STATE COLLEGE AREA SCHOOL DISTRICT
HVAC SYSTEM OPTIONS
FOR
PANORAMA VILLAGE ELEMENTARY SCHOOL
State College, Pennsylvania

STATE COLLEGE AREA SCHOOL DISTRICT

We are the future!

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State College School District
Panorama Village Elementary School
HVAC System Alternatives

Executive Summary

The State College School District has retained the services of Barton Associates Inc. through SCHRADERGROUP architecture LLC to provide mechanical and electrical systems engineering for an elementary school at 240 Villa Crest Drive in State College, Pennsylvania of approximately 57,000 ft^2. The project will be registered with the U. S. Green Building Council's LEED for Schools rating system to certify the facility is sustainable and environmentally friendly. The purpose of this evaluation is to provide guidance to the School District in selecting a heating, ventilating, and air conditioning (HVAC) system for the school that best fits the facility and District needs.

Five alternative HVAC systems suitable for the school were identified for this project. They include:

1. Vertical unit ventilators below the windows in each classroom and packaged rooftop units for assembly spaces with an air cooled chiller plant and a heating water boiler plant.
2. A variable air volume (VAV) packaged rooftop unit system with a heating water boiler plant.
3. A water source heat pump system with a dedicated ventilation system, a rooftop evaporative cooler for heat rejection, and a heating water boiler plant.
4. An air to air heat pump system with variable refrigerant volume control and a dedicated ventilation system.
5. A ground coupled water source heat pump system with a dedicated ventilation system.

These systems are explained and compared in the following pages.

All of the systems evaluated are appropriate for the type of building occupancy, building characteristics and region in which the building is proposed. We have presented the systems in a manner to allow the district to understand its options and make an educated decision regarding the HVAC system that best meets the District's needs. Please consider the following criteria during the evaluation:

- Relative importance of background noise
- Relative importance of dehumidification control
- Relative probable construction costs
- Architectural aesthetics
- Maintenance requirements of the system
- Energy efficiency
- LEED certification requirements.

An energy analysis was conducted by the 7 group on the HVAC systems that would meet LEED certification requirements. This analysis and probable construction cost estimates were used to determine the life cycle cost of the modeled systems. The ground coupled water source heat pump system was the most energy efficient system and had the lowest life cycle cost.

Although the final decision rests with the district, Barton Associates recommends that a ground coupled water source heat pump system with a dedicated ventilation system be installed at the Panorama Village Elementary School.

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Alternative 1: Unit Ventilators with Hot Water Heating and Chilled Water Cooling:

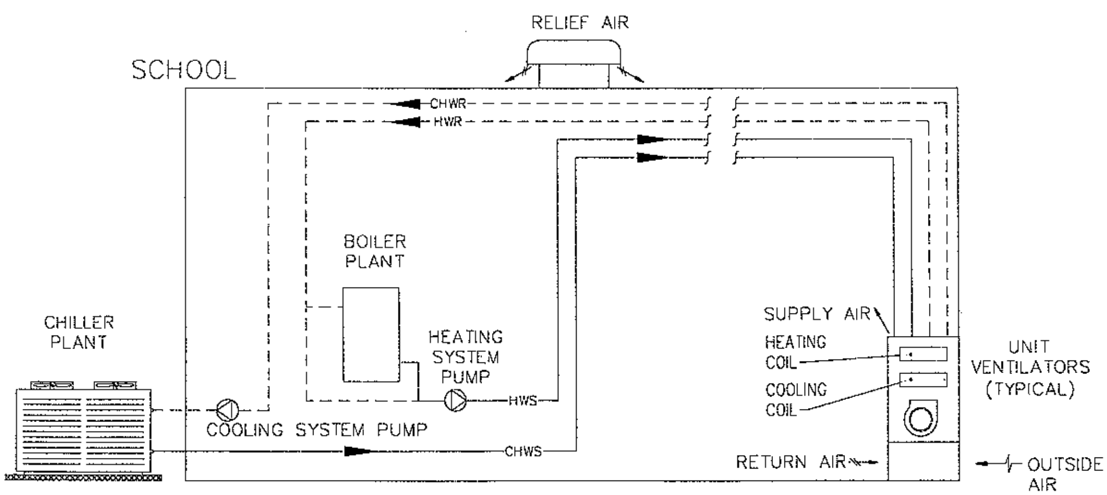
This system alternative would utilize unit ventilators with a hot water heating coil and a chilled water cooling coil delivering conditioned air to classrooms. An outdoor air cooled chiller would generate chilled water to be distributed throughout the school by chilled water pumps and piping. Heating hot water would be generated and distributed by a gas fired hot water boiler(s), hot water pumps and hot water distribution piping. A dehumidification cycle would cool the supply air using the cooling coil, causing moisture to condense out, and then warm the air back to setpoint using the hydronic heating coils when relative humidity rises above setpoint.

