.5	1750	30	9-7/8"
P-3	Cooling Tower	950	55	82.4	1750	20	8-3/4"
P-4	Cooling Tower	950	55	82.4	1750	20	8-3/4"
P-5	Boiler Circulator	188	20	63	1750	2	5-5/8"
P-6	Boiler Circulator	188	20	63	1750	2	5-5/8"
P-7	Boiler Circulator	188	20	63	1750	2	5-5/8"

Schematic System Diagrams:

Air-Side Schematic:

In Figure 6 below, the schematic diagram for the Air-Side system is shown. Air first flows into the ERV unit to from outside and is conditioned before it is sent down to the WSHP's in the second and first floors. When the air travels down the duct there is a possibility for heat transfer through the duct by conduction, or convection. Before, the air turns to enter the WSHP it must pass through a volume damper. This volume damper controls the amount of air going through each WSHP. Dampers should be balanced at turnover of the building and periodically throughout the lifespan of the building. After passing the volume damper there is a reheat coil within the WSHP to combat the heat transfer that may have occurred on the way to the unit.

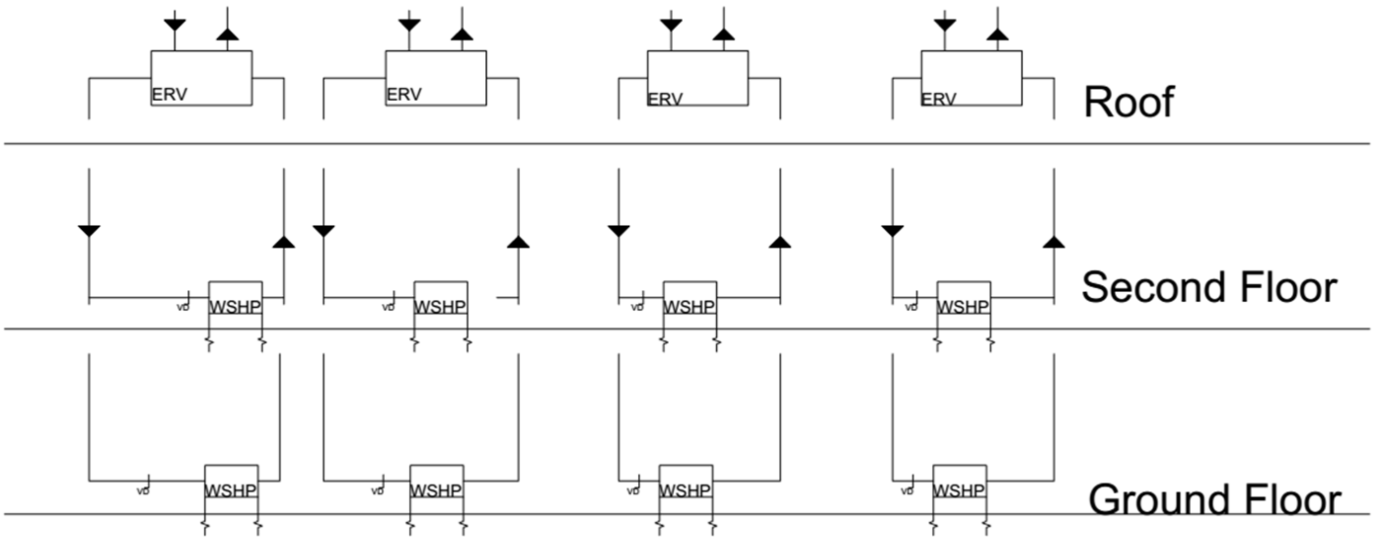


Figure 6: Air-Side Schematic

Water-Side Schematic:

In the water-side schematic, Figure 1Figure 7 below, starting at the boilers the water is heated up and passes through the boilers where it encounters the Air Separator, to remove air bubbles from the vapor gas, and then it can go through a series of valves to the expansion tank where excess pressure can be let out. Before going in the Expansion tank there is an automatic air vent to vent excess pressure. Condensate then moves through to the pressure gage where it is determined if it needs to go through the pressure reducing valve and out of the system. Back before the split to the Expansion tank is the suction from the pumps. The condensate will go through a gate valve down into the pump and discharged through to the other side after running through a pressure gauge, monitoring pressure. Condensate is then distributed to the WSHP where it is again run through a temperature gauge. After being run through the unit it goes through a balancing valve and is sent back to the boilers. On the cooling tower side of the loop, it comes out of the cooling tower, with the pressure being monitored and is sent directly to the WSHP. After the condensate is run through the WSHP it is sent back to the cooling tower to lower the temperature again and continuously runs through the loop.

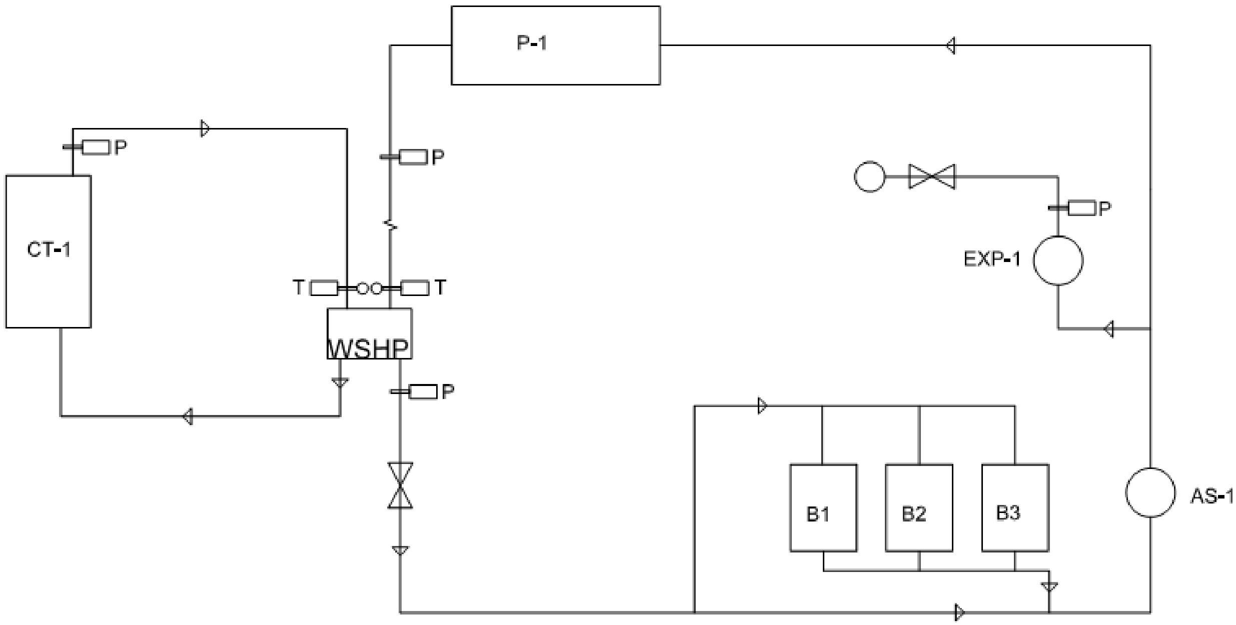


Figure 7: Water-Side Schematic Drawing

Mechanical System Space Considerations:

Shown below, Table 20 shows the square footage of floor space lost to mechanical equipment and services in each zone of the building.

Table 20: Floor Space Lost to Mechanical Chases

Floor Space Lost											
Zone	1A	1B	1C	1D	1E	2A	2B	2C	2D	2E	Total
Area (SF)	251	72	34	309	159	272	155	21	183	119	1575

Water source heat pumps take up the most space of the 1575 square feet lost. This is because the WSHP units are located into closets in the hallways and are given a large amount of space to be easily accessible. In preliminary designs of the building these spaces were developed and included because it was a requirement of easy maintenance for the client. Square feet vary from area to area due to the types of spaces within the zones as well as what types of areas are located above the zones. It is also important to note there are ten ERV units, seven RTWSHP units, three boilers, and a cooling tower on the roof. By allowing a large amount of equipment on the roof it frees up space within the building to allow for programmable areas.

Mechanical System Costs:

Currently the winning bid for construction of the building was 31.1 million dollars. Of the 31.1 million dollar total cost of the building 4.0 million dollars was the base mechanical system bid. At the time of publishing the mechanical contractor has yet to publish a specific itemized list of cost per item. To note, the mechanical bid included alternates such as geothermal heat pumps instead of water source heat pumps which would raise the cost 1.5 million dollars with the cost of each additional geothermal well, beyond the scope, to be 10,000 dollars each.

Mechanical Depth:

Design alternatives for the Phoenixville Early Learning Center are discussed below. These designs will be compared to the original system from studies of their performance in construction cost, space utilization, operating cost, ease of maintenance, and energy usage. Potential benefits, effects to the design as well as their impact on other systems was taken into consideration to make a final recommendation for the owners of the Early Learning Center.

The following systems were studied as alternatives for the final design of the project, geothermal heat pumps, centralized air handling unit, variable refrigerant flow system. Systems were compared and evaluated based on cost, energy efficiency, space utilization and ease of maintenance.

Geothermal Heat Pump System Analysis:

A geothermal heat pump system means there is a use of a refrigerant that will pass through the ground using the earth as a heat source and a heat sink. There are many factors to take into consideration when choosing to put in a geothermal heat pump system. The first is ground temperature and well depth. Depending on the ground temperature the bore holes will be very long or be shorter and will possibly have to have supplemental heating and cooling. Designers decide to choose a geothermal heat pump system because of its energy efficiency because there does not need to have electric or natural gas to heat and cool the building, such as a cooling tower or a boiler would operate. Over a lifespan of 20 to 30 years a geothermal system will save a considerable amount of energy.

Saving energy does not come without costs though. Geothermal systems have high first costs because the well system needs to be constructed. Depending on the system this could include drilling boreholes or digging trenches and then filling the area with a thermally enhanced grout aiding heat transfer. Earthwork becomes a large portion of cost for geothermal systems. Other factors that affect cost include temperature drop if inlet and outlet temperatures, well depth, flow rates, distance between well site and the building, as well as ground temperature.

Geothermal Sizing Calculations:

Geothermal heat pump systems require wells or bore holes to transfer the heat from inside the ground to the refrigerant within pipes where the heat is carried into the building and able to supply warm air. Similar is true for the opposite reaction of cooling. In the summer months, the ground is cooler than the air and will be able to cool down the building.

Pipe sizing is very important to ensure the heat transfer is adequate. Various calculations were derived to create and understand the piping system. The first equation is the equation to solve for the length of the bore holes. In order to solve for this equation many other variables also need to be solved. The process of solving for these variables will be explained on the next page.

$$L_C = \frac{q_a R_{ga} + (q_{lh} - 3.41 W_{h)}\left(R_b + PLF_m R_{gm} + F_{sc} R_{gd}\right)}{t_g - \frac{ELT+LLT}{2} + t_p} \quad (4)$$

$$L_h = \frac{q_a R_{ga} + (q_{lc} - 3.41 W_{c)}(R_b + PLF_m R_{gm} + F_{sc} R_{gd})}{t_g - \frac{ELT+LLT}{2} + t_p} \quad (5)$$

Equations and Variables from ASHRAE 2015 Handbook, HVAC Applications

Where;

F_{sc} = Short-circuit heat loss factor
L_C = Required Bore Length for cooling, ft
L_h = Required bore length for heating, ft
PLF_m = Part-load factor during design month
q_a = net annual average heat transfer to ground, Btu/hr
q_{lc} = Building design Cooling block load, Btu/hr
q_{lh} = Building design heating block load, Btu/hr
R_{ga} = effective thermal resistance of ground (annual pulse), (ft*hr* °F)/Btu
R_{gd} = effective thermal resistance of ground (peak daily pulse), (ft*hr* °F)/Btu
R_{gm} = effective thermal resistance of ground (monthly pulse), (ft*hr* °F)/Btu
R_b = thermal resistance of bore, (ft*hr* °F)/Btu
t_g = undisturbed ground temperature, °F
t_p = temperature penalty for interference of adjacent bores, °F
t_{wi} = liquid temperature at heat pump inlet, °F
t_{wo} = liquid temperature at heat pump outlet, °F
W_c = system power input at design cooling load, W
W_h = system power input at design heating load, W

Many of these variables needed to be calculated before they can be inputted into equations. The following section will review how each variable was solved.

Short-Circuit Heat Loss Factor, F_{sc}

The Short Circuit Heat Loss Factor is the factor considered for the heat loss and gain from fluid in pipes being too close to each other they transfer heat. This factor is found in the ASHRAE Handbook in chapter 34. It was assumed there would be one bore per loop with a flow rate of 3 gpm/ton. Therefore, the Short-Circuit Heat Loss factor was found to be 1.04.

	F_{sc}	
Bores per Loop	**2 gpm/ton**	**3 gpm/ton**
1	1.06	1.04
2	1.03	1.02
3	1.02	1.01

Figure 8: Short Circuit Heat Loss Factor

Part-load factor during design month, PLF_m

Part-load factor was assumed to be 1.0 because it represented the worst case possible.

Net annual average heat transfer to ground, q_a Btu/hr:

Average heat transfer to the ground was calculated by finding the average of the heating block load and the cooling block load. This average turned out to be 248319 Btu/hr.

Building design Cooling block load, q_{cond} Btu/hr:

The cooling block load was determined based off of the energy model created with Trane Trace 700 and factoring many elements to the building. The calculated cooling block load is 401040 Btu.

Building design Heating block load, q_{evap} Btu/hr:

The heating block load was determined based off of the energy model created with Trane Trace 700 and factoring many elements to the building. The calculated heating block load is 376200 Btu.

*Effective thermal resistance of ground (annual pulse), R_{ga} (ft*hr* °F)/Btu*

Thermal resistance of the ground was acquired from a formula used in ASHRAE Chapter 34 that is displayed below in the calculations section. Thermal resistance of the ground is 0.228 (ft*hr* °F)/Btu

*Effective thermal resistance of ground (peak daily pulse), R_{gd} (ft*hr* °F)/Btu*

Formulas provided in ASHRAE Chapter 34 give an equation for the peak daily pulse of thermal resistance. Calculations of the thermal resistance are given below in the calculations section. Peak Daily pulse thermal resistance is 0.132 (ft*hr* °F)/Btu.

*Effective thermal resistance of ground (monthly pulse), R_{gm} (ft*hr* °F)/Btu*

Similar to R_{ga} and R_{gd} the monthly pulse was calculated using formulas from ASHRAE Chapter 34 which are displayed below. The thermal resistance monthly pulse is 0.205 (ft*hr* °F)/Btu.

Geothermal Calculations:

The following equations were used to predict the thermal resistance of the ground. G-Factors were solved using Figure 9 from ASHRAE Handbook, 34.19.16 after the Fourier numbers were computed. This resulted in being able to calculate the thermal resistances, since G-Factors are known.

$$R_{ga} = \frac{G_f - G_1}{k_g} \qquad R_{gm} = \frac{G_1 - G_2}{k_g} \qquad R_{gst} = \frac{G_2}{k_g}$$

$$R_{ga} = \frac{(0.943 - 0.562)}{1.67} = 0.228 \qquad R_{gm} = \frac{(0.562 - 0.220)}{1.67} = 0.205 \qquad R_{gst} = \frac{0.220}{1.67} = 0.132$$

$$F_o = \frac{4\alpha_g \tau}{d^2}$$

$$Fo_1 = \frac{4 * 1.06 * (3680.25 - 3650)}{0.5^2} = 513.04$$

$$\tau_1 = 3650\ days$$

$$Fo_2 = \frac{4 * 1.06 * (3680.25 - 3680)}{0.5^2} = 4.24$$

$$\tau_2 = 3650 + 30 = 3680\ days$$

$$Fo_f = \frac{4 * 1.06 * 3680.25}{0.5^2} = 62417$$

$$\tau_f = 3650 + 30 + 0.25 = 3680.25\ days$$

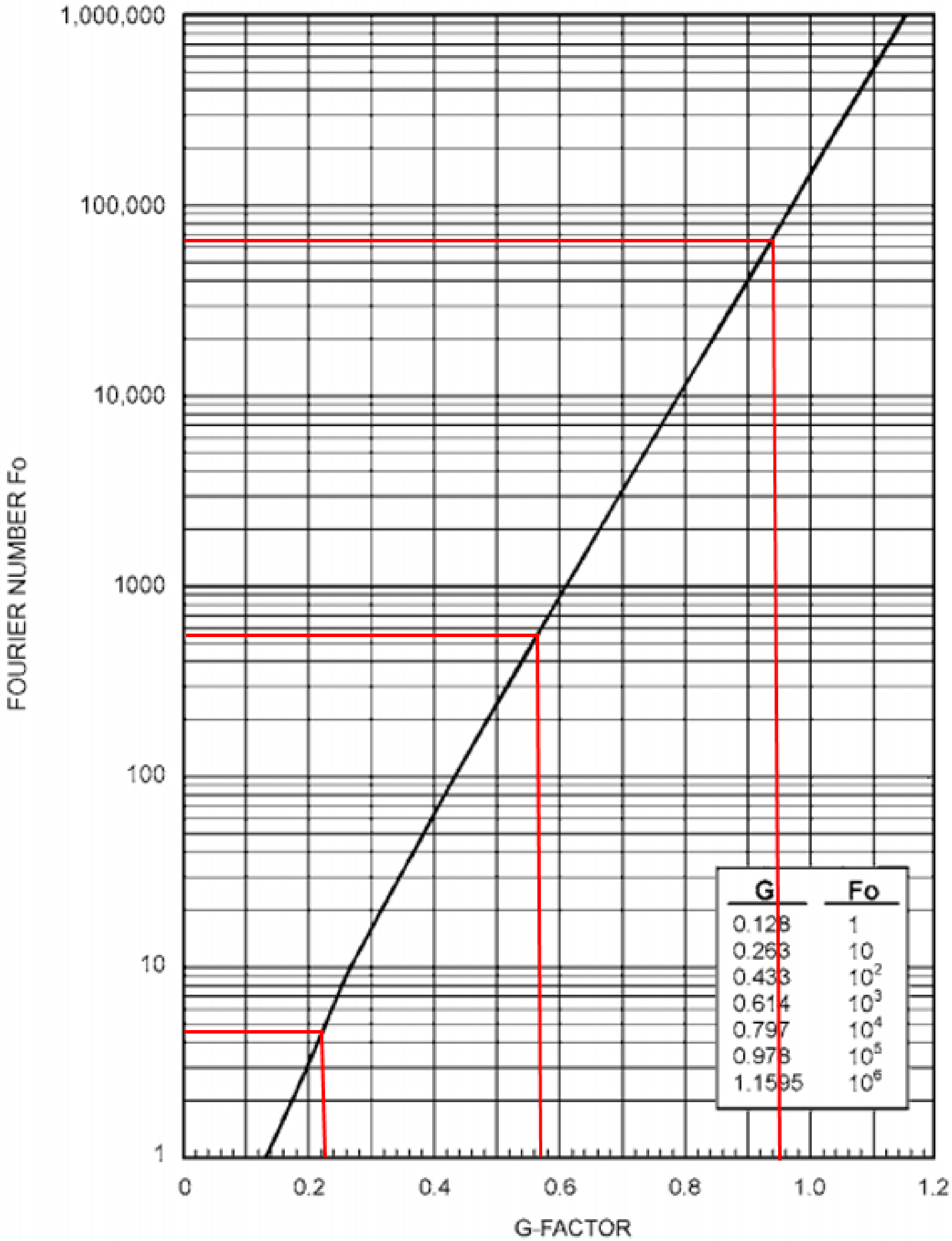


Figure 9: Fourier/G-Factor Graph for Ground Thermal Resistance, ASHRAE Handbook 34.19.16

Thermal Resistance of Bore, R_b (hr*ft* °F)/Btu

The thermal resistance of the bore was found using a table within the ASHRAE Handbook, chapter 34. The thermal resistance was determined from Figure 10 to be 0.09.

