Executive Summary

A life cycle cost analysis (LCCA) was performed to determine the most cost effective HVAC system to install at Sample Middle School. Four systems were evaluated as part of this analysis including a VAV system with an air-cooled chiller, a VAV system with a water-cooled chiller, a geothermal system with individual water to air heat pumps and a four-pipe fan coil unit system. The results of the LCCA indicate that the geothermal system is the most cost-effective solution for the school over a 40 year period. While the geothermal system has the greatest first cost when compared to the VAV systems and fan coil units, the energy savings (and other factors) were enough to offset the large first cost delta.

Table 1 below indicates the net present value costs of each of the four heating/cooling options for Sample Middle School. The energy model and cost analysis are described in more detail in the Results section of this report.

Table 1: Net Present Value over a 40 Year Analysis Period

HVAC System Option	Net Present Value
Option 1: VAV w/ Air Cooled Chiller	$17,080,635
Option 2: VAV w/ Water Cooled Chiller	$17,003,880
Option 3: Geothermal	$15,626,059[1]
Option 4: Four Pipe Fan Coil Units	$18,724,304

Note:

1. Most cost effective system.

Building Information

This is a multi-story approximately 200,000 square foot new middle school. The new facility is anticipated to have a state rated capacity (SRC) of approximately 1,500 students and will include the following spaces: general classrooms, art and music classrooms, media center, digital learning space, cafeteria, gymnasium, stage, locker rooms, as well as the administrative and health/guidance areas. This building will also house space dedicated to the Parks and Recreation program including activity rooms, office space and storage spaces.

The design team performed a 40-year life cycle cost analysis comparing four mechanical systems in order to determine the most effective heating/cooling system to use in the school. This report will summarize the findings of the life cycle analysis. Please note, the values indicated for this report do not represent actual cost data and should only be used for comparison between systems. Several factors such as scheduling, set points, maintenance costs, actual weather, etc. could affect actual energy cost data.

Description of HVAC System Options

Option 1 – Four-pipe VAV System with Air Cooled Chiller: The heating/cooling source includes a high efficiency air cooled chiller and multiple gas-fired condensing boilers to provide four-pipe heating and chilled water to central air handling unit equipment. Central station rooftop air handling units serving all-air variable air volume (VAV) systems will condition the classroom spaces as well as the gymnasium cafeteria, stage and media center spaces. Based on discussions with the school, the administration area will be equipped with air cooled VRF systems and packaged DX DOAS units.

Option 2 – Four-pipe VAV System with Water Cooled Chiller: The heating/cooling source includes a high efficiency water cooled chiller and multiple gas-fired condensing boilers to provide four-pipe heating and chilled water to central air handling unit equipment. A cooling tower and condenser water loop will be provided to serve the water-cooled chiller. Central station rooftop air handling units serving all-air variable air volume (VAV) systems will condition the classroom spaces as well as the gymnasium cafeteria, stage and media center spaces. Similar to all other options, the administration area will be equipped with air cooled VRF systems and packaged DX DOAS units.

Option 3 – Geothermal System: The heating/cooling source includes heat pumps utilizing geothermal heat exchange (via vertical wells) as the heat rejection for the heating/cooling system. A condenser water loop will serve individual water-to-air heat pumps located in mechanical closets adjacent to each classroom. Ventilation will be provided to the classrooms by water cooled dedicated outside air (DOAS) units. The DOAS units will also be tied into the condenser water loop and will be equipped with energy recovery wheels. The gymnasium, cafeteria, stage and media center spaces will be served by packaged DX rooftop air handling units decoupled from the geothermal loop. Similar to all other options, the administration area will be equipped with air cooled VRF systems and packaged DX DOAS units.