Large assembly spaces (cafeteria, gymnasium, etc.) would utilize packaged rooftop units delivering conditioned supply air to each space through distribution ductwork. The units would control the space temperature in each by regulating the delivered air quantity and adjusting the supplied air temperature in response to outside air temperatures. Heating would be provided by duct mounted hot water coils connected to the heating water distribution piping. Cooling would be provided by using outside air for cooling (when appropriate) or by using the rooftop's direct expansion (DX) cooling coil and integral condenser-compressor unit. The rooftop units would draw in outside air and mix it with return air for ventilation. A dehumidification cycle would cool the supply air using the DX cooling coil, causing moisture to condense out, and then warm the air back to setpoint using the hydronic heating coils when relative humidity rises above setpoint.

Building entries, stairwells, storage, mechanical / electrical rooms, and kitchen would be heated with hydronic heaters.

Kitchen exhaust air would be replaced with tempered air (not air conditioned) using a gas-fired rooftop make-up air unit.

A DDC control system would regulate space temperature according to an occupied / unoccupied schedule.



Alternative 1 System Schematic

Benefits:

- Equipment similar to existing systems in school district.
- Active dehumidification capability.
- Lowest probable construction cost of alternatives evaluated.

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Drawbacks:

- Outdoor chiller plant and boiler plant require maintenance.
- Architectural aesthetics of visible outdoor equipment and boiler flues.
- Each space would have a unit with a fan and filters to maintain.
- Unit fans in occupied spaces generate background noise.
- Building floor space required for boiler plant.
- Use of system would preclude LEED certification.
- Floor plan modification to accommodate system would add approximately $250,000 to the building's construction cost.

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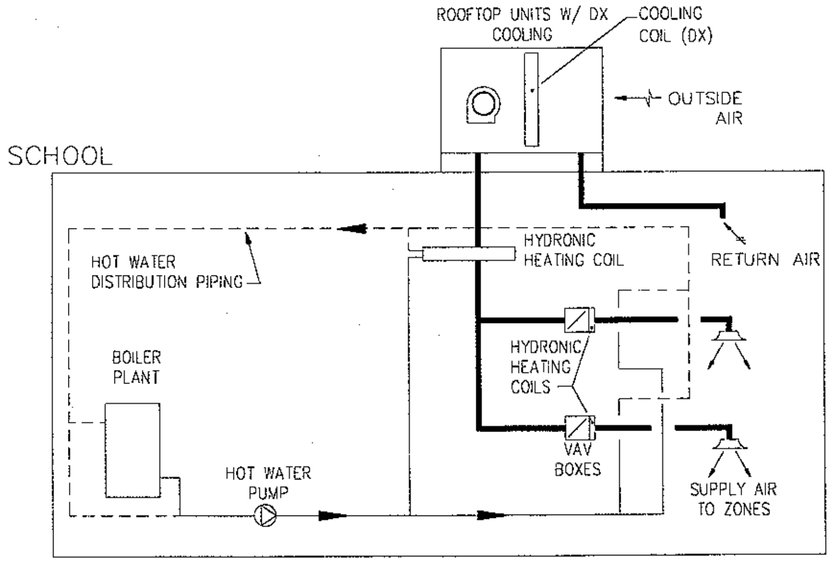
Alternate 2: Variable Air Volume Packaged Rooftop Units with Hydronic Heating:

This system alternative would utilize packaged rooftop units delivering conditioned supply air to variable air volume (VAV) units in each space through distribution ductwork located above the ceilings. The VAV units would control the temperature in each space by regulating the air quantity delivered to air outlets distributed throughout the served space and adding heat as required. Heating would be provided by duct mounted hot water coils and VAV heating coils connected to distribution piping circulating hot water heated by a gas or oil fired boiler plant. Cooling would be provided by using outside air for cooling (when appropriate) or by using the rooftop's direct expansion (DX) cooling coil and integral condenser-compressor unit. The rooftop units would draw in outside air and mix it with return air for ventilation. A dehumidification cycle would cool the supply air using the DX cooling coil, causing moisture to condense out, and then warm the air back to setpoint using the hydronic heating coils when relative humidity rises above setpoint.