Table 6 Thermal Resistance of Bores R_b for High-Density Polyethylene U-Tube Vertical Ground Heat Exchangers

U-Tube Diameter, in.	Bore Fill Conductivity,* Btu/h·ft·°F — 4 in. Diameter Bore			6 in. Diameter Bore		
	0.5	1.0	1.5	0.5	1.0	1.5
3/4	0.19	0.09	0.06	0.23	0.11	0.08
1	0.17	0.08	0.06	0.20	0.10	0.07
1 1/4	0.15	0.08	0.05	0.18	0.09	0.06

*Based on DR 11, HDPE tubing with turbulent flow

Corrections for Other Tubes and Flows

DR 9 Tubing	Re = 4000	Re = 1500
+0.02 Btu/h·ft·°F	+0.008 Btu/h·ft·°F	+0.025 Btu/h·ft·°F

Sources: Kavanaugh (2001) and Remund and Paul (2000).

Figure 10: Thermal Resistance of Bores, Rb

Undisturbed Ground Temperature, t_g, °F

A geothermal heat pump system was considered for this building because the building is in a good region of the country for stable and moderate temperatures. As demonstrated earlier, the Early Learning Center is located within climate zone 4A, meaning it is warm and humid. When analyzing the location of the building on Figure 11 below, the site has approximately a 54°F undisturbed ground temperature. Location of the building site is denoted as a red star. This temperature will require more bore length than a warmer climate but will perform very well in cooling.

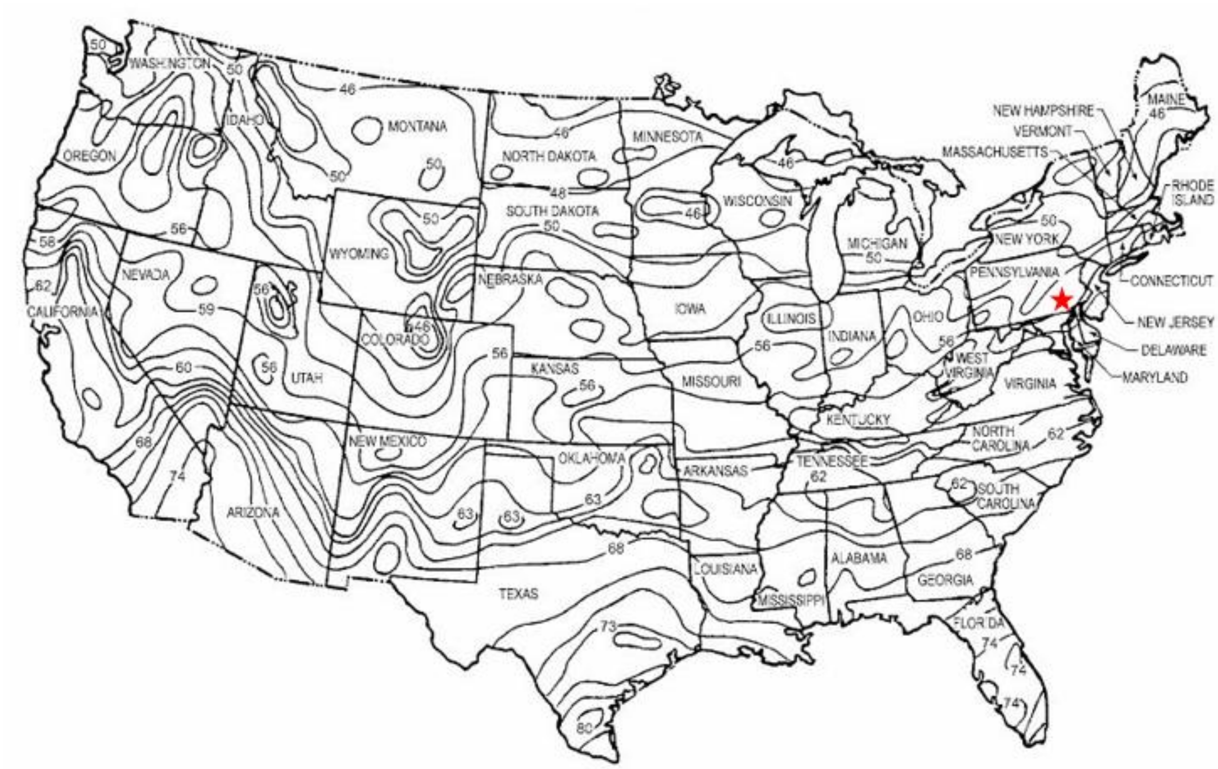


Figure 11: Approximate Groundwater Temperatures (°F): ASHRAE Handbook, HVAC Applications 34.19.18

Long-term Ground Temperature Penalty, t_p, °F

Long-term Ground Temperature Penalty is based on the separation between bores, the Equivalent Full- Load Hours and the bore length. Based on a chart in the ASHRAE Handbook Chapter 34, the EFLH of the site is around 750. This represents the typical number of hours of occupancy. Based off of this number the temperature penalty was found using the following figure and a bore separation of 20 feet. The temperature penalty is 1.8.

Table 7 Long-Term Temperature Penalty for Worst-Case Nonporous Formations for 10 × 10 grid and 100 ton Load

$EFLH_c$, h/yr	$EFLH_h$, h/yr	EER, Btu/W·h	COP	T_g, °F	Bore Separation, ft	Bore Length, ft	$T_{penalty}$, °F
250	1250	17.6	3.6	42	15	230	–1.3
		17.6	3.6		20	221	–0.7
		17.6	3.6		25	217	–0.4
500	1000	16.8	3.7	45	15	218	–1.4
		16.8	3.7		20	210	–0.7
		16.8	3.7		25	206	–0.4
750	750	14.3	4.0	55	15	206	3.4
		14.3	4.0		20	195	1.8
		14.3	4.0		25	190	1.0
1000	500	13.3	4.4	65	15	284	6.9
		13.3	4.4		20	248	3.8
		13.3	4.4		25	231	2.0
1250	250	13.0	4.6	68	15	362	10.0
		13.0	4.6		20	289	5.7
		13.0	4.6		25	256	3.0
0	1500	Not recommended without solar or thermal regeneration					
1500	0	Not recommended without fluid cooler or cooling tower assist					

Note:
k_g = 1.4 Btu/h·ft·°F, k_{grout} = 0.85 Btu/h·ft·°F, rated EER/COP = 20.0/4.2 (GLHP).

Correction Factors for Other Grid Patterns:

1 × 10 grid	2 × 10 grid	5 × 5 grid	20 × 20 grid
C_f = 0.36	C_f = 0.45	C_f = 0.75	C_f = 1.14

Figure 12: Long-Term Temperature Penalty, ASHRAE Handbook, 34.19.7

Heat Pump Entering Liquid Temperature

In cooling mode the optimum temperature is 20°F to 30°F higher than the undisturbed ground temperature. This range varies based on climate. In colder climates it is advised to be on the higher end of the range and for warmer climates to be on the lower range. The inlet cooling temperature is 79 degrees, 25 degrees above the undisturbed ground temperature.

In heating the range for optimal conditions is 8°F to 15°F less than the undisturbed ground temperature. Climate also dictates which side of the range the building should be near, with warmer climates being on the lower side of the range and colder climates being on the higher range. The entering temperature for heating is 40°F.

Heat Pump Leaving Liquid Temperature

Optimum leaving temperature for cooling at a 3 gpm/ton flow rate is 10 degrees higher for the cooling. The leaving temperature for cooling is 89°F.

Optimum leaving temperature for heating at a 3 gpm/ton flow rate is 6 degrees lower than the entering temperature. The leaving temperature for heating is 34°F.

System Power Input

System power input is based on the power from the pump that circulates the refrigerant. The largest pump was chosen based on pump head. The pump selected is a series 60 Bell & Gossett inline circulator pump with 3 horsepower. There will be two pumps in series to accommodate the head. The power input is 4474.2 Watts

Borehole Length Calculations

A summary of the previous variables is represented in Table 21: Bore Length Summary below.

Table 21: Bore Length Summary

Bore Length Calculation			
Cooling	Heating	Variable	Description
1.04	1.04	Fsc	Short-circuit heat loss factor
1	1	PLFm	Part-load factor
248319	248319	qa	Net annual average heat transfer to the ground
0.228	0.228	Rga	Thermal resistance of the ground (annual pulse)
0.132	0.132	Rgd	Thermal resistance of the ground (daily pulse)
0.205	0.205	Rgm	Effective thermal resistance of the ground (monthly pulse)
0.09	0.09	Rb	Thermal resistance of bore
54	54	tg	Undisturbed ground temperature
1.8	1.8	tp	Ground temperature penalty
79	40	ELT	heat pump entering liquid temperature
89	34	LLT	heat pump leaving liquid temperature
401040	376200	qlc/qlh	Building design block load
4474.2	4474.2	Wc/Wh	Pump Power
62275	66882	Lc/ Lh	Required bore length

Boreholes will be sized to the largest length for heat transfer. The bore length must be at least 66882 feet. Having the bore length at 66882 feet, the system will be able to manage the loads put forth by the building.

Geothermal Layout:

Vertical bore holes have been decided to be used for the well field of the Early Learning Center. The surrounding area was analyzed for a plot of land to host the wells and a vertical well system best fit the space. Most of the surrounding area from the elementary school is being planned for development which leaves little room to install a 67000 foot piping system.

Table 22: Required Number of Bores

Required Number of Bores		
Bore Depth	Number of Bores	20% Safety
100	669	803
200	334	401
300	223	268
400	167	201
500	134	161

The number of bores required is given for the corresponding bore depth in Table 22 above. The bore depth chosen was 400 feet. This was chosen because it will allow the bores to be spaced out rather than having to go down farther and minimize space. Since there is allowable space on the baseball field for the bores to be spread out, it will also ease maintenance, and will be comparative in cost.

The well field will need to be constructed under one of the baseball fields. This layout allows easy maintenance upon breakdown of pipes or pumps. A baseball field can easily be dug up and re-sodded for a relatively inexpensive cost if the school district needed to perform maintenance on the system. Overtop of the field, the pipes will not have a lot of weight over top of them leading to less cracked pipes and less maintenance issues than if they were under a parking lot. Figure 13: Bore FieldFigure 13 below shows the proposed bore field layout.

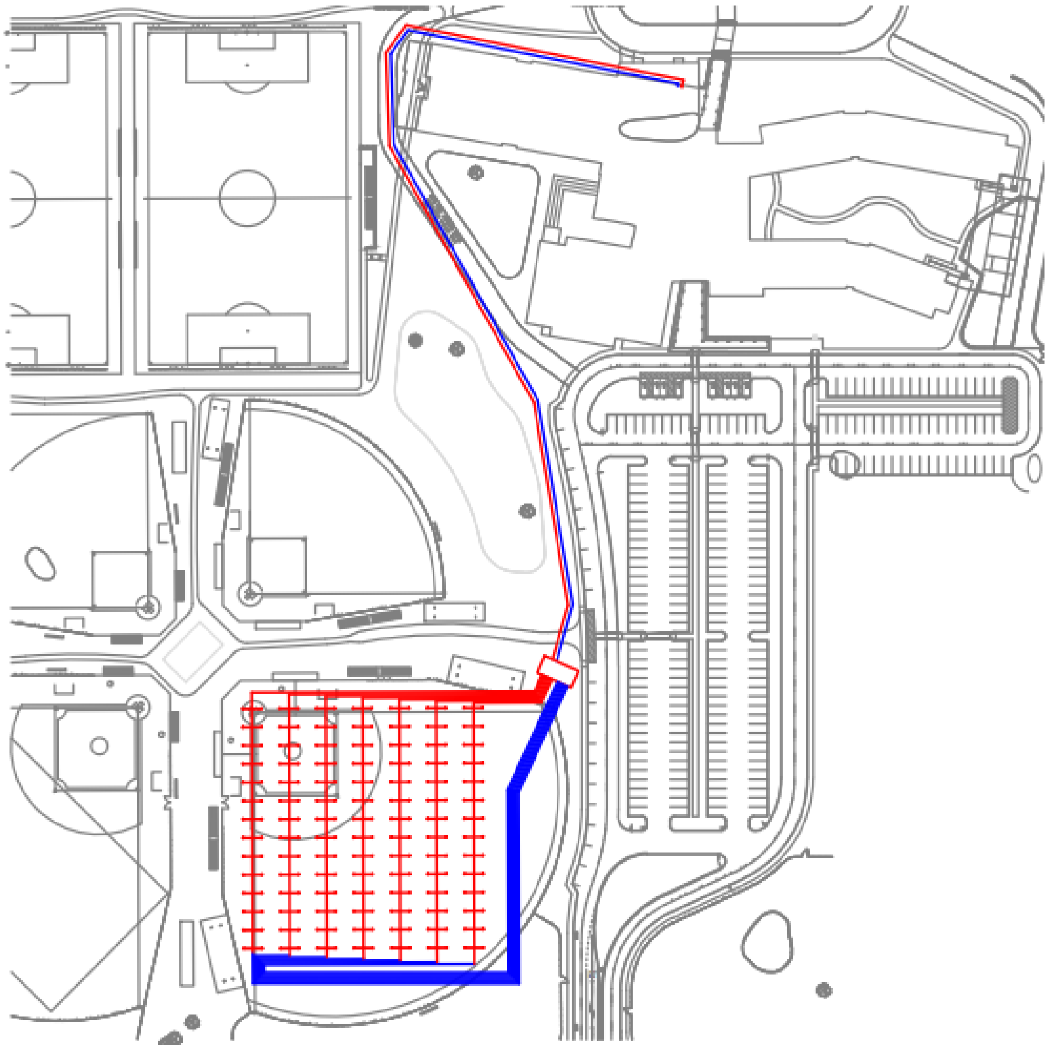


Figure 13: Bore Field

The supply, in red comes out of the mechanical room and serves the bore field after splitting into multiple pipes to serve the seven rows of wells. The pipes are supplied down to one of 28 bore holes and sent down the rest of the pipe to be supplied back to the building. At the end of the runs pipes are bent back to equal out length from each row and supplied back to the building.