Option 4 – Four-pipe Fan Coil Unit System: This option will include an air-cooled chiller and gas fired condensing boilers as the main cooling and heating sources for the building. Chilled and heating water will be circulated throughout the building to serve fan coil units (FCUs) in each classroom. The FCUs will be re-circulating units providing heating and cooling to each occupied space. Ventilation air will be provided through rooftop air cooled DOAS units with energy recovery wheels. These units will have DX cooling and hot water heat. The gymnasium, cafeteria stage and media center will be served by four-pipe single zone rooftop units. Similar to all other options, the administration area will be equipped with air cooled VRF systems and packaged DX DOAS units.

Assumptions

Several assumptions were be made in order to complete the life cycle cost analysis for the building. Items such as scheduling, energy rates and maintenance costs can have a large impact on the results of the economic analysis. For this reason, all assumptions indicated below were provided to the school for review and updated accordingly.

Table 2: Temperature Setpoints

Mode	Occupied	Unoccupied
Cooling	75 °F	85 °F
Heating	70 °F	60 °F

Table 3: Utility Costs and Financial Information

Item	Assumption
Electric Rate	$0.12 / KWh
Natural Gas Rate	$0.97 / therm

Table 4: School Year Weekday Scheduling

Time / Schedule Type	12 AM – 6 AM	6 AM – 8 AM	8 AM – 10 AM	10 AM – 1 PM	1 PM – 2 PM	2 PM – 4 PM	4 PM – 6 PM	6 PM – 8 PM	8 PM – 12 AM
Classroom Internal Loads	0 %	10 %	90 %	70%	90%		10 %	0 %	
Art / Music Classroom Internal Loads	0 %	10 %	100 %				10 %	0%	
Gym Internal Loads	0 %	10 %	100 %						0%
Media Center Internal Loads	0 %	10%	100 %				10 %	0 %	
Admin/Health Internal Loads	0 %	20 %	100 %				20 %	0 %	
Cafeteria Internal Loads	0 %	50 %	10 %	100 %	10 %		50 %	0 %	
Kitchen Internal Loads	0 %	75 %	100 %			10 %		0 %	
Lighting	10 %	100 %							10 %
Gym Temperature Setpoint	Unocc	Occupied							Unocc
All Other Spaces Temperature Setpoint	Unocc	Occupied						Unoccupied	

Notes:

1. Internal loads refer to occupant and equipment loads within the space.
2. Ventilation loads are tracked with occupant loads.

Table 5: Summer Weekday Scheduling

Time / Schedule Type	12 AM – 6 AM	6 AM – 8 AM	8 AM – 10 AM	10 AM – 1 PM	1 PM – 2 PM	2 PM – 4 PM	4 PM – 6 PM	6 PM – 8 PM	8 PM – 12 AM
Classroom Internal Loads	0 %		50 %					0 %	
Gym Internal Loads	0 %		100 %						0%
Admin Internal Loads	0 %	20 %	100 %				20 %	0 %	
All Other Spaces Internal Loads	0 %								
Classroom Lighting	10 %		50 %					10 %	
Gym Lighting	10 %		100 %						10 %
Admin Lighting	10 %	100 %						10 %	
All Other Spaces Lighting	10%								
Classroom Temperature Setpoint	Unoccupied		Occupied					Unoccupied	
Gym Temperature Setpoint	Unoccupied		Occupied						Unocc
Admin Temperature Setpoint	Unocc	Occupied						Unoccupied	
All Other Spaces Temperature Setpoint	Unoccupied								

Notes:

1. Internal loads refer to occupant and equipment loads within the space.
2. Ventilation loads are tracked with occupant loads.

Table 6: Weekend Scheduling

Time / Schedule Type	12 AM – 6 AM	6 AM – 8 AM	8 AM – 10 AM	10 AM – 1 PM	1 PM – 2 PM	2 PM – 4 PM	4 PM – 6 PM	6 PM – 8 PM	8 PM – 12 AM
Gym Internal Loads	0 %		100 %						0 %
All Other Spaces Internal Loads	0 %								
Gym Lighting	10 %		100 %						10 %
All Other Lighting	10 %								
Gym Temperature Setpoint	Unoccupied		Occupied						Unocc
All Other Spaces Temperature Setpoint	Unoccupied								

Notes:

1. Internal loads refer to occupant and equipment loads within the space.
2. Ventilation loads are tracked with occupant loads.