Building entries, stairwells, storage, mechanical / electrical rooms, and kitchen would be heated with hydronic heaters.

Kitchen exhaust air would be replaced with tempered air (not air conditioned) using a gas-fired rooftop make-up air unit.

A DDC control system would regulate space temperature according to an occupied / unoccupied schedule.



Alternative 2 System Schematic

Benefits:

- HVAC systems capable of active dehumidification.
- HVAC systems capable of 'free' cooling mode (utilizing cold outside air to cool the building).
- Good temperature control.

Drawbacks:

- Boiler plant requires maintenance.
- Building floor space required for boiler plant.
- Architectural aesthetics of rooftop equipment and boiler flues.
- Floor plan modification to accommodate system would add approximately $350,000 to the building's construction cost.

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- Rooftop unit servicing would be outdoors on the roof.

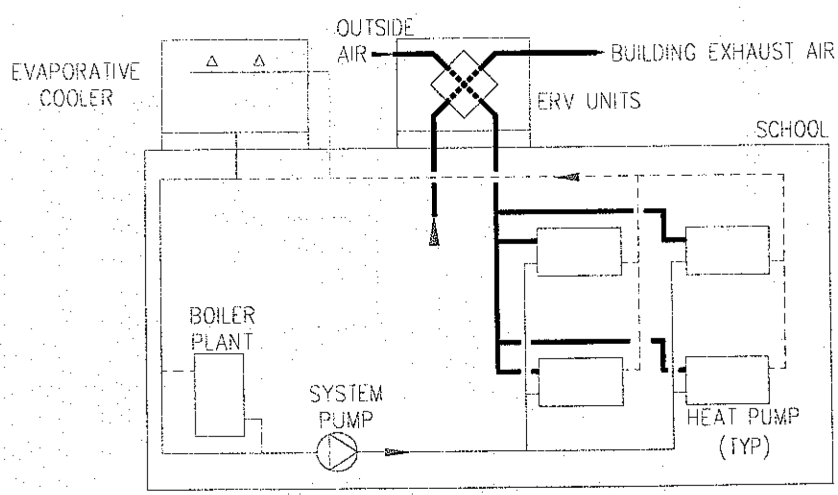
Alternative 3: Water source heat pumps with dedicated ventilation system:

This system alternative would utilize water source heat pumps above the corridor ceilings or in mechanical closets adjacent each zone or space, except for large assembly spaces which would have equipment located on the roof (or mechanical room). Each heat pump would heat and cool its associated zone with conditioned supply air delivered through ductwork located above the ceilings to air outlets distributed throughout the served zone. The supply air temperature would vary in response to a space temperature sensor using a direct expansion (DX) compressor to reject or absorb heat to and from a condenser water loop that extends throughout the building. The condenser water loop temperature would be maintained by a gas-fired boiler that would add heat to the loop during the heating season and an evaporative cooler that would reject heat to the atmosphere during the cooling season. Outside air for ventilation would be tempered and dehumidified by rooftop energy recovery ventilators (ERVs) ducted to the return air ductwork of each heat pump.

Building entries, stairwells, storage, mechanical / electrical rooms, and kitchen would be heated with electric heaters.

Kitchen exhaust air would be replaced with tempered air (not air conditioned) using a gas-fired rooftop make-up air unit.

A DDC control system would regulate space temperature according to an occupied / unoccupied schedule.



Alternative 3 System Schematic

Each heat pump would be capable of independent operation in either a heating or cooling mode. Energy savings can be achieved when some zones require heat while others require cooling. The zones in cooling mode would reject heat to the condenser loop while the zones in heating mode absorb heat from the condenser loop. Essentially, the condenser loop moves heat energy from areas that have an excess to areas that have a deficit.

Energy recovery ventilators temper outside air using an enthalpy wheel to transfer heat and moisture from a warm air stream to a cooler airstream. In the cooling season when the outside air is warmer and more humid than the indoor air, heat and moisture would transfer from the outdoor ventilation airstream to the cooler, drier building exhaust airstream, effectively precooling and dehumidifying

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the air before being supplied to the heat pumps. In the heating season when the outside air is cooler and less humid than the indoor air, heat and moisture would transfer from the building exhaust airstream to the cooler, drier outdoor ventilation airstream, preheating and humidifying the air before being supplied to the heat pumps.