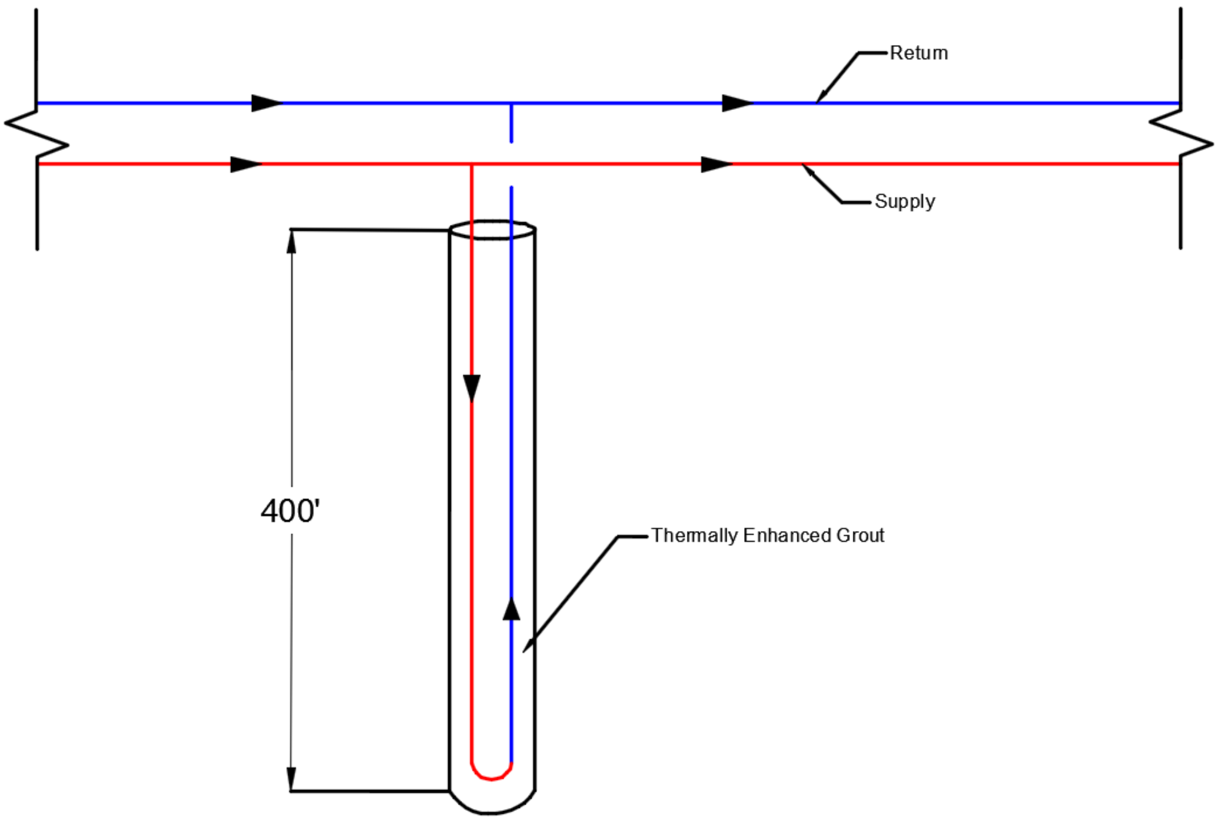


Figure 14: Borehole Detail

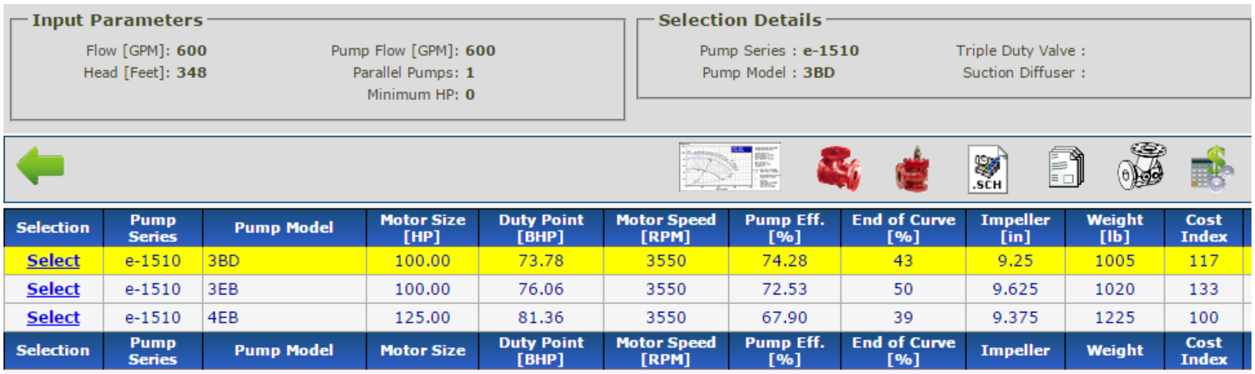
Inside the borehole will be high-density polyethylene pipe. This pipe was chosen because it can hold up to the pressures included with the ground-coupled system as well as the pumping pressures. Downsides to the piping layout include the extra distance from the building's mechanical system to the beginning of the geothermal well field. Distance covered from the mechanical room to the pumps on the exterior of the well field is roughly 1300 feet. Therefore, having to cover the distance twice, supply and return, the distance is 2600 feet. Therefore, the distance even before the 67000 feet of piping is about a half mile which will increase head loss. Head loss for getting the ethylene glycol to the building is calculated using three different equations. First the average velocity needs to be found. Then, the Reynolds number needs to be found to find the moody friction factor. Finally, the head loss can be found using the Darcy-Weisbach equation.

$$\bar{V} = \frac{\dot{Q}}{A} \qquad Re = \frac{\rho \bar{V} D}{v} \qquad l_f = f \frac{L}{D} \frac{\bar{V}^2}{2g}$$

The three equations are found above to find the total head loss. For the 2600 foot run from the wells to the building the lost head is Pa or 1.4 ${}^{lb_f}/_{in^2}$, also 3.2 foot of head. The head loss for the total system including to and from the building is 1082909 Pa or 363 foot of head.

Geothermal Equipment Selection

The pump selected for the geothermal system is a Bell & Gossett Series e-1510 3BD 3550RPM pump. This pump was selected because it had the right capacity and could pump the total head that was required of the system. It was selected using the pump selection software from Bell & Gossett.



Selection	Pump Series	Pump Model	Motor Size [HP]	Duty Point [BHP]	Motor Speed [RPM]	Pump Eff. [%]	End of Curve [%]	Impeller [in]	Weight [lb]	Cost Index
Select	e-1510	3BD	100.00	73.78	3550	74.28	43	9.25	1005	117
Select	e-1510	3EB	100.00	76.06	3550	72.53	50	9.625	1020	133
Select	e-1510	4EB	125.00	81.36	3550	67.90	39	9.375	1225	100
Selection	Pump Series	Pump Model	Motor Size	Duty Point [BHP]	Motor Speed [RPM]	Pump Eff. [%]	End of Curve [%]	Impeller	Weight	Cost Index

Figure 15: Bell & Gossett Pump Selection

As shown in figure below the pump meets a percent efficiency of 74.28%.

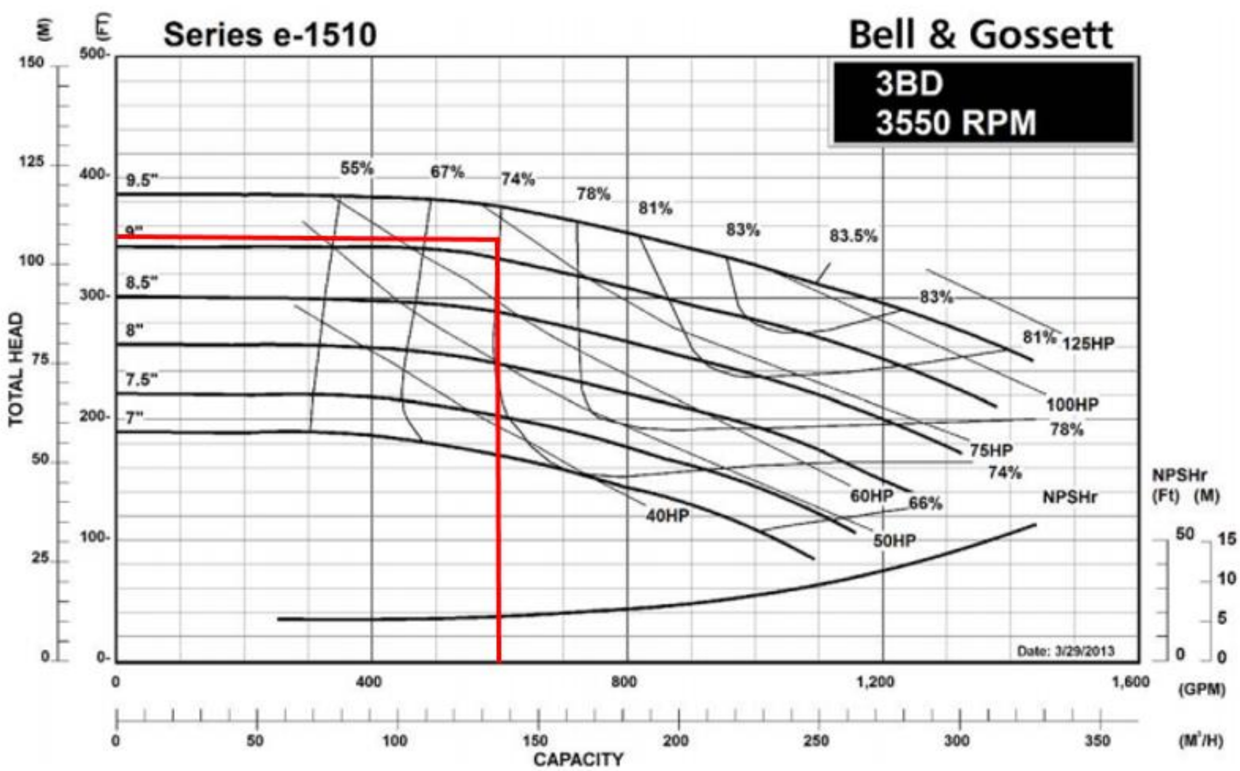


Figure 16: Pump Efficiency Curve for the Vertical Wells

Variable Refrigerant Flow System Analysis:

Variable refrigerant flow (VRF) systems have become more available and thus have been implemented more in the past few years. Variable refrigerant flow systems vary the flow rates of refrigerant throughout the building and blow air across the coils in terminal units to supply heating and cooling to the spaces. Advantages to using a VRF systems are multi-zone heating and cooling, efficiency at part loads, local and remote monitoring and zoned comport control. The schematic in Figure 1Figure 17 below shows the configuration of the system components.

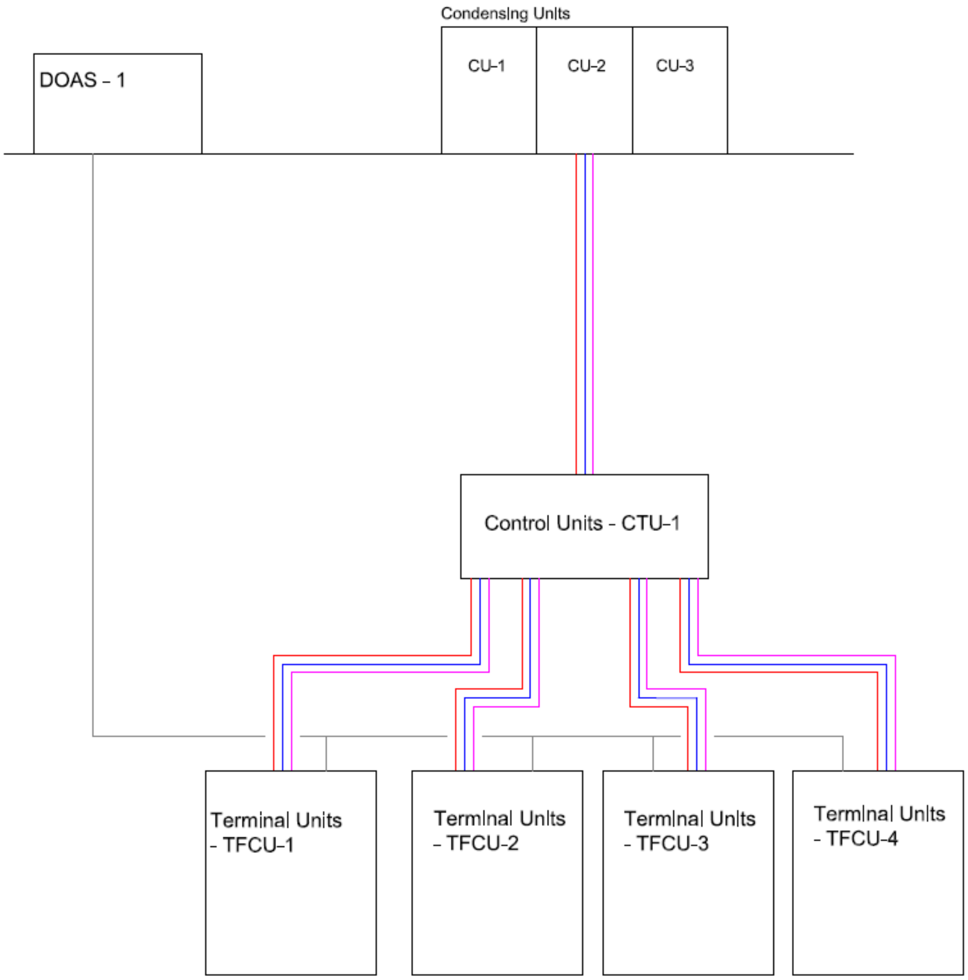


Figure 17: VRF System Schematic

The VRF system is broken up into water-side components and the air-side components. In the diagram the blue and red lines represent chilled refrigerant and hot refrigerant respectively. The magenta line is return and the grey line is airside ventilation distribution.

Water-Side Components

Loads within the Early Learning Center are based off of a VRF energy model. Cooling loads for the building are 336 tons and the heating load is 235 tons. Each zone will be supplied with a terminal VRF unit which will condition the air circulated to the space from the VRF outside unit with supplemental air from the DOAS system. Temperatures for the rooms will be adjusted based on the control unit sending information to the terminal units. Final heating and cooling will take place within the terminal units. Having the central control unit generating the room temperatures is how VRF systems can simultaneously heat and cool the building. The building will use 15 outdoor VRF heat recovery units. These units will be able to supply the load and distribute refrigerant through the building. Controls for the VRF system will be H-LINK II BACnet adapter for integration into BMS. This control system enables control over the entire system through the building management system. There is unlimited control when working with the control system in the building. Therefore, the H-LINK II BACnet adapter optimizes comfort, saves energy and unifies the interface for all of the HVAC Systems. The terminal VRF units will be ducted with the outdoor air and will recondition the air before it enters the space to correctly supply the right temperature of air. These high-performance terminal units distribute air into the end spaces and can be fully integrated with the control system and the energy recovery rooftop VRF units. Integration of these units allows the building owners to have a better understanding of the operations within the building, allowing precise control to be able to modify when the system starts to vary from the correct operation. The total cooling load for the building is 336 tons. On each floor there are 170 tons, and roughly the same layout. Three terminal units were chosen to satisfy the loads for the building. This size unit was chosen because roughly the average tonnage per room equates to about three tons. Therefore, in total, throughout the building there will be 115 terminal VRF units.

Air-Side Components

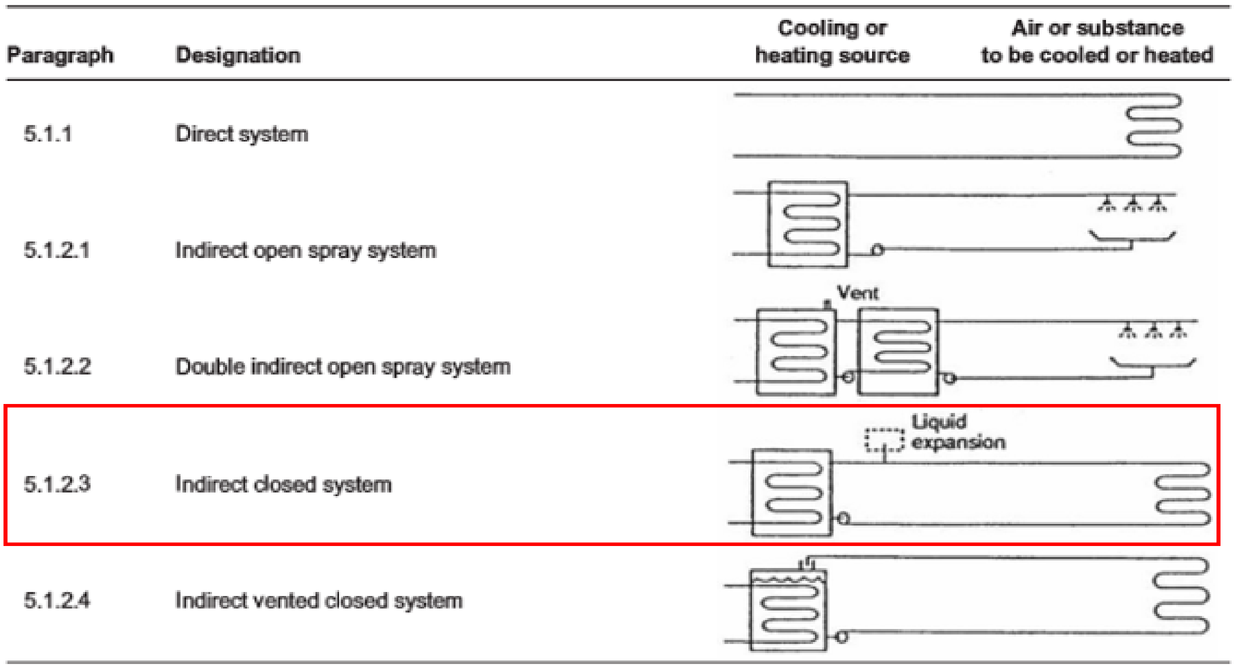
The air-side components in the VRF design are going to be supplied by multiple DOAS units on the rooftop. DOAS units draw in outdoor air and supply the minimum outdoor airflows required by ASHRAE standard 62.1. There will be six DOAS units on the rooftop to provide ventilation into the building. The sum of ventilation being supplied into the building will be 60,000 CFM, based off of energy models made in Trane Trace 700. An extra DOAS unit was placed on the roof to supply more airflow to the gymnasium, accounting for higher metabolic rates.