Equipment Replacement Costs

Per the request of Baltimore County Public Schools, a 40-year life cycle cost analysis was performed. Since 40 years is longer than the anticipated life expectancy of the HVAC equipment, the cost for replacing the equipment associated with each system was considered. Table 7 below describes the equipment associated with each system and the total equipment replacement cost associated with each system. Budget prices for all pieces of equipment were received from a professional cost estimator to assist in this analysis.

Table 7: Equipment Replacement Cost for Each System Over 40 Years

System Option	Equipment to be Replaced	Total Equipment Replacement Cost in Present Value
Option 1: VAV w/ Air Cooled Chiller	4 Variable Volume AHU's 4 Single Zone AHU's 100 VAV boxes w/ Hot Water Heating Coil 1 Air Cooled Chiller 4 Condensing Boilers 2 Chilled Water Pumps 2 Heating Water Pumps	$2,014,000
Option 2: VAV w/ Water Cooled Chiller	4 Variable Volume AHU's 4 Single Zone AHU's 100 VAV boxes w/ Hot Water Heating Coil 1 Water Cooled Chiller 1 Cooling Tower 4 Condensing Boilers 2 Condenser Water Pumps 2 Chilled Water Pumps 2 Heating Water Pumps	$2,026,500
Option 3: Geothermal	4 Single Zone AHU's 100 Heat Pumps 4 Water Cooled DOAS Units 2 Condenser Water Pumps	$1,208,000
Option 4: Four Pipe Fan Coil Units	4 Single Zone AHU's 100 Fan Coil Units 4 Air Cooled DOAS Units 1 Air Cooled Chiller 4 Condensing Boilers 2 Chilled Water Pumps 2 Heating Water Pumps	$1,807,250

Results

This report summarizes the life cycle cost analysis performed by the engineer, to aide the school in determining which cooling/heating system to install at Sample Middle School. The report compared four prevalent systems used throughout schools today; a VAV system with an air-cooled chiller and condensing boilers, a VAV system with a water-cooled chiller and condensing boilers, a geothermal heat pump system with water cooled DOAS units, and four-pipe fan coil unit system with air cooled DOAS units. Please note that equipment common to all four system options (i.e. admin VRF, exhaust fans, etc.) were not included in this analysis since the impact would be equal across all options.

The latest version of the Trane Trace program was used to run an energy simulation for the school. First cost and equipment replacement cost were received from a professional cost estimator to assist in this analysis. The maintenance costs were calculated using values found in the ASHRAE HVAC Applications Handbook. The energy model indicated noticeable energy usage savings for the geothermal system when compared to the VAV systems and the four-pipe fan coil unit system as shown on Table 8 below. The VAV systems offer a low first cost, however, over the 40-year life cycle the energy usage savings makes up for large first cost associated with the geothermal wells. For this reason, the geothermal heat pump system proves to be the most cost-effective solution for the school. Outputs from the Trane Trace modeling can be provided upon request.

Table 8: Summary of Results

HVAC System Option	Option 1: VAV w/ Air Cooled Chiller	Option 2: VAV w/ Water Cooled Chiller	Option 3: Geothermal	Option 4: Four Pipe Fan Coil Units
First Cost	$5,977,000	$6,255,000	$7,645,000	$6,672,000
Equipment Repl. Cost	$2,014,000	$2,026,500	$1,208,000	$1,807,250
Maintenance Cost (per SF/year)	$0.82	$0.82	$0.56	$1.11
Energy Usage (Kbtu/year)	3,697,263	3,423,037	2,870,099	3,561,659
Energy Usage % Savings	-	7.47%	22.37%	3.67%
Energy Cost / year	$124,934	$115,292	$100,232	$115,008
Energy Cost % Savings	-	7.72%	19.77%	7.94%
Lifecycle Cost	$17,080,635	$17,003,880	**$15,626,059**	$18,724,304

Note: % savings are in relation to Option 1.