Benefits:

- Good temperature control.
- Reduced operational cost would occur with the use of the energy recovery units.

Drawbacks:

- Reduced dehumidification load with dedicated ventilation system / no active dehumidification
- An airside economizer mode utilizing outside air to cool the building would not be provided.
- Equipment servicing would require ceiling removal and a ladder if a service closet is not provided.
- Building floor space required for boiler plant.
- Heat pump compressors located adjacent to occupied spaces generate audible noise.
- Visibility of rooftop equipment, boiler flues, and evaporative cooler may be undesirable. Evaporative cooler may generate visible vapor cloud.
- Maintenance would be similar to alternative 1 – each zone would have a unit with compressors and filters to maintain. Boiler plant and evaporative cooler also require maintenance.
- Relatively lower comfort level due to cool air discharge for heating by heat pump.
- Floor plan modification to accommodate system would add approximately $250,000 to the building's construction cost.

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Alternative 4: Air to air pumps with variable refrigerant volume control and dedicated ventilation system:

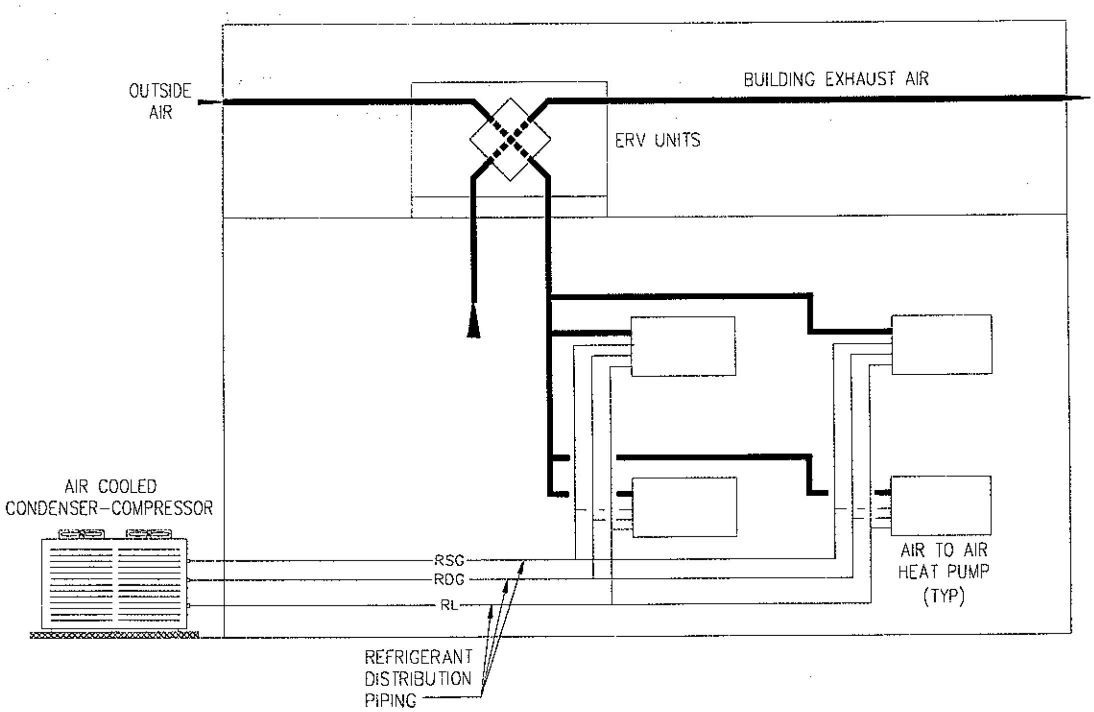
This system alternative would utilize air to air heat pumps above the corridor ceilings or in mechanical closets adjacent each zone or space, except for large assembly spaces which would have packaged rooftop heat pumps. Each heat pump would heat and cool its associated zone with conditioned supply air delivered through ductwork located above the ceilings to air outlets distributed throughout the served zone, with supplemental electric duct heaters for low ambient temperature operation. The supply air temperature would vary in response to a space temperature sensor using a direct expansion (DX) compressor to reject or absorb heat to and from the atmosphere. Outdoor units would have a dedicated DX compressor for each unit and indoor units would have multiple indoor units connected to a single outdoor condensing unit by common refrigerant piping. Outside air for ventilation would be tempered and dehumidified by rooftop energy recovery ventilators (ERVs) ducted to the return air ductwork of each heat pump.