Refrigerant Safety

The refrigerant being used within the VRF system is R-410A. R-410A is a highly efficient refrigerant mixture required by use from the Montreal Protocol in 2010. R-410A is a more efficient heat exchanger between sources and has a much higher vapor pressure than previously used R-22. This refrigerant doesn't deplete the ozone like former refrigerants.

ASHRAE Standard 15

ASHRAE instituted standard 15 to regulate the safe use of refrigeration equipment in design, construction, installation and operation. The standard safeguards refrigeration to protect human life and health based on three classifications. These classifications are occupancy, system, and refrigerant. Occupancy classification is divided based on the ability of people to respond to the potential exposures of refrigerant. The Early Learning Center's occupancy classification is public assembly occupancy. Refrigeration system classification refers to how the system extracts and delivers heat to the space. The refrigeration system for the Early Learning Center is shown in the figure below. The system is classified as an indirect closed system which puts it in the low-probability category because if there were a leak to occur there would be no leak to the occupied occupancy space.



Paragraph	Designation	Cooling or heating source	Air or substance to be cooled or heated
5.1.1	Direct system		
5.1.2.1	Indirect open spray system		
5.1.2.2	Double indirect open spray system		
5.1.2.3	Indirect closed system		
5.1.2.4	Indirect vented closed system		

Figure 18: Refrigeration System Classification, ASHRAE Standard 15

ASHRAE then developed a chart displaying safety groups to distinguish between highly flammable and highly toxic refrigerants. The refrigerant in the VRF system is R410A, which is a combination of difluoromethane, R32, and pentaflouroethane, R125. Therefore, R410A is classified as a blend.

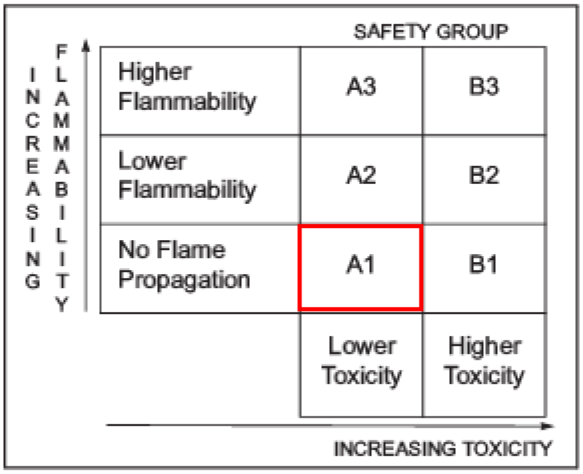


Figure 19: Refrigerant Classification, ASHRAE Standard 15.6.1

R410A is in the A1 safety group. The A represents the occupational exposure limit is 400ppm or greater. Occupational exposure limit is the time weighted average concentration for a normal eight hour workday and a 40 hour workweek that occupants can be exposed to and not have ill effects. Fire tests also showed a low flammability rating. At a temperature of 140°F the refrigerant did not cause fire. The amount of refrigerant in the system must be limited to 26 lb/MCF. Following calculation procedures from ASHRAE Standard 15, the smallest room allowed is 2750 Cubic Feet. For rooms that do not comply, the terminal VRF unit will be placed in the corridor.

Centralized Air Handling Unit:

A centralized air handling unit was studied to analyze how the system would perform within the Early Learning Center. The centralized air handling unit provides all heating, cooling, and ventilation within one unit. This unit will be placed on the roof of the Early Learning Center and distribute airflow throughout the building. There are very large ducts that need to run through the building to accommodate the loads in every space. The largest duct will be The cooling and heating loads calculated with an energy model using Trane Trace 700 are displayed in Table 23 below.

Table 23: Rooftop Unit Design Parameters from Energy Model

Rooftop Unit Design Parameters				
	Peak Cooling Load (Tons)	Peak Heating Load (Tons)	Peak Outside Airflow (CFM)	Peak Airflow (CFM)
RTU-1	108	152	18426	54207
RTU-2	100	220	10002	27203
RTU-3	50	90	20226	65072

Rooftop Unit Sizing:

Sizing for the rooftop units involves researching and choosing equipment that corresponds with the given information from Trane Trace. After much research rooftop units from Daikin were selected because of the flexible features and their ability to meet the building load. The units chosen are one 130 ton unit, two 120 ton units and one 90 ton unit. The maximum unit size available is 140 tons. By splitting up RTU-2 and a small part of RTU-1 the loads are able to be better distributed throughout four air handling units. Specifications of the air handling units are in the appendix.

Air-Side Components

The rooftop unit is providing outside air and ventilation to the building. The air starts from the outside air vent on the end of the rooftop unit. It is then mixed with return air from the building to recover heat from existing warm air. Air is then blown through carbon filters to eliminate particulates. Continuing, the air is cooled and then heated to supply temperature, 55°F or 85°F depending on if heating or cooling. Controls then monitor the temperature, humidity and velocity as the variable frequency drives push the conditioned air into the building at supply temperature.

Water-Side Components:

There will be three high efficiency boilers in the mechanical room providing hot water to the fan coils in the rooftop units. The gas combustion efficiency of water is 81.6 percent with a gross water output of 2357 MBH. There are also two cooling towers on the roof to accommodate the cooling coils.

System Comparisons:

Not all mechanical systems are created equal. Each mechanical system has positive and negative attributes. It is necessary examine these systems to appropriately select which system will be the best for the end user. The owner's goals include energy efficiency, ease of maintenance, space utilization and cost. These four factors are how the systems will be compared to determine the best system for the Early Learning Center.

Energy Efficiency

Each system has its advantages and disadvantages in terms of energy efficiency. Each of the four systems were modeled in Trane Trace 700 and then compared. In the figure below the monthly energy consumption data is shown. The outlier for this data is the VRF system. This could be caused by needing more energy to heat in the winter months. The heat transfer from fluid to air could be lacking

The water-source heat pump system, geothermal heat pump system and the air handling unit for the most part are very similar. The geothermal heat pump system stays relatively more constant than the other systems. This result is expected because it is using the ground as a heat exchanger. By using the ground as a heat exchanger the flow rates and heat transfer rates are similar year round, thus producing a more level graph as shown.

In particular, the rooftop air handling unit spikes above the heat pumps in the summer months. These results could be because of the high amount of energy it takes for the large volumes of air to circulate through the air handling unit.

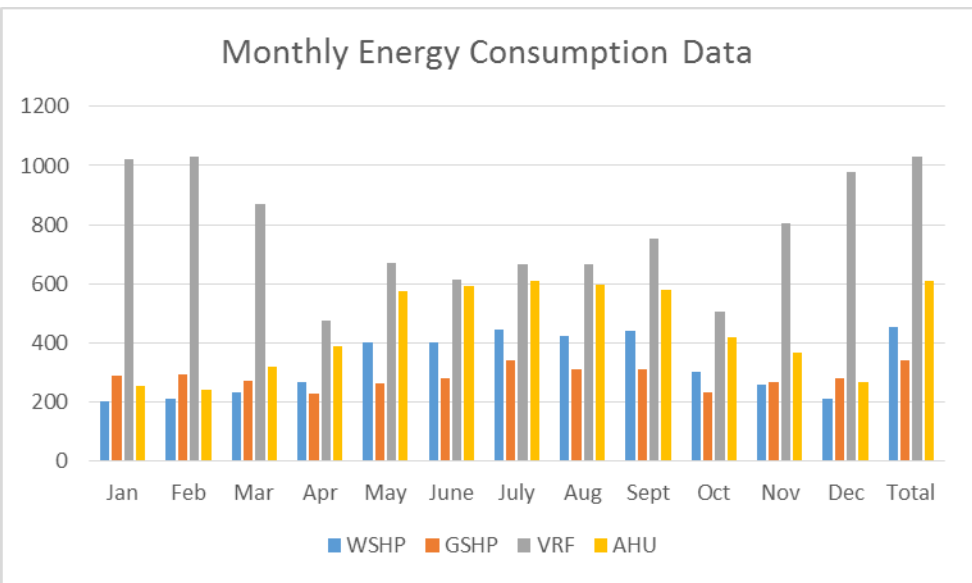


Figure 20: Monthly Energy Consumption Comparisons

When examining the whole year, the VRF system uses the most energy, followed by the air handling unit, water-source heat pumps and geothermal heat pumps. The figure for the Yearly Energy Consumption Comparisons is below. This figure sows the energy consumption used from the source as well as from the building.

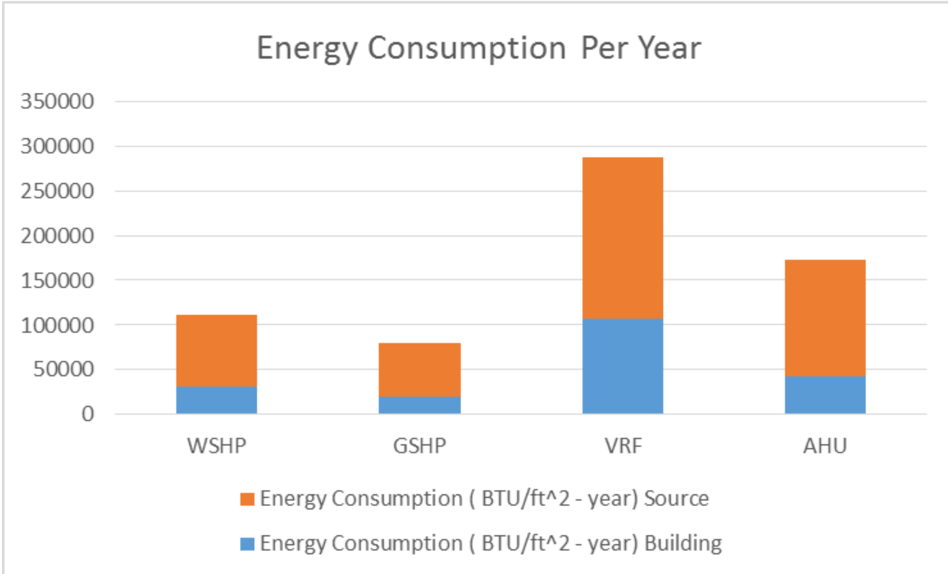
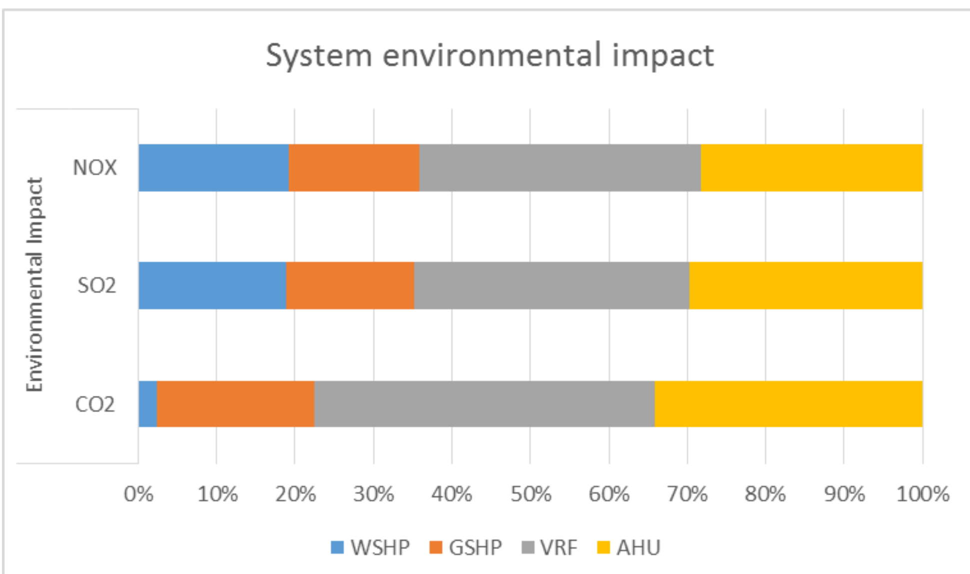


Figure 21: Yearly Energy Consumption Comparisons

Next, the environmental impacts of contaminants were studied. It was found the VRF system has the largest environmental impact with the water-source heat pump system releasing the least amount of toxins.



Ease of Maintenance

The client is looking for ease of maintenance because as a school building they need to have students come everyday and cannot afford to have the building or even half of the building down for maintenance. The existing system of water-source heat pumps locate the heat pumps within closets outside of the classrooms for easy access. The heat pumps would stay in the same location for the geothermal heat pump system and take advantage of the corridor maintenance. Having the technicians able to work on units while class is still in session is a major draw to the client.

The VRF system has the lowest maintenance cost in comparison to the other systems. The low cost is due to the straight forward terminal units. There are very few moving parts distributing the refrigerant to the classrooms. Figure 22 below shows the comparisons of maintenance costs.

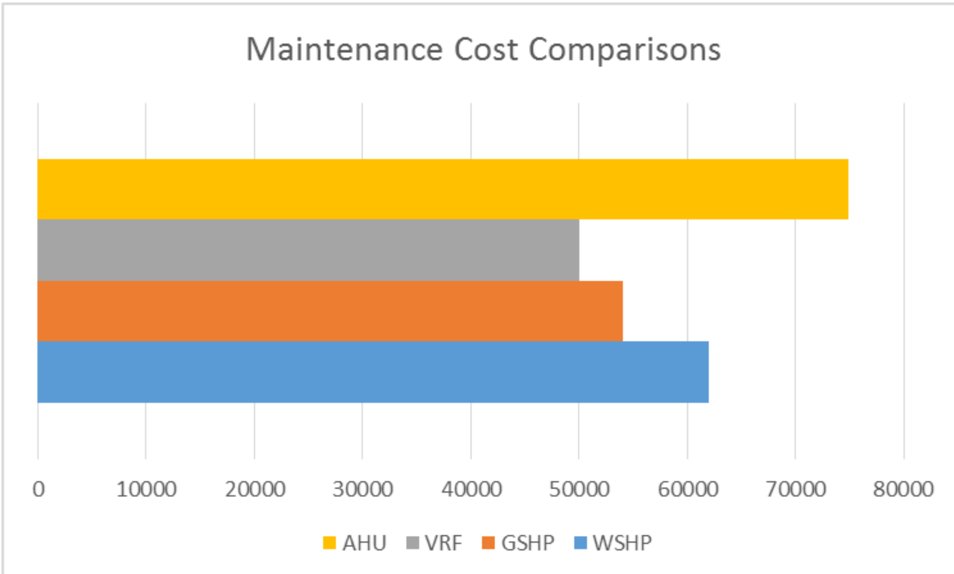


Figure 22: Maintenance Cost Data

Space Utilization

The heat pump systems are relatively identical in space utilization. The largest difference in the geothermal heat pump system as compared with the water-source heat pumps is the bore field. It may not be space in the building but there is a large amount of space outside the building. The geothermal heat pump system also takes up a large portion of the mechanical room, being filled with metering and terminal connections to the rest of the building.

The rooftop air handling unit will take a large amount of chase space to be able to fit large mains into the building. There will be a large expanses of duct work to accommodate providing air to all of the spaces in the building.

In contrast, the VRF system will take up the least amount of space. Ventilation provided by the DOAS unit will be minimal because only the outdoor air loads need to be met.

Cost

An analysis was constructed to find the life cycle cost analysis of all of the systems to evaluate which systems are the most expensive. It was determined the VRF system and the rooftop air handling unit did not payback when compared with the water-source heat pump.

The geothermal heat pump system was compared to the water-source heat pump system for cost analysis. It was found the geothermal heat pump system had a discount payback period of 11.38 years. This is well within the clients' goals for payback time. In total the life cycle cost of the geothermal heat pump system is $7,444,722. In comparison the life cycle cost for the water-source heat pump system is $7,662,769. There is a difference of $218,047 over the life of the equipment. The net present value of geothermal heat pump system and the water-source heat pump system at twenty-five years is $4,446,056 and $4,453,324 respectively.

Breadth: Scheduling and Cost Impact on Construction

Implementation of a geothermal heat pump system has adverse effects on the schedule and cost impact of construction for the Early Learning Center. Wells need to be drilled, fitted with pipes, pumps and then refilled all in a concise time schedule. The wells also need a location near the school to bore the holes for the wells. The drilling of geothermal wells was analyzed to consider the impact on the critical path. Factors evaluated include number of wells, well orientation (horizontal or vertical), location of wells, depth and length of wells, extra equipment required for digging or installing the wells, lifecycle cost analysis, and construction schedule. Addressing these main points allows for the analysis to address concerns on the feasibility of a geothermal heat pump system

RS Means was used in the cost and scheduling impact study. It was found digging the trenches for a horizontal bore field would take approximately approximate the same. However, analyzing the surrounding conditions it was found the site cannot support a horizontal bore field because of the amount of available space on site. See below the site layout for surrounding site conditions.

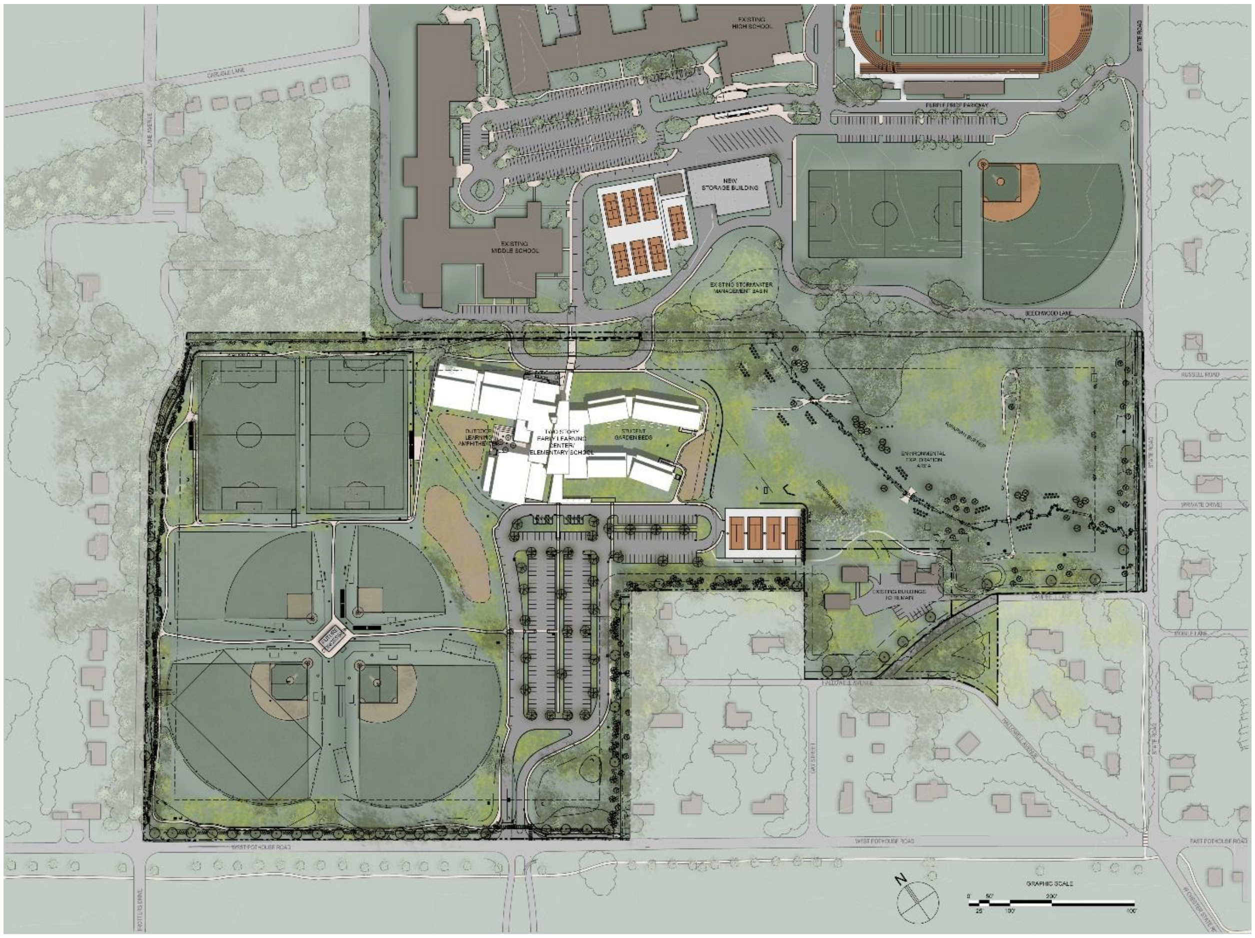


Figure 23: Surrounding Site Conditions, Image used with permission from SCHRADERgroup Architects

A comparison was then made between the construction of the vertical bore field and the installation of the boilers and cooling tower units. RS Means was consulted to calculate the overall time it would take for both of the installations. Results from the study are found in the table below.

Construction Schedule Impact		
	Number of Days	Cost
WSHP	5	150000
GSHP	42	1540000

Figure 24: System Schedule Impact

Extra equipment in the construction of the geothermal well field included a backhoe, dump truck, Truck-mounted borehole drilling machine as well as a dozer. In contrast, the list of equipment to install boilers and a rooftop cooling unit is a crane. There is a crane on site for steel erection and will be used for mechanical equipment placement.

Breadth: VRF Impact on Electrical Load

The second breath will examines the impacts of a VRF heating and cooling system on the electrical system of the building. Analysis includes analyzing building loads to determine if the electrical load increases or decreases.

With the current system there are 95 water-source heat pump units within the building as well as three boilers and one cooling tower. These current units are being replaced with 115 three ton terminal VRF units. On the roof are 10 energy recovery ventilators which will be replaced with 15 VRF rooftop heat recovery units as well as a DOAS unit.

Roughly half of the water-source heat pumps have an amperage of 21 amps and the other half are 11 amps. The 3 ton terminal units are 208V/60Hz/1-phase units with a motor nominal output. The minimum circuit ampacity is 1.33 amps. Wire sizing for the terminal, control and rooftop VRF units are in the table below.

Table 24: VRF Wire Sizing

Wire Sizing							
					THWN	Aluminum	EMT
	# of Units	Amps	Cond Amps	Total	Wire Size	Grnd Sz	Cond
Terminal Unit	115	1.33	152.95	191.1875	2#3	2	3/4"
Control Unit	30	0.4	12	15	#12	12	3/4"
Rooftop VRF Unit	15	21	315	393.75	2#3/0	1	1-1/2"

The total heating and cooling watts of each system were compared to analyze if the electrical load decreased or increased. As shown in Table 25 below, the total watts decreased from the base line of the water-source heat pump system.

Table 25: Watts System Comparisons

Total Watts		
	Heating (kW)	Cooling (kW)
WSHP	367	355
VRF	326	336

Conclusions

Based on the four categories the owner is most looking for in their building, energy efficiency, ease of maintenance, space utilization, and a low cost system the choice is between the water-source heat pump system and the geothermal heat pump system. The only difference between the two systems is the heat exchanger. In the water-source heat pump design there are boilers and cooling towers mixing in a heat exchanger in the mechanical room to evaporate and condense the liquids. With the geothermal heat pump system the geothermal wells become the heat exchanger with the earth.

Based on life cycle cost and yearly energy consumption it is recommended the owner select the geothermal heat pump system to be implemented into the building. The geothermal system also offers ease of maintenance and out of classroom space utilization for heat pumps Overall, the owner can be excited knowing their mechanical system will save money in the long term, creating more opportunities for educational opportunities.

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APPENDIX A: Existing Systems

TABLE 6.2.2.1 Minimum Ventilation Rates in Breathing Zone
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values: Occupant Density (see Note 4)	Default Values: Combined Outdoor Air Rate (see Note 5)		Air Class
	cfm/person	L/s·person	cfm/ft²	L/s·m²		#/1000 ft² or #/100 m²	cfm/person	L/s·person	
Correctional Facilities									
Cell	5	2.5	0.12	0.6		25	10	4.9	2
Dayroom	5	2.5	0.06	0.3		30	7	3.5	1
Guard stations	5	2.5	0.06	0.3		15	9	4.5	1
Booking/waiting	7.5	3.8	0.06	0.3		50	9	4.4	2
Educational Facilities									
Daycare (through age 4)	10	5	0.18	0.9		25	17	8.6	2
Daycare sickroom	10	5	0.18	0.9		25	17	8.6	3
Classrooms (ages 5–8)	10	5	0.12	0.6		25	15	7.4	1
Classrooms (age 9 plus)	10	5	0.12	0.6		35	13	6.7	1
Lecture classroom	7.5	3.8	0.06	0.3		65	8	4.3	1
Lecture hall (fixed seats)	7.5	3.8	0.06	0.3		150	8	4.0	1
Art classroom	10	5	0.18	0.9		20	19	9.5	2
Science laboratories	10	5	0.18	0.9		25	17	8.6	2
University/college laboratories	10	5	0.18	0.9		25	17	8.6	2
Wood/metal shop	10	5	0.18	0.9		20	19	9.5	2
Computer lab	10	5	0.12	0.6		25	15	7.4	1
Media center	10	5	0.12	0.6	A	25	15	7.4	1
Music/theater/dance	10	5	0.06	0.3		35	12	5.9	1
Multiuse assembly	7.5	3.8	0.06	0.3		100	8	4.1	1
Food and Beverage Service									
Restaurant dining rooms	7.5	3.8	0.18	0.9		70	10	5.1	2
Cafeteria/fast-food dining	7.5	3.8	0.18	0.9		100	9	4.7	2
Bars, cocktail lounges	7.5	3.8	0.18	0.9		100	9	4.7	2
Kitchen (cooking)	7.5	3.8	0.12	0.6		20	14	7.0	2
General									
Break rooms	5	2.5	0.06	0.3		25	7	3.5	1

GENERAL NOTES FOR TABLE 6.2.2.1

1 **Related requirements:** The rates in this table are based on all other applicable requirements of this standard being met.
2 **Environmental Tobacco Smoke:** This table applies to ETS-free areas. Refer to Section 5.17 for requirements for buildings containing ETS areas and ETS-free areas.
3 **Air density:** Volumetric airflow rates are based on an air density of 0.075 lb_{da}/ft^3 (1.2 kg_{da}/m^3), which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70°F (21°C). Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.
4 **Default occupant density:** The default occupant density shall be used when actual occupant density is not known.
5 **Default combined outdoor air rate (per person):** This rate is based on the default occupant density.
6 **Unlisted occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities, and building construction shall be used.

ITEM-SPECIFIC NOTES FOR TABLE 6.2.2.1

A For high-school and college libraries, use values shown for Public Assembly Spaces—Libraries.
B Rate may not be sufficient when stored materials include those having potentially harmful emissions.
C Rate does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture. "Deck area" refers to the area surrounding the pool that would be expected to be wetted during normal pool use, i.e., when the pool is occupied. Deck area that is not expected to be wetted shall be designated as a space type (for example, "spectator area").
D Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.
E When combustion equipment is intended to be used on the playing surface or in the space, additional dilution ventilation and/or source control shall be provided.
F Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.
G Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.

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TABLE 6.2.2.1 Minimum Ventilation Rates in Breathing Zone *(Continued)*
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values			Air Class
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/ person	L/s· person	cfm/ft²	L/s·m²		#/1000 ft² or #/100 m²	cfm/ person	L/s·person	
Coffee stations	5	2.5	0.06	0.3		20	8	4	1
Conference/meeting	5	2.5	0.06	0.3		50	6	3.1	1
Corridors	—	—	0.06	0.3		—			1
Occupiable storage rooms for liquids or gels	5	2.5	0.12	0.6	B	2	65	32.5	2
Hotels, Motels, Resorts, Dormitories									
Bedroom/living room	5	2.5	0.06	0.3		10	11	5.5	1
Barracks sleeping areas	5	2.5	0.06	0.3		20	8	4.0	1
Laundry rooms, central	5	2.5	0.12	0.6		10	17	8.5	2
Laundry rooms within dwelling units	5	2.5	0.12	0.6		10	17	8.5	1
Lobbies/prefunction	7.5	3.8	0.06	0.3		30	10	4.8	1
Multipurpose assembly	5	2.5	0.06	0.3		120	6	2.8	1
Office Buildings									
Breakrooms	5	2.5	0.12	0.6		50	7	3.5	1
Main entry lobbies	5	2.5	0.06	0.3		10	11	5.5	1
Occupiable storage rooms for dry materials	5	2.5	0.06	0.3		2	35	17.5	1
Office space	5	2.5	0.06	0.3		5	17	8.5	1
Reception areas	5	2.5	0.06	0.3		30	7	3.5	1
Telephone/data entry	5	2.5	0.06	0.3		60	6	3.0	1
Miscellaneous Spaces									
Bank vaults/safe deposit	5	2.5	0.06	0.3		5	17	8.5	2
Banks or bank lobbies	7.5	3.8	0.06	0.3		15	12	6.0	1
Computer (not printing)	5	2.5	0.06	0.3		4	20	10.0	1

GENERAL NOTES FOR TABLE 6.2.2.1

1 **Related requirements:** The rates in this table are based on all other applicable requirements of this standard being met.
2 **Environmental Tobacco Smoke:** This table applies to ETS-free areas. Refer to Section 5.17 for requirements for buildings containing ETS areas and ETS-free areas.
3 **Air density:** Volumetric airflow rates are based on an air density of 0.075 lb_{da}/ft^3 (1.2 kg_{da}/m^3), which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70°F (21°C). Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.
4 **Default occupant density:** The default occupant density shall be used when actual occupant density is not known.
5 **Default combined outdoor air rate (per person):** This rate is based on the default occupant density.
6 **Unlisted occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities, and building construction shall be used.

ITEM-SPECIFIC NOTES FOR TABLE 6.2.2.1

A For high-school and college libraries, use values shown for Public Assembly Spaces—Libraries.
B Rate may not be sufficient when stored materials include those having potentially harmful emissions.
C Rate does not allow for humidity control. Additional ventilation or dehumidification may be required to remove moisture. "Deck area" refers to the area surrounding the pool that would be expected to be wetted during normal pool use, i.e., when the pool is occupied. Deck area that is not expected to be wetted shall be designated as a space type (for example, "spectator area").
D Rate does not include special exhaust for stage effects, e.g., dry ice vapors, smoke.
E When combustion equipment is intended to be used on the playing surface or in the space, additional dilution ventilation and/or source control shall be provided.
F Default occupancy for dwelling units shall be two persons for studio and one-bedroom units, with one additional person for each additional bedroom.
G Air from one residential dwelling shall not be recirculated or transferred to any other space outside of that dwelling.

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Job No. Tech 1	Subject		Sheet 1 of 1
Date Sep-15	ELC Building Loads	Minimum Ventilation & Exhaust Requirements	By NJA / Ckd By

System Type:	Multi-zone system	System Ventilation Efficiency E_v	61.02 Uncorrected Outdoor Intake V_{ou}	2209774 cfm
Total Zone Population	2685 people	Occupant Diversity	100.00 Design AHU Outdoor Intake V_{ot}	**36214 cfm**
Air Distribution Config.	Ceiling or floor supply of warm air and floor return		Ez = 1	

Space	Usage	V_z	P_z	A_z	$V_{z,min}$	R_p	$R_p \times P_z$	R_a	$R_A \times A_z$	V_{bz}	V_{oz}	Z_p	E_{vz}	Exhaust
Zone 1	Classrooms (ages 5-8)	5220	162	7317	1566	10	1620	0.12	878.04	2498.04	2498.04	1.595	62.139	0
Zone 2	Corridors	2015	5	4910	605	0	0	0.06	294.6	294.6	294.6	0.487	63.247	0
Zone 3	Classrooms (ages 5-8)	5220	162	7383	1566	10	1620	0.12	885.96	2505.96	2505.96	1.600	62.134	0
Zone 4	Sports Locker Rooms	300	32	1597	90	0	0	0	0	0	0	0.000	63.734	798.5
Zone 5	Storage	300	3	2600	90	0	0	0.06	156	156	156	1.733	62.001	0
Zone 6	Corridors	1700	15	5228	510	0	0	0.06	313.68	313.68	313.68	0.615	63.119	0
Zone 7	Cafeteria / fast food	6360	500	5061	1908	7.5	3750	0.18	910.98	4660.98	4660.98	2.443	61.291	0
Zone 8	Kitchens (cooking)	1670	10	3034	501	0	0	0	0	0	0	0.000	63.734	2123.8
Zone 9	Media center	1245	50	2457	374	10	500	0.12	294.84	794.84	794.84	2.128	61.606	0
Zone 10	Classrooms (ages 5-8)	1395	81	2716	419	10	810	0.12	325.92	1135.92	1135.92	2.714	61.020	0
Zone 11	Corridors	1750	10	3221	525	0	0	0.06	193.26	193.26	193.26	0.368	63.366	0
Zone 12	Office space	2185	47	4064	656	5	235	0.06	243.84	478.84	478.84	0.730	63.004	0
Zone 13	Gym, stadium, arena (play area)	11100	1159	10321	3330	0	0	0.3	3096.3	3096.3	3096.3	0.930	62.804	0
Zone 14	Art classroom	1820	45	2473	546	10	450	0.18	445.14	895.14	895.14	1.639	62.095	1731.1
Zone 15	Classrooms (ages 5-8)	7010	220	8498	2103	10	2200	0.12	1019.76	3219.76	3219.76	1.531	62.203	0
Zone 16	Corridors	5270	5	3469	1581	0	0	0.06	208.14	208.14	208.14	0.132	63.602	0
Zone 17	Toilet Room - Public, Continuous	300	4	280	90	0	0	0	0	0	0	0.000	63.734	14000
Zone 18	Corridors	3355	5	4409	1007	0	0	0.06	264.54	264.54	264.54	0.263	63.471	0
Zone 19	Classrooms (ages 5-8)	4940	165	6317	1482	10	1650	0.12	758.04	2408.04	2408.04	1.625	62.109	0
Zone 20	Classrooms (ages 5-8)	5570	165	7000	1671	10	1650	0.12	840	2490	2490	1.490	62.244	0
Zone 21	Corridors	3970	5	5445	1191	0	0	0.06	326.7	326.7	326.7	0.274	63.460	0
Zone 22	Classrooms (ages 5-8)	5875	165	6965	1763	10	1650	0.12	835.8	2485.8	2485.8	1.410	62.324	0
Zone 23	Toilet Room - Public, Continuous	550	25	1000	165	0	0	0	0	0	0	0.000	63.734	50000
Zone 24	Reception areas	7080	300	11230	2124	5	1500	0.06	673.8	2173.8	2173.8	1.023	62.711	0
Zone 25	Art classroom	2915	50	2000	875	10	500	0.18	360	860	860	0.983	62.751	1400
Zone 26	Classrooms (ages 5-8)	1800	90	2825	540	10	900	0.12	339	1239	1239	2.294	61.440	0
Zone 27	Conference/meeting	3500	20	3400	1050	5	100	0.06	204	304	304	0.290	63.444	0
Zone 28	Classrooms (age 9 plus)	8000	140	8600	2400	10	1400	0.12	1032	2432	2432	1.013	62.721	0
Zone 29	Corridors	5000	10	5500	1500	0	0	0.06	330	330	330	0.220	63.514	0
Zone 30	Corridors	5000	10	3800	1500	0	0	0.06	228	228	228	0.152	63.582	0
Zone 31	Classrooms (age 9 plus)	5000	140	6800	1500	10	1400	0.12	816	2216	2216	1.477	62.257	0
		117415	3800		35225		21935		16274.34	38209	38209			70053

TABLE 9.5.1 Lighting Power Densities Using the Building Area Method

Building Area Type[a]	LPD, W/ft^2
Automotive facility	0.80
Convention center	1.01
Courthouse	1.01
Dining: Bar lounge/leisure	101
Dining: Cafeteria/fast food	0.90
Dining: Family	0.95
Dormitory	0.57
Exercise center	0.84
Fire station	0.671
Gymnasium	0.94
Health-care clinic	0.90
Hospital	1.05
Hotel/Motel	0.87
Library	1.19
Manufacturing facility	1.17
Motion picture theater	0.76
Multifamily	0.51
Museum	1.02
Office	0.82
Parking garage	0.21
Penitentiary	0.81
Performing arts theater	1.39
Police station	0.87
Post office	0.87
Religious building	1.00
Retail	1.26
School/university	0.87
Sports arena	0.91
Town hall	0.89
Transportation	0.70
Warehouse	0.66
Workshop	1.19

a. In cases where both a general building area type and a specific building area type are listed, the specific building area type shall apply.