Building entries, stairwells, storage, mechanical / electrical rooms, and kitchen would be heated with electric heaters.

Kitchen exhaust air would be replaced with tempered air (not air conditioned) using a natural gas fired rooftop make-up air unit.

A DDC control system would regulate space temperature according to an occupied / unoccupied schedule.

Alternative 4 System Schematic



Alternative 4 System Schematic

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Each heat pump would be capable of independent operation in either a heating or cooling mode. Energy savings for indoor heat pumps can be achieved when some zones require heat while others require cooling. The zones in cooling mode would reject heat to the refrigerant loop while the zones in heating mode absorb heat from the refrigerant loop. Essentially, the refrigerant loop moves heat energy from areas that have an excess to areas that have a deficit.

Energy recovery ventilators temper outside air using an enthalpy wheel to transfer heat and moisture from a warm air stream to a cooler airstream. In the cooling season when the outside air is warmer and more humid than the indoor air, heat and moisture would transfer from the outdoor ventilation airstream to the cooler, drier building exhaust airstream, effectively precooling and dehumidifying the air before being supplied to the heat pumps. In the heating season when the outside air is cooler and less humid than the indoor air, heat and moisture would transfer from the building exhaust airstream to the cooler, drier outdoor ventilation airstream, preheating and humidifying the air before being supplied to the heat pumps.

Benefits:

- Good temperature control.
- Reduced operational cost would occur with the use of the energy recovery units.
- No building space required for boiler plant.

Drawbacks:

- Anticipated to have highest probable operating cost due to supplemental electric duct heaters required to maintain indoor conditions when outdoor temperatures exceed heat pump condenser minimum ambient operating temperature of approximately 10°F.
- Reduced dehumidification load with dedicated ventilation system / no active dehumidification.
- An airside economizer mode utilizing outside air to cool the building would not be provided.
- Equipment servicing would require ceiling removal and a ladder if a service closet is not provided.
- Heat pump compressors located adjacent to occupied spaces generate audible noise.
- Relatively lower comfort level due to cool air discharge for heating by heat pump.
- No 'free' heat from the earth like the ground-coupled system.
- Minimal building core space provides limited opportunity for energy transfer from interior to exterior zones.
- Floor plan modification to accommodate system would add approximately $50,000 to the building's construction cost.

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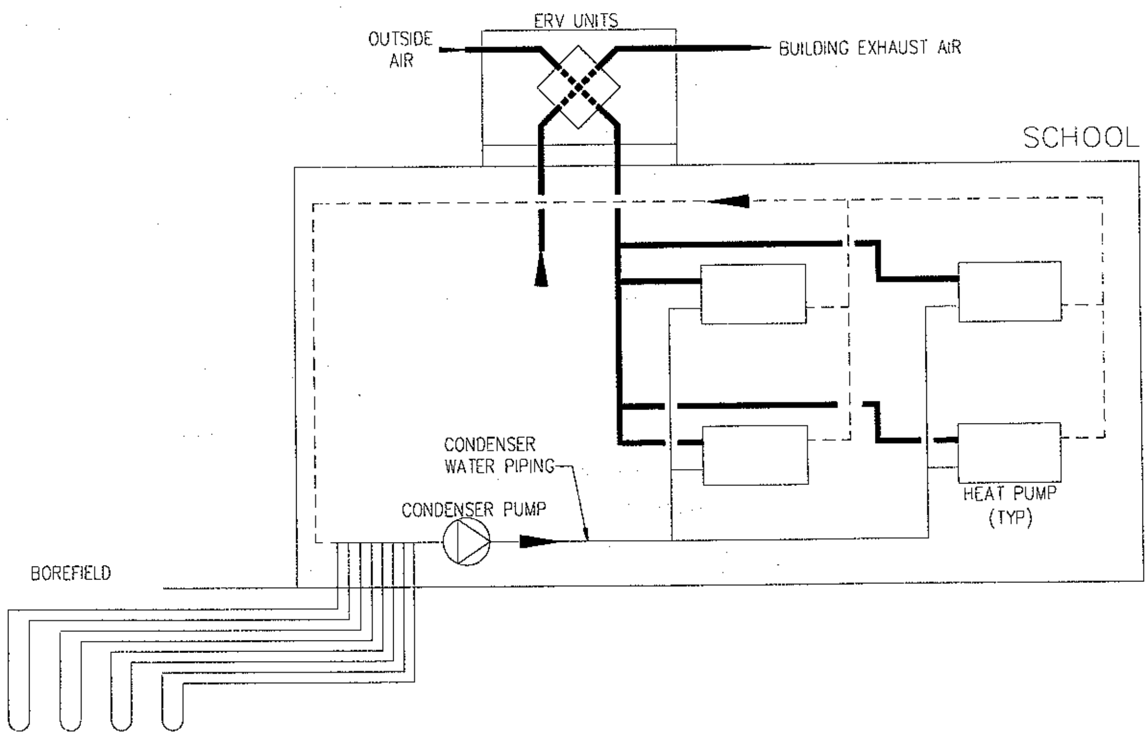
Alternative 5: Ground coupled water source heat pumps with dedicated ventilation system:

This system alternative would utilize water source heat pumps above the corridor ceilings or in mechanical closets adjacent each zone or space, except for large assembly spaces which would have equipment located on the roof (or mechanical room). Each heat pump would heat and cool its associated zone with conditioned supply air delivered through ductwork located above the ceilings to air outlets distributed throughout the served zone. The supply air temperature would vary in response to a space temperature sensor using a direct expansion (DX) compressor to reject or absorb heat to and from a condenser water loop that extends throughout the building. Condenser water pumps would circulate an antifreeze solution between the building's condenser piping and a closed loop borehole field. The field would be a series of vertical piping loops installed in boreholes that moderate the antifreeze solution temperature by rejecting or absorbing heat from the ground, which stays at a relatively constant temperature. Outside air for ventilation would be tempered and dehumidified by rooftop energy recovery ventilators (ERVs) ducted to the return air ductwork of each heat pump.

Building entries, stairwells, storage, mechanical / electrical rooms, and kitchen would be heated with electric heaters.

Kitchen exhaust air would be replaced with tempered air (not air conditioned) using a gas-fired rooftop make-up air unit.

A building automation system with DDC unit controllers would provide centralized HVAC system control, scheduling, and monitoring.



Alternative 5 System Schematic

Each heat pump would be capable of independent operation in either a heating or cooling mode. Energy savings can be achieved when some zones require heat while others require cooling. The zones in cooling mode would reject heat to the condenser loop while the zones in heating mode absorb heat from the condenser loop. Essentially, the condenser loop moves heat energy from areas that have an excess to areas that have a deficit.

Energy recovery ventilators temper outside air using an enthalpy wheel to transfer heat and moisture from a warm air stream to a cooler airstream. In the cooling season when the outside air is warmer and more humid than the indoor air, heat and moisture would transfer from the outdoor ventilation airstream to the cooler, drier building exhaust airstream, effectively precooling and dehumidifying the air before being supplied to the heat pumps. In the heating season when the outside air is cooler and less humid than the indoor air, heat and moisture would transfer from the building exhaust airstream to the cooler, drier outdoor ventilation airstream, preheating and humidifying the air before being supplied to the heat pumps.

The size of the borefield is determined by the cooling requirements of the facility which is approximately 120 to 140 tons. Using the typical 300' deep borehole capacity of 2 tons when spaced approximately 20' apart, 60 to 70 bore holes over approximately 22,500 ft^2 would be required (the area could be used for athletic fields or parking when construction is complete). A test borehole during design would be recommended to determine the available capacity of the borehole field, as conditions vary between sites.

Benefits:

- Good temperature control.
- Anticipated to have lowest operational cost with the use of the energy recovery units & ground coupled system.
- Ground-coupled system provides 'free' heat from the earth.
- Active dehumidification could be provided with equipment having refrigerant hot gas reheat capability.
- Maintenance would be less than alternative 1 – each zone would have a unit with a fan, compressor and filters to maintain but no chiller or boiler plant.
- No building space required for boiler plant.
- No outdoor equipment.
- Additional LEED credits may be available for this system.