APPENDIX B: VRF System

Outdoor Unit 208/230V HR | 12-16 TON SYSTEMS

12-16 Ton Systems	Type				Twin Unit Systems					
	Tonnage				12 Ton (6+6)		14 Ton (8+6)		16 Ton (8+8)	
Model (combination)					YVAHR144B31S		YVAHR168B31S		YVAHR192B31S	
Model (individual)	Unit A				YVAHR072B31S		YVAHR096B31S		YVAHR096B31S	
	Unit B				YVAHR072B31S		YVAHR072B31S		YVAHR096B31S	
Power Supply					208/230V/ 3PH 60Hz		208/230V/ 3PH 60Hz		208/230V/ 3PH 60Hz	
Capacity (Nominal) *	Cooling	Capacity (Nominal)	Btu/h	(kW)	144,000	(42.2)	168,000	(49.2)	192,000	(56.3)
		Power input	kW		12.16		13.69		15.22	
		Current input	A (208V/230V)		36.6/ 33.2		41.3/ 37.4		46.0/ 41.6	
	Heating	Capacity (Nominal)	Btu/h	(kW)	162,000	(47.5)	189,000	(55.4)	216,000	(63.3)
		Power input	kW		11.86		13.26		14.66	
		Current input	A (208V/230V)		35.8/32.4		41.0/38.4		46.2/44.4	
Efficiency Ratings *	Cooling	Capacity (Rated)	Btu/h	(kW)	138,000	(40.5)	160,000	(46.9)	182,000	(53.4)
		EER	Btu/Wh	(W/W)	14.50	(4.25)	11.40	(3.34)	10.60	(3.11)
		IEER	Btu/Wh	(Wh/Wh)	24.20	(7.10)	19.70	(5.78)	19.10	(5.60)
	Heating High	Capacity (Rated)	Btu/h	(kW)	154,000	(45.2)	178,000	(52.2)	204,000	(59.8)
		COP	W/W		4.11		3.69		3.64	
	Heating Low	Capacity	Btu/h	(kW)	109,000	(32.0)	129,000	(37.8)	150,000	(44.0)
		COP	W/W		2.78		2.27		2.34	
	Heat Recovery	SCHE	W/W		29.50		26.80		27.80	
Cooling Operating Range**	Indoor		°F WB (°C WB)		59(15) - 73(23)		59(15) - 73(23)		59(15) - 73(23)	
	Outdoor		°F DB (°C DB)		14(-10) - 118(48)		14(-10) - 118(48)		14(-10) - 118(48)	
Heating Operating Range	Indoor		°F DB (°C DB)		59(15) - 80(27)		59(15) - 80(27)		59(15) - 80(27)	
	Outdoor		°F WB (°C WB)		-4(-20) - 59(15)		-4(-20) - 59(15)		-4(-20) - 59(15)	
Cabinet Color (Munsell Code)					2.5Y 8/2					
Outer Dimensions	Height		in	(mm)	68-1/8	(1730)	68-1/8	(1730)	68-1/8	(1730)
	Width***		in	(mm)	76-5/32	(1934)	86-3/8	(2194)	96-5/8	(2454)
	Depth		in	(mm)	31-7/32	(793)	31-7/32	(793)	31-7/32	(793)
Package Dimensions	Height		in	(mm)	Reference: YVAHR072B31S YVAHR072B31S		Reference: YVAHR096B31S YVAHR072B31S		Reference: YVAHR096B31S YVAHR096B31S	
	Width		in	(mm)						
	Depth		in	(mm)						
Weight	Net		lbs	(kg)	1080	(490)	1270	(576)	1460	(662)
	Gross		lbs	(kg)	1173	(532)	1374	(623)	1574	(714)
Connection Ratio	Total Indoor Unit Capacity		%		150 - 75		140 - 65		135 - 65	
	Max. (Recommendation) indoor units/ system		-		36 (26)		39 (32)		43 (32)	
Heat Exchanger	Type		-		Multi-Pass Cross-Finned Tube					
	Material		-		Cu-Al (Anti-corrosion)					
Compressor	Type		Inverter		DA65PHD×2		DA65PHD×2		DA65PHD×2	
			Fixed Speed		-		E655DH×1		E655DH×2	
	Motor Output (Pole)		kW (Pole)		7.26(6) 7.26(6)		4.8(6)+4.4(2) 7.26(6)		4.8(6)+4.4(2) 4.8(6)+4.4(2)	
	Start Method		-		Inverter					
	Operation Range		%		10 - 100		9 - 100		8 - 100	
	Refrigeration Oil Type		-		FVC68D		FVC68D		FVC68D	
Crank Case Heater			W×Q'ty		40.8 (230V) ×4		40.8 (230V) ×6		40.8 (230V) ×8	
Fan	Type		-		Propeller Fan					
	Motor Output (Pole)		kW (Pole)		0.49(8) x2		0.66(8)+0.49(8)		0.66(8)×2	
	Quantity		Q'ty		2					
	Air Flow Rate		cfm	(m3/min)	6178+6178	(175+175)	6884+6178	(195+175)	6884+6884	(195+195)
	External static pressure ****		in.WG	(Pa)	0 (0)					
	Drive				Direct drive					
Electrical	Min Circuit Amps		A		Reference: YVAHR072B31S YVAHR072B31S		Reference: YVAHR096B31S YVAHR072B31S		Reference: YVAHR096B31S YVAHR096B31S	
	Recommended Fuse/Breaker Size		A							
	Maximum Fuse Size		A							
Sound Pressure Level	Cooling (Night-Shift)		dB(A)		63	(58)	65	(60)	65	(60)
	Heating		dB(A)		63		65		65	
Protection devices	Cycle		-		High pressure switch at 601psi (4.15MPa)					
	Inverter		-		Over-current protection / Over-heat protection					
	Compressor		-		Over-heat protection					
	PCB		-		Over-current protection					
Refrigerant	Type-Qty		-		R410A					
	Charge amount		lbs	(kg)	16.1+16.1	(7.3+7.3)	18.7+16.1	(8.5+7.3)	18.7+18.7	(8.5+8.5)
Refrigeration Oil	Charge amount		gal/Unit	(l/Unit)	1.6+1.6	(6.0+6.0)	2.1+1.6	(7.9+6.0)	2.1+2.1	(7.9+7.9)
Defrost Method			-		Reversed Refrigerant Cycle					
Main Refrigerant Piping (Heat Recovery)	Low Pressure Gas Line		in	(mm)	1-1/8	(28.58)	1-3/8	(34.93)	1-3/8	(34.93)
	High/Low Pressure Gas Line		in	(mm)	7/8	(22.2)	1-1/8	(28.58)	1-1/8	(28.58)
	Liquid Line		in	(mm)	5/8	(15.88)	3/4	(19.05)	3/4	(19.05)

* Rating conditions are based on the AHRI 1230 test standard. See www.ahrinet.org for more information.
** Operation under harsh condition may require optional accessories.
*** The table shows an example where there is 7/8in.(22mm) clearance between the base units.
**** External static pressure can be changed using the DSW setting 0.24in.W.G.(60Pa).

VRF

Outdoor Unit 208/230V HR | 18-26 TON SYSTEMS

18-26 Ton Systems	Type				Triple Unit Systems			
	Tonnage				18 Ton (6+6+6)		20 Ton (8+6+6)	
Model (combination)					YVAHR216B31S		YVAHR240B31S	
Model (individual)	Unit A				YVAHR072B31S		YVAHR096B31S	
	Unit B				YVAHR072B31S		YVAHR072B31S	
	Unit C				YVAHR072B31S		YVAHR072B31S	
Power Supply					208/230V/ 3PH 60Hz		208/230V/ 3PH 60Hz	
Capacity (Nominal) *	Cooling	Capacity (Nominal)	Btu/h	(kW)	216,000	(63.3)	240,000	(70.3)
		Power input	kW		18.24		19.77	
		Current input	A (208V/230V)		54.9 / 49.8		59.6 / 54.0	
	Heating	Capacity (Nominal)	Btu/h	(kW)	243,000	(71.2)	270,000	(79.1)
		Power input	kW		17.79		19.19	
		Current input	A (208V/230V)		53.7 / 48.6		58.9 / 54.6	
Efficiency Ratings *	Cooling	Capacity (Rated)	Btu/h	(kW)	206,000	(60.4)	228,000	(66.9)
		EER	Btu/Wh	(W/W)	10.60	(3.11)	10.60	(3.11)
		IEER	Btu/Wh	(Wh/Wh)	19.20	(5.63)	20.30	(5.95)
	Heating High	Capacity (Rated)	Btu/h	(kW)	232,000	(68.1)	258,000	(75.7)
		COP	W/W		3.49		3.80	
	Heating Low	Capacity	Btu/h	(kW)	164,000	(48.1)	182,000	(53.4)
		COP	W/W		2.34		2.42	
	Heat Recovery	SCHE	W/W		25.90		27.80	
Cooling Operating Range**	Indoor		°F WB (°C WB)		59(15) - 73(23)		59(15) - 73(23)	
	Outdoor		°F DB (°C DB)		14(-10) - 118(48)		14(-10) - 118(48)	
Heating Operating Range	Indoor		°F DB (°C DB)		59(15) - 80(27)		59(15) - 80(27)	
	Outdoor		°F WB (°C WB)		-4(-20) - 59(15)		-4(-20) - 59(15)	
Cabinet Color (Munsell Code)					2.5Y 8/2			
Outer Dimensions	Height		in	(mm)	68-1/8	(1730)	68-1/8	(1730)
	Width***		in	(mm)	114-13/32	(2906)	124-21/32	(3166)
	Depth		in	(mm)	31-7/32	(793)	31-7/32	(793)
Package Dimensions	Height		in	(mm)	Reference: YVAHR072B31S		Reference: YVAHR096B31S	
	Width		in	(mm)	YVAHR072B31S		YVAHR072B31S	
	Depth		in	(mm)	YVAHR072B31S		YVAHR072B31S	
Weight	Net		lbs	(kg)	1621	(735)	1810	(821)
	Gross		lbs	(kg)	1760	(798)	1960	(889)
Connection Ratio	Total Indoor Unit Capacity		%		150 - 70		150 - 70	
	Max. (Recommendation) indoor units/ system		-		54 (32)		60 (38)	
Heat Exchanger	Type		-		Multi-Pass Cross-Finned Tube			
	Material		-		Cu-Al (Anti-corrosion)			
Compressor	Type		Inverter		DA65PHD×3		DA65PHD×3	
			Fixed Speed		-		E655DH×1	
	Motor Output (Pole)		kW (Pole)		7.2(6) 7.2(6) 7.2(6)		4.8(6)+4.4(2) 7.2(6) 7.2(6)	
	Start Method		-		Inverter			
	Operation Range		%		7 - 100		6 - 100	
	Refrigeration Oil Type		-		FVC68D		FVC68D	
Crank Case Heater			W×Q'ty		40.8 (230V) ×6		40.8 (230V) ×8	
Fan	Type		-		Propeller Fan		Propeller Fan	
	Motor Output (Pole)		kW (Pole)		0.49(8)×3		0.66(8)+0.49(8)×2	
	Quantity		Q'ty		3		3	
	Air Flow Rate		cfm	(m3/min)	6178+6178 +6178	175+175 +175	6884+6178 +6178	195+175 +175
	External static pressure****		in.WG	(Pa)	0 (0)			
	Drive				Direct drive			
Electrical	Min Circuit Amps		A		Reference: YVAHR072B31S		Reference: YVAHR096B31S	
	Recommended Fuse/Breaker Size		A		YVAHR072B31S		YVAHR072B31S	
	Maximum Fuse Size		A		YVAHR072B31S		YVAHR072B31S	
Sound Pressure Level	Cooling (Night-Shift)		dB(A)		65	(60)	66	(61)
	Heating		dB(A)		65		66	
Protection devices	Cycle		-		High pressure switch at 601psi (4.15MPa)			
	Inverter		-		Over-current protection / Over-heat protection			
	Compressor		-		Over-heat protection			
	PCB		-		Over-current protection			
Refrigerant	Type-Qty		-		R410A			
	Charge amount		lbs	(kg)	16.1+16.1 +16.1	(7.3+7.3+7.3)	18.7+16.1+16.1	(8.5+7.3 +7.3)
Refrigeration Oil	Charge amount		gal/Unit	(l/Unit)	1.6+1.6 +1.6	(6.0+6.0 +6.0)	2.1+1.6 +1.6	(7.9+6.0 +6.0)
Defrost Method			-		Reversed Refrigerant Cycle			
Main Refrigerant Piping (Heat Recovery)	Low Pressure Gas Line		in	(mm)	1-3/8	(34.93)	1-5/8	(41.28)
	High/Low Pressure Gas Line		in	(mm)	1-1/8	(28.58)	1-3/8	(34.93)
	Liquid Line		in	(mm)	3/4	(19.05)	3/4	(19.05)

* Rating conditions are based on the AHRI 1230 test standard. See www.ahrinet.org for more information.
** Operation under harsh condition may require optional accessories.
*** The table shows an example where there is 7/8in.(22mm) clearance between the base units.
**** External static pressure can be changed using the DSW setting 0.24in.W.G.(60Pa).

YORK VRF OUTDOOR UNITS

Outdoor Unit 208/230V HR | 18-26 TON SYSTEMS *(continued)*

18-26 Ton Systems	Type			Triple Unit Systems		
	Tonnage			22 Ton (10+6+6)	24 Ton (10+8+6)	26 Ton (10+10+6)
Model (combination)				YVAHR264B31S	YVAHR288B31S	YVAHR312B31S
Model (individual)	Unit A			YVAHR120B31S	YVAHR120B31S	YVAHR120B31S
	Unit B			YVAHR072B31S	YVAHR096B31S	YVAHR120B31S
	Unit C			YVAHR072B31S	YVAHR072B31S	YVAHR072B31S
Power Supply				208/230V/ 3PH 60Hz	208/230V/ 3PH 60Hz	208/230V/ 3PH 60Hz
Capacity (Nominal) *	Cooling	Capacity (Nominal)	Btu/h (kW)	264,000 (77.4)	288,000 (84.4)	312,000 (91.4)
		Power input	kW	22.73	24.26	27.22
		Current input	A (208V/230V)	69.6 / 64.8	74.3 / 69.0	84.3 / 79.8
	Heating	Capacity (Nominal)	Btu/h (kW)	297,000 (87.0)	324,000 (95.0)	351,000 (102.9)
		Power input	kW	21.59	22.99	25.39
		Current input	A (208V/230V)	66.1 /61.1	71.3 /67.1	78.5 / 73.6
Efficiency Ratings *	Cooling	Capacity (Rated)	Btu/h (kW)	252,000 (73.9)	274,000 (80.4)	296,000 (86.8)
		EER	Btu/Wh (W/W)	10.30 (3.02)	10.00 (2.93)	9.60 (2.82)
		IEER	Btu/Wh (Wh/Wh)	18.80 (5.51)	18.60 (5.46)	18.80 (5.51)
	Heating High	Capacity (Rated)	Btu/h (kW)	280,000 (82.1)	308,000 (90.3)	334,000 (98.0)
		COP	W/W	3.61	3.70	3.56
	Heating Low	Capacity	Btu/h (kW)	200,000 (58.7)	216,000 (63.4)	236,000 (69.2)
		COP	W/W	2.37	2.42	2.37
	Heat Recovery	SCHE	W/W	27.00	25.20	26.00
Cooling Operating Range**	Indoor		°F WB (°C WB)	59(15) - 73(23)	59(15) - 73(23)	59(15) - 73(23)
	Outdoor		°F DB (°C DB)	14(-10) - 118(48)	14(-10) - 118(48)	14(-10) - 118(48)
Heating Operating Range	Indoor		°F DB (°C DB)	59(15) - 80(27)	59(15) - 80(27)	59(15) - 80(27)
	Outdoor		°F WB (°C WB)	-4(-20) - 59(15)	-4(-20) - 59(15)	-4(-20) - 59(15)
Cabinet Color (Munsell Code)				2.5Y 8/2		
Outer Dimensions	Height		in (mm)	68-1/8 (1730)	68-1/8 (1730)	68-1/8 (1730)
	Width***		in (mm)	124-21/32 (3166)	134-7/8 (3426)	134-7/8 (3426)
	Depth		in (mm)	31-7/32 (793)	31-7/32 (793)	31-7/32 (793)
Package Dimensions	Height		in (mm)	Reference: YVAHR120B31S	Reference: YVAHR120B31S	Reference: YVAHR120B31S
	Width		in (mm)	YVAHR072B31S	YVAHR096B31S	YVAHR120B31S
	Depth		in (mm)	YVAHR072B31S	YVAHR072B31S	YVAHR072B31S
Weight	Net		lbs (kg)	1813 (822)	2002 (908)	2004 (909)
	Gross		lbs (kg)	1962 (890)	2163 (981)	2165 (982)
Connection Ratio	Total Indoor Unit Capacity		%	140 - 65	135 - 65	130 - 65
	Max. (Recommendation) indoor units/ system		-	61 (38)	64 (38)	64 (38)
Heat Exchanger	Type		-	Multi-Pass Cross-Finned Tube		
	Material		-	Cu-Al (Anti-corrosion)		
Compressor	Type		Inverter	DA65PHD×3	DA65PHD×3	DA65PHD×3
			Fixed Speed	E655DH×1	E655DH×2	E655DH×2
	Motor Output (Pole)		kW (Pole)	6.0(6)+4.4(2) 7.2(6) 7.2(6)	6.0(6)+4.4(2) 4.8(6)+4.4(2) 7.2(6)	6.0(6)+4.4(2) 6.0(6)+4.4(2) 7.2(6)
	Start Method		-	Inverter		
	Operation Range		%	6 - 100	6 - 100	6 - 100
	Refrigeration Oil Type		-	FVC68D	FVC68D	FVC68D
Crank Case Heater			W×Q'ty	40.8 (230V) ×8	40.8 (230V) ×10	40.8 (230V) ×10
Fan	Type		-	Propeller Fan		
	Motor Output (Pole)		kW (Pole)	0.91(8)+0.49(8)×2	0.91(8)+0.66(8)+0.49(8)	0.91(8)×2+0.49(8)
	Quantity		Q'ty	3	3	3
	Air Flow Rate		cfm (m3/min)	7413+6178 +6178 (210+175 +175)	7413+6884 +6178 (210+195 +175)	7413+7413 +6178 (210+210 +175)
	External static pressure****		in.WG (Pa)	0 (0)		
	Drive			Direct drive		
Electrical	Min Circuit Amps		A	Reference: YVAHR120B31S	Reference: YVAHR120B31S	Reference: YVAHR120B31S
	Recommended Fuse/Breaker Size		A	YVAHR072B31S	YVAHR096B31S	YVAHR120B31S
	Maximum Fuse Size		A	YVAHR072B31S	YVAHR072B31S	YVAHR072B31S
Sound Pressure Level	Cooling (Night-Shift)		dB(A)	67 (61)	67 (62)	68 (62)
	Heating		dB(A)	67	67	68
Protection devices	Cycle		-	High pressure switch at 601psi (4.15MPa)		
	Inverter		-	Over-current protection / Over-heat protection		
	Compressor		-	Over-heat protection		
	PCB		-	Over-current protection		
Refrigerant	Type-Qty		-	R410A	R410A	R410A
	Charge amount		lbs (kg)	20.9+16.1+16.1 (9.5+7.3+7.3)	20.9+18.7+16.1 (9.5+8.5+7.3)	20.9+20.9+16.1 (9.5+9.5+7.3)
Refrigeration Oil	Charge amount		gal/Unit (l/Unit)	2.1+1.6+1.6 (7.9+6.0+6.0)	2.1+1.6+1.6 (7.9+7.9+6.0)	2.1+1.6+1.6 (7.9+7.9+6.0)
Defrost Method			-	Reversed Refrigerant Cycle		
Main Refrigerant Piping (Heat Recovery)	Low Pressure Gas Line		in (mm)	1-5/8 (41.28)	1-5/8 (41.28)	1-5/8 (41.28)
	High/Low Pressure Gas Line		in (mm)	1-3/8 (34.93)	1-3/8 (34.93)	1-3/8 (34.93)
	Liquid Line		in (mm)	3/4 (19.05)	3/4 (19.05)	3/4 (19.05)

* Rating conditions are based on the AHRI 1230 test standard. See www.ahrinet.org for more information.
** Operation under harsh condition may require optional accessories.
*** The table shows an example where there is 7/8in.(22mm) clearance between the base units.
**** External static pressure can be changed using the DSW setting 0.24in.W.G.(60Pa).

Outdoor Unit 208/230V HR | 28-30 TON SYSTEMS

28-30 Ton Systems	Type				Quad Unit Systems			
	Tonnage				28 Ton (8+8+6+6)		30 Ton (10+8+6+6)	
Model (combination)					YVAHR336B31S		YVAHR360B31S	
Model (individual)	Unit A				YVAHR096B31S		YVAHR120B31S	
	Unit B				YVAHR096B31S		YVAHR096B31S	
	Unit C				YVAHR072B31S		YVAHR072B31S	
	Unit D				YVAHR072B31S		YVAHR072B31S	
Power Supply					208/230V/ 3PH 60Hz		208/230V/ 3PH 60Hz	
Capacity (Nominal) *	Cooling	Capacity (Nominal)	Btu/h	(kW)	336,000	(98.5)	360,000	(105.5)
		Power input	kW		27.38		30.34	
		Current input	A (208V/230V)		82.6 / 74.8		92.6 / 85.6	
	Heating	Capacity (Nominal)	Btu/h	(kW)	378,000	(110.8)	405,000	(118.7)
		Power input	kW		26.52		28.92	
		Current input	A (208V/230V)		82.0	/ 76.8	89.2	/ 83.3
Efficiency Ratings *	Cooling	Capacity (Rated)	Btu/h	(kW)	320,000	(93.8)	342,000	(100.3)
		EER	Btu/Wh	(W/W)	11.10	(3.26)	9.50	(2.79)
		IEER	Btu/Wh	(Wh/Wh)	21.20	(6.22)	18.50	(5.43)
	Heating High	Capacity (Rated)	Btu/h	(kW)	360,000	(105.6)	386,000	(113.2)
		COP	W/W		3.87		3.88	
	Heating Low	Capacity	Btu/h	(kW)	268,000	(78.6)	284,000	83.3
		COP	W/W		2.60		2.46	
	Heat Recovery	SCHE	W/W		26.90		27.60	
Cooling Operating Range**	Indoor		°F WB (°C WB)		59(15) - 73(23)		59(15) - 73(23)	
	Outdoor		°F DB (°C DB)		14(-10) - 118(48)		14(-10) - 118(48)	
Heating Operating Range	Indoor		°F DB (°C DB)		59(15) - 80(27)		59(15) - 80(27)	
	Outdoor		°F WB (°C WB)		-4(-20) - 59(15)		-4(-20) - 59(15)	
Cabinet Color (Munsell Code)					2.5Y 8/2			
Outer Dimensions	Height		in	(mm)	68-1/8	(1730)	68-1/8	(1730)
	Width***		in	(mm)	173-5/32	(4398)	173-5/32	(4398)
	Depth		in	(mm)	31-7/32	(793)	31-7/32	(793)
Package Dimensions	Height		in	(mm)	Reference: YVAHR096B31S YVAHR096B31S YVAHR072B31S YVAHR072B31S		Reference: YVAHR120B31S YVAHR096B31S YVAHR072B31S YVAHR072B31S	
	Width		in	(mm)				
	Depth		in	(mm)				
Weight	Net		lbs	(kg)	2540	(1152)	2542	(1153)
	Gross		lbs	(kg)	2747	(1246)	2750	(1247)
Connection Ratio	Total Indoor Unit Capacity		%		140 - 65		135 - 65	
	Max. (Recommendation) indoor units/system		-		64 (38)		60 (38)	
Heat Exchanger	Type		-		Multi-Pass Cross-Finned Tube			
	Material		-		Cu-Al (Anti-corrosion)			
Compressor	Type		Inverter		DA65PHD×4		DA65PHD×4	
			Fixed Speed		E655DH×2		E655DH×2	
	Motor Output (Pole)		kW (Pole)		*4.8(6)+4.4(2) 4.8(6)+4.4(2) 7.26(6) 7.26(6)*		*6.0(6)+4.4(2) 4.8(6)+4.4(2) 7.26(6) 7.26(6)*	
	Start Method		-		Inverter			
	Operation Range		%		5 - 100		5 - 100	
	Refrigeration Oil Type		-		FVC68D		FVC68D	
Crank Case Heater			W×Q'ty		40.8 (230V) ×12		40.8 (230V) ×12	
Fan	Type		-		Propeller Fan			
	Motor Output (Pole)		kW (Pole)		0.66(8)×2+0.49(8)×2		0.91(8)+0.66(8)+0.49(8)×2	
	Quantity		Q'ty		4			
	Air Flow Rate		cfm	(m³/min)	6884+6884+6178+6178	195+195+175+175	7413+6884+6884+6178	210+195+195+175
	External static pressure****		in.WG	(Pa)	0 (0)			
	Drive				Direct drive			
Electrical	Min Circuit Amps		A		Reference: YVAHR096B31S YVAHR096B31S YVAHR072B31S YVAHR072B31S		Reference: YVAHR120B31S YVAHR096B31S YVAHR072B31S YVAHR072B31S	
	Recommended Fuse/Breaker Size		A					
	Maximum Fuse Size		A					
Sound Pressure Level	Cooling (Night-Shift)		dB(A)		68	(63)	68	(63)
	Heating		dB(A)		68		68	
Protection devices	Cycle		-		High pressure switch at 601psi (4.15MPa)			
	Inverter		-		Over-current protection / Over-heat protection			
	Compressor		-		Over-heat protection			
	PCB		-		Over-current protection			
Refrigerant	Type-Qty		-		R410A			
	Charge amount		lbs	(kg)	18.7+18.7+16.1+16.1	(8.5+8.5+7.3+7.3)	20.9+18.7+16.1+16.1	(9.5+8.5+7.3+7.3)
Refrigeration Oil	Charge amount		gal/Unit	(l/Unit)	2.1+2.1+1.6+1.6	(7.9+7.9+6.0+6.0)	2.1+2.1+1.6+1.6	(7.9+7.9+6.0+6.0)
Defrost Method			-		Reversed Refrigerant Cycle			
Main Refrigerant Piping (Heat Recovery)	Low Pressure Gas Line		in	(mm)	1-5/8	(41.28)	1-5/8	(41.28)
	High/Low Pressure Gas Line		in	(mm)	1-3/8	(34.93)	1-3/8	(34.93)
	Liquid Line		in	(mm)	3/4	(19.05)	3/4	(19.05)

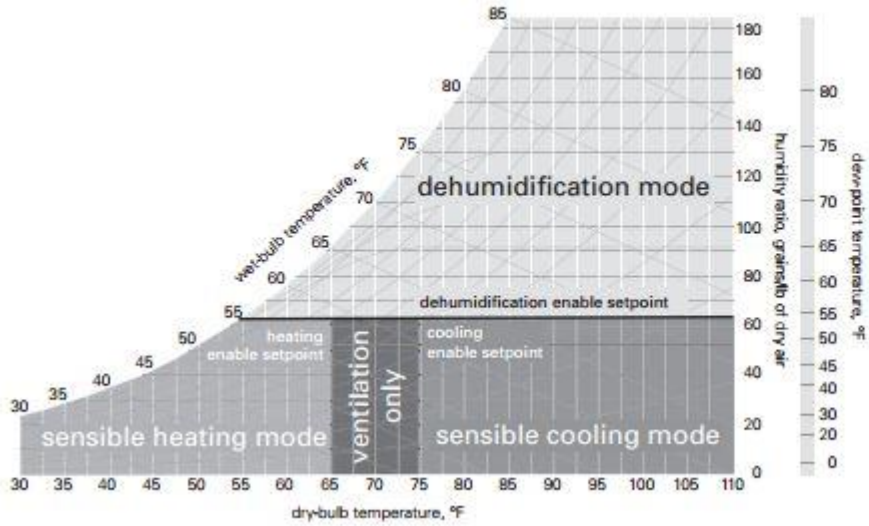
* Rating conditions are based on the AHRI 1230 test standard. See www.ahrinet.org for more information.
** Operation under harsh condition may require optional accessories.
*** The table shows an example where there is 7/8in.(22mm) clearance between the base units.
**** External static pressure can be changed using the DSW setting 0.24in.W.G.(60Pa).

Table 18. OANE General Data—Cooling 30–40 Tons High Efficiency

	30 Tons Downflow	35 Tons Downflow	40 Tons Downflow
	OANE360A	**OANE420A**	**OANE480A**
Cooling Performance			
Gross Cooling Capacity, Btu (kW)	379,546 (111.23)	451,733 (132.39)	491,044 (143.91)
Heating Performance			
Gross Heating Capacity, Btu (kW)	361,914 (106.07)	406,655 (119.18)	450,153 (131.93)
CFM			
Nominal cfm/AHRI rated cfm (m^3/h)	3750–7500 (6371–12743)	4375–8750 (7433–14866)	5000–10000 (8495–16990)
Compressor			
Number	2	3	3
Type	Scroll	Scroll	Scroll
Outdoor Coil			
Type	High Performance	High Performance	High Performance
Tube Size—OD, in. (mm)	1/2 (12.7)	1/2 (12.7)	1/2 (12.7)
Face Area, ft^2 (m^2)	50 (4.65)	62 (5.76)	62 (5.76)
Rows	2	2	2
FPI	12	12	12
Indoor Coil			
Type	High Performance	High Performance	High Performance
Tube Size—OD, in. (mm)	1/2 (12.7)	1/2 (12.7)	1/2 (12.7)
Face Area, ft^2 (m^2)	22 (2.04)	28 (2.60)	28 (2.60)
Rows	4	4	4
FPI	12	12	12
Refrigerant Control	TXV	TXV	TXV
Drain Connection Size, in. (mm)	1-1/4 (31.8)	1-1/4 (31.8)	1-1/4 (31.8)
Outdoor Fan			
Type	Propeller	Propeller	Propeller
Number Used	4	4	4
Diameter, in. (mm)	24 (609.6)	24 (609.6)	24 (609.6)
Drive Type	Direct Drive	Direct Drive	Direct Drive
No. Speeds	1	1	1
CFM (m^3/h)	26,000 (44,174)	26,000 (44,174)	26,000 (44,174)
Number Motors	4	4	4
Motor HP (kW), per motor	1.0 (0.75)	1.0 (0.75)	1.0 (0.75)
Motor RPM	1,140	1,140	1,140
Indoor Fan			
Type	Backward Inclined	Backward Inclined	Backward Inclined
Number Used	1	1	1 or 2
Diameter	Varies	Varies	Varies
Drive Type	Direct Drive	Direct Drive	Direct Drive
Number Motors	1	1	1 or 2
Motor HP (kW), Standard-Oversized	1.5–15 (1.12–11.19)	1.5–15 (1.12–11.19)	2.0–15 (1.49–11.19)
Motor RPM, Standard-Oversized	1750–3500	1750–3500	1750–3500
Motor Frame Size, Standard-Oversized	Varies	Varies	Varies
Filters			
Type Furnished / Number Size Recommended	Refer to "OAU Filter Guide" in "Appendix," p. 84	Refer to "OAU Filter Guide" in "Appendix," p. 84	Refer to "OAU Filter Guide" in "Appendix," p. 84
Refrigerant Charge, lb of R-410A			
Downflow	See Nameplate	See Nameplate	See Nameplate

OAU-PRC001E-EN

Figure 10. Dedicated OA unit control modes (OA control)



PRODUCT GUIDE **DUCTED HIGH-STATIC**

PEFY-P72/96NMHSU-E

Model Name			PEFY-P72NMHSU-E	PEFY-P96NMHSU-E
Power Source			208 / 230V, 1-phase, 60Hz	
Cooling Capacity *1		Btu/h	72,000	96,000
Heating Capacity *1		Btu/h	80,000	108,000
Power Consumption	Cooling	W	63	82
	Heating	W	63	82
Current	Cooling	A	3.67 / 3.32	4.89 / 4.43
	Heating	A	3.67 / 3.32	4.89 / 4.43
External Finish			Galvanized Steel Plate	
Dimensions	Height	In.	18-9/16"	
	Width	In.	49-1/4"	
	Depth	In.	44-1/8"	
Net Weight	Unit	Pounds	214	221
Heat Exchanger			Cross Fin (Aluminum plate fin and copper tube)	
Fan	Type x Quantity		Sirocco Fan x 2	Sirocco Fan x 2
	Airflow Rate *2	CFM	1,766 - 2,154 - 2,542	2,048 - 2,507 - 2,966
	Ext. Static Pressure (208 / 230V)	In. W.G.	0.20 - 0.40 - 0.60 - 0.80 - 1.00	
	Motor Type		DC Motor	
Air Filter			Optional Part	
Refrigerant Pipe Dimensions	Low Pressure	In.	3/4" (Brazed)	7/8" (Brazed)
	High Pressure	In.	3/8" (Brazed)	3/8" (Brazed)
Drain Pipe Dimension (O.D.)		In.	1-1/4"	1-1/4"
Sound Levels *2 (Lo-Mid-Hi)		dB(A) @ 230V	36 - 39 - 43	39 - 42 - 46

Notes:
***1 Cooling/Heating capacity indicates the maximum value at operation under the following conditions:**
Cooling | Indoor: 80° F (27° C) DB / 67° F (19° C) WB; Outdoor: 95° F (35° C) DB
Heating | Indoor: 70° F (21° C) DB; Outdoor: 47° F (8° C) DB / 43° F (6° C) WB
***2 Airflow rate/sound levels are at (Lo-Mid-Hi)**

Specifications are subject to change.

		FEATURES	ADVANTAGES	BENEFITS
BUILDING OWNER	System	Rotational operation	• In multiple-unit applications at partial load, outdoor units operate alternately so that operating hours are shared equally.	• Optimizes efficiency • Extends service life • Increases reliability
		Backup operation function	• Allows one outdoor unit to be taken off-line for maintenance while remaining units keep operating.	• Avoids system downtime • Protects occupant comfort
		Efficiency optimized for part-load operation	• SCHE among industry's highest for VRF systems	• Saves energy
		Optimum individualized comfort	• Heat recovery systems deliver simultaneous heating and cooling	• Efficient heating/cooling • Maximizes occupant comfort
		Noise reduction preference mode	• Lets users choose from three settings for a "not to exceed" sound level	• Extremely quiet (sound ratings as low as 50 dBA for outdoor units; 27 dBA for indoor units) • Ideal where outdoor units are positioned on side of building or in locations where there are noise restrictions
	Compressor	DC inverter-driven scroll compressor	• Engineered to deliver the optimum efficiency at normal load conditions	• Among industry's most efficient VRF systems: • Highest IEER • Highest SCHE • Highest COP in low and high heating modes
		Compressor modulation in 1 Hz increments	• Smoothly delivers only the exact amount of refrigerant needed for the load	• Allows fine control for optimum comfort • Saves energy
	Outdoor Units	Demand control	• Users can select from a wide variety of power settings from 100% to 60% and program "not to exceed" a given power level	• Limits electric demand charges • Limits equipment wear and tear • Reduces noise
		Load shedding	• Allows programming to turn units on/off in rotation at 10- to 20-minute intervals	• Saves energy • Limits demand charges
		Double-blade fan	• Longer fan blades increase airflow quantity by 25%, resulting in higher static pressure	• Reduces noise • Extends motor life
	Indoor Units	As high as .74 WG static pressure in ducted systems	• Offers adjustable speeds to match the static pressure requirement	• Flexibility to accommodate long or short ductwork runs
		Optional motion and radiant sensors	• Sets back temperature when space is unoccupied, increasing efficiency even further	• Saves energy
	Controls	H-Link II Protocol	• Controls multiple indoor and outdoor units from one control point • Adds versatility to connect various central control options	• Maximizes indoor comfort • Saves energy • Improves system management
		Temperature control	• Adjusts in 1 degree F increments • Adjustable fan speeds	• Auto-adjusts for daylight saving time • Provides options to satisfy multiple projects/ buildings
		H-LINK II BACnet adapter for integration into BMS	• Enables control of VRF systems by way of a building management system (e.g. Metasys®) for almost unlimited control in a building of campus enterprise.	• Optimizes comfort • Saves energy • Unified interface for all HVAC systems

APPENDIX C: Centralized Air Handling Unit

Physical Data - 080 through 105

Data	Unit Size				
	080D/081D	085D	090D/091D	100D/101D	105D
Compressor					
Quantity–hp	6–11.5	6–26	6–13	3–13 3–15	6–15
Capacity control	100-83-67-50-33-17-0			100-83-67-49-33-16-0	100-84-67-50-33-17-0
Condenser fans					
Qty–diameter (in)	6–26	6–26	8–26	9–26	8–26
Condenser fan motors					
Qty–hp	6–1.0	6–1.0	8–1.0	9–1.0	8–1.0
Supply fans					
Type	DWDI airfoil				
Qty–diameter (in)	1–33, 36	1–33, 36	1–33, 36	1–36, 40	1–36, 40
Motor hp range	5–75	5–75	5–75	5–75	5–75
Return fans					
Type	SWSI airfoil				
Qty–diameter (in)	1–44.5	1–44.5	1–44.5	1–44.5	1–44.5
Motor hp range	5–60	5–60	5–60	5–60	5–60
Exhaust fans					
Type	Propeller				
Diameter (in)	36	36	36	36	36
Qty	1–3 per unit	1–3 per unit	1–3 per unit	1–3 per unit	1–3 per unit
Motor hp	5 each	5 each	5 each	5 each	5 each
Evaporator coils					
Rows	4, 5	4, 5	4, 5	4, 5	4, 5
FPI	10, 12	10, 12	10, 12	10, 12	10, 12
Face area, small (sq ft)	53.9	53.9	53.9	60.8	60.8
Face area, large (sq ft)	60.8	60.8	60.8	76.0	76.0

Hot water coils					
Type–rows	5WH–1, 5WS–2	5WH–1, 5WS–2	5WH–1, 5WS–2	5WH–1, 5WS–2	5WH–1, 5WS–2
FPI	9	9	9	9	9
Face area (sq ft)	42.2	42.2	42.2	42.2	42.2
Steam coils					
Type–rows	5JA–1, 2	5JA–1, 2	5JA–1, 2	5JA–1, 2	5JA–1, 2
FPI	6, 12	6, 12	6, 12	6, 12	6, 12
Face area (sq ft)	42.2	42.2	42.2	42.2	42.2
Gas furnace					
Input (MBh)	625, 800, 812, 988, 1000, 1250, 1375, 1750, 1875, 2500				
Nominal output (MBh)	500, 640, 650, 790, 800, 1000, 1100, 1400, 1500, 2000				
Electric heat					
Nominal output (kW)	80, 100, 120, 160, 200, 240, 280, 320				
Panel filters					
Type	85% (MERV 13) or 30% (MERV 7 or 8), pleated				
Area (sq ft)	116.1	116.1	116.1	116.1	116.1
Qty–size (in)	11–16×20×2, 33–16×25×2				
Prefilters (for cartridge filters)					
Type	Prefilter, 30% (MERV 7 or 8), standard flow				
Area (sq ft)	56.0	56.0	56.0	56.0	56.0
Qty–size (in)	4–12×24×2, 12–24×24×2			16–24×24×2	
Type	Prefilter, 30% (MERV 7 or 8), standard flow				
Area (sq ft)	64.0	64.0	64.0	64.0	64.0
Qty–size (in)	16–24×24×2			8–12×24×2, 16–24×24×2	

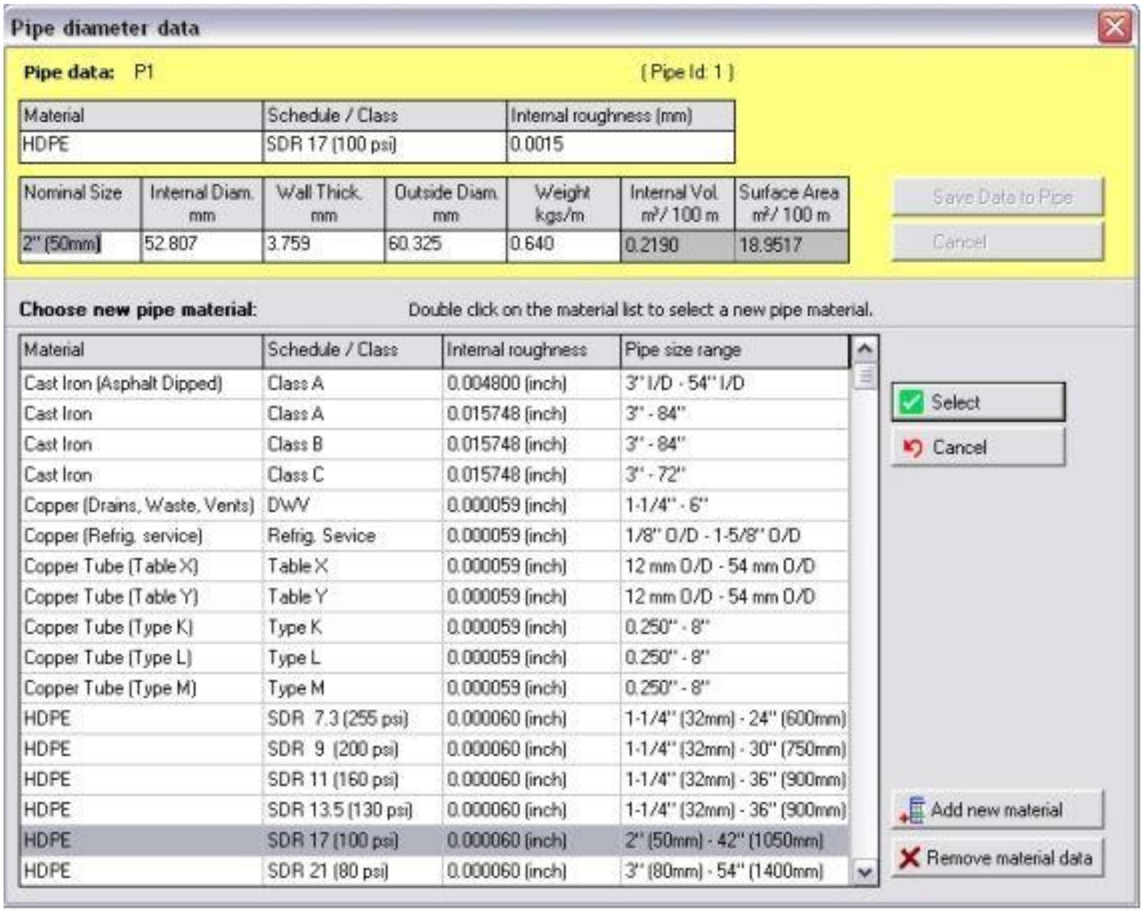
Cartridge filters					
Type	65% (MERV 11) or 95% (MERV 14), standard flow				
Area (sq ft)	56.0	56.0	56.0	56.0	56.0
Qty–size (in)	4–12×24×12, 12–24×24×12			16–24×24×12	
Type	65% (MERV 11) or 95% (MERV 14), standard flow				
Area (sq ft)	64.0	64.0	64.0	64.0	64.0
Qty–size (in)	16–24×24×12			8–12×24×12 16–24×24×12	

NOTE:
1. Gas furnace size availability is limited by minimum airflow (RFS/RPS only).
2. 460-volt capacities are shown. Electric heat availability is limited by minimum airflow (RFS/RPS only).

Physical Data - 110 through 140

Data	Unit Size				
	110D	120D	125D	130D	140D
Compressor					
Quantity–hp	6–15	3–15 3–20	6–20	6–20	3–20 3–25
Capacity control	100-84-67-50-33-17-0	100-83-67-49-33-16-0	100-84-67-50-33-17-0		100-83-67-49-33-16-0
Condenser fans					
Qty–diameter (in)	8–26	9–26	10–26	12–26	12–26
Condenser fan motors					
Qty–hp	8–1.0	9–1.0	10–1.0	12–1.0	12–1.0
Supply fans					
Type	DWDI airfoil				
Qty–diameter (in)	1–36, 40	1–36, 40	1–36, 40	1–36, 40	1–36, 40
Motor hp range	5–75	5–75	5–75	5–75	5–75
Return fans					
Type	SWSI airfoil				
Qty–diameter (in)	1–44.5	1–44.5	1–44.5	1–44.5	1–44.5
Motor hp range	5–60	5–60	5–60	5–60	5–60
Exhaust fans					
Type	Propeller				
Diameter (in)	36	36	36	36	36
Qty	1–3 per unit	1–3 per unit	1–3 per unit	1–3 per unit	1–3 per unit
Motor hp	5 each	5 each	5 each	5 each	5 each
Evaporator coils					
Rows	4, 5	4, 5	4, 5	4, 5	4, 5
FPI	10, 12	10, 12	10, 12	10, 12	10, 12
Face area, small (sq ft)	60.8	60.8	–	–	–
Face area, large (sq ft)	76.0	76.0	76.0	76.0	76.0

APPENDIX D: Construction Breadth



Pipe diameter data

Pipe data: P1 [Pipe Id: 1]

Material	Schedule / Class	Internal roughness (mm)
HDPE	SDR 17 (100 psi)	0.0015

Nominal Size	Internal Diam. mm	Wall Thick. mm	Outside Diam. mm	Weight kgs/m	Internal Vol. m³/ 100 m	Surface Area m²/ 100 m
2" (50mm)	52.807	3.759	60.325	0.640	0.2190	18.9517

Save Data to Pipe

Cancel

Choose new pipe material: Double click on the material list to select a new pipe material.

Material	Schedule / Class	Internal roughness	Pipe size range
Cast Iron (Asphalt Dipped)	Class A	0.004800 (inch)	3" I/D - 54" I/D
Cast Iron	Class A	0.015748 (inch)	3" - 84"
Cast Iron	Class B	0.015748 (inch)	3" - 84"
Cast Iron	Class C	0.015748 (inch)	3" - 72"
Copper (Drains, Waste, Vents)	DWV	0.000059 (inch)	1-1/4" - 6"
Copper (Refrig. service)	Refrig. Sevice	0.000059 (inch)	1/8" O/D - 1-5/8" O/D
Copper Tube (Table X)	Table X	0.000059 (inch)	12 mm O/D - 54 mm O/D
Copper Tube (Table Y)	Table Y	0.000059 (inch)	12 mm O/D - 54 mm O/D
Copper Tube (Type K)	Type K	0.000059 (inch)	0.250" - 8"
Copper Tube (Type L)	Type L	0.000059 (inch)	0.250" - 8"
Copper Tube (Type M)	Type M	0.000059 (inch)	0.250" - 8"
HDPE	SDR 7.3 (255 psi)	0.000060 (inch)	1-1/4" (32mm) - 24" (600mm)
HDPE	SDR 9 (200 psi)	0.000060 (inch)	1-1/4" (32mm) - 30" (750mm)
HDPE	SDR 11 (160 psi)	0.000060 (inch)	1-1/4" (32mm) - 36" (900mm)
HDPE	SDR 13.5 (130 psi)	0.000060 (inch)	1-1/4" (32mm) - 36" (900mm)
HDPE	SDR 17 (100 psi)	0.000060 (inch)	2" (50mm) - 42" (1050mm)
HDPE	SDR 21 (80 psi)	0.000060 (inch)	3" (80mm) - 54" (1400mm)

Select

Cancel

Add new material

Remove material data

Table F.1 Properties of Antifreeze Solutions

Fluid	Solution Volume, %	Freeze Point* °F	Freeze Point* °C	Viscosity (cp) 32°F 0°C	Viscosity (cp) 59°F 15°C	Viscosity (cp) 86°F 30°C	Density lb/ft³ 32°F	Density kg/m³ 0°C	Density lb/ft³ 59°F	Density kg/m³ 15°C	Density lb/ft³ 86°F	Density kg/m³ 30°C
Water	0	32	0	1.79	1.14	0.80	62.4	998	62.3	997	62.1	994
Ethanol	10	25	-4	3.00	1.67	1.09			61.4	982		
Ethanol	20	17	-8	4.62	2.32	1.42			60.7	971		
Ethylene glycol	10	25	-4	2.09	1.37	0.97	63.6	1018	63.4	1014	63.1	1010
Ethylene glycol	20	16	-9	3.03	1.89	1.31	64.7	1035	64.5	1032	64.1	1026
Ethylene glycol	30	3.5	-16	3.17	2.54	1.70	65.7	1051	65.4	1046	65.1	1042
Methanol	10	22	-6	2.44	1.48	0.99			61.4	982		
Methanol	20	11	-12	3.02	1.77	1.15			60.9	974		
Propylene glycol	10	26	-3	2.70	1.63	1.11	63.4	1014	63.1	1010	62.8	1005
Propylene glycol	20	19	-7	4.07	2.37	1.52	64.1	1026	63.8	1021	63.4	1014
Propylene glycol	30	10	-12	7.10	3.70	2.20	64.8	1037	64.4	1030	64.0	1024

Freeze point values are for pure fluids and vary depending on inhibitor concentrations.

APPENDIX E: Electrical Breadth

Wire Size and Amp Ratings

Wire Gauge Size	Copper			Aluminum	
	60°C (140°F)	75°C (167°F)	90°C (194°F)	75°C (167°F)	90°C (194°F)
	NM-B	THW	THWN-2	THW	XHHW-2
	UF-B	THWN	THHN	THWN	THHN
	---	SE	XHHW-2	SE	TWHN-2
	---	USE	---	USE	---
	---	XHHW	---	XHHW	---
14	15	15	15	---	---
12	20	20	20	15	15
10	30	30	30	25	25
8	40	50	55	40	45
6	55	65	75	50	55
4	70	85	95	65	75
3	85	100	115	75	85
2	95	115	130	90	100
1	---	130	145	100	115
1/0	---	150	170	120	135
2/0	---	175	195	135	150
3/0	---	200	225	155	175
4/0	---	230	260	180	205
250	---	255	290	205	230
300	---	285	320	230	260
350	---	310	350	250	280
500	---	380	430	310	350
600	---	420	475	340	385
750	---	475	535	385	435
1000	---	545	615	445	500

WARNING! Installation of electrical wire can be hazardous, if done improperly, can result in personal injury or property damage. For safe wiring practices, consult the National Electrical Code® and your local building inspector.

(From NEC Table 250–95)[1])

Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit etc., Not Exceeding (Amperes)	Size	
	Copper Wire Number	Aluminum or Copper Clad Aluminum Wire Number
15	14	12
20	12	10
30	10	8
40	10	8
60	10	8
100	8	6
200	6	4
300	4	2
400	3	1
500	2	1/0
600	1	2/0
800	1/0	3/0
1000	2/0	4/0
1200	3/0	250 kcmil
1600	4/0	350 kcmil
2000	250 kcmil	400 kcmil
2500	350 kcmil	600 kcmil
3000	400 kcmil	600 kcmil
4000	500 kcmil	800 kcmil
5000	700 kcmil	1200 kcmil
6000	800 kcmil	1200 kcmil