Drawbacks:

- An airside economizer mode, utilizing outside air to cool the building, when appropriate, would not be provided.
- Equipment servicing would occur in occupied spaces and requires ceiling removal and a ladder if equipment closets not provided.
- Heat pump compressors located adjacent to occupied spaces generate audible noise.
- Anticipated to have highest first cost of the alternatives evaluated primarily due to the borehole field.
- The discharge air temperature from heat pumps operating in heating mode is typically lower than conventional systems and occupants may have comfort concerns.
- Existing ground conditions may not be suitable (sinkholes have occurred in the area).

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ALTERNATIVE COMPARISON TABLE

Alternative / Criteria	-1- Vertical unit ventilators with hydronic heat, chilled water cooling and packaged air-cooled chiller	-2- Packaged Variable Air Volume (VAV) Rooftop Units with and Hydronic Heat	-3- Water Source Heat Pumps w/ dedicated ventilation system	-4- Variable Refrigerant Heat Pumps w/ dedicated ventilation system	-5- Ground Coupled Water Source Heat Pumps w/ dedicated ventilation system
Construction Cost* ($/SF)	$22.50	$25.50	$21.50	$28.00	$31.00
Probable HVAC Cost* (57,000 SF)	$1,300,000 + $250,000 building modification $1,550,000	$1,450,000 + $350,000 building modification $1,800,000	$1,225,000 + $250,000 building modification $1,475,000	$1,600,000+ $50,000 building modification $1,650,000	$1,767,000
Life, Years	20	15	20	15	15
Air Distribution	Fair	Good	Good	Good	Good
Floor Space Requirement	Medium – Units occupy space in classrooms. Boiler room required.	Medium - Boiler room and chases required for ductwork	Medium - Boiler room and outside air duct chases required. Heat pump closets recommended.	Low – Outside air duct chases required. Heat pump closets recommended.	Low – Pump room required and outside air duct chases required. Heat pump closets recommended.
Temperature Control	Fair temperature control (due to air distribution).	Good temperature control	Good temperature control	Good temperature control	Good temperature control
Humidity Control	Fair - active dehumidification would be provided.	Good - active dehumidification would be provided.	Fair (reduced dehumidification load with dedicated ventilation system / no active dehumidification)	Fair (reduced dehumidification load with dedicated ventilation system / no active dehumidification)	Good - active dehumidification would be provided.
Architectural Aesthetics	Fair – Outdoor chiller and boiler flues may be visible.	Fair – Rooftop equipment and boiler flues may be visible.	Fair – Rooftop equipment and boiler flues may be visible.	Good - Rooftop ERVs may be visible	Good - Rooftop ERVs may be visible

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Alternative / Criteria	-1- Vertical unit ventilators with hydronic heat, chilled water cooling and packaged air-cooled chiller	-2- Packaged Variable Air Volume (VAV) Rooftop Units with and Hydronic Heat	-3- Water Source Heat Pumps w/ dedicated ventilation system	-4- Variable Refrigerant Heat Pumps w/ dedicated ventilation system	-5- Ground Coupled Water Source Heat Pumps w/ dedicated ventilation system
Maintenance Considerations	Ventilator filters, chiller plant, and boiler plant to maintain.	Fewer units to service but located on roof.	Heat pump filters and compressors, evaporative cooler and boiler plant to maintain.	Heat pump filters and compressors to maintain.	Heat pump filters and compressors to maintain.
Sound/Noise	Medium - units located in or near occupied spaces	Low – rooftop compressors located over occupied spaces	Medium - heat pumps located in occupied spaces	Medium - heat pumps located in or near occupied spaces	Medium - heat pumps located in or near occupied spaces
Major Equipment	• Unit ventilators • Packaged rooftop Units • Boilers, pumps, hot water piping • Packaged air cooled chiller, pumps, chilled water piping • Hydronic heaters • DDC controls	• Packaged rooftop units • Boilers, pumps, hot water piping • VAV boxes • Hydronic heaters • DDC controls	• Heat pumps • Condenser water piping, pumps • Energy recovery units • Boiler, pumps • Evaporative cooler • Electric heaters • DDC controls	• Heat pumps • Air cooled condensers • Energy recovery units • Electric heaters • DDC controls	• Heat pumps • Condenser water piping, pumps • Energy recovery units • Electric heaters • Electric duct heaters. • DDC controls • Borehole field

* Probable Costs should be used for comparative purposes only. These costs can be further refined as the design is developed.

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Life-Cycle Cost Analysis

A life-cycle cost analysis was performed on the selected HVAC systems to help assess which system would have the lowest overall cost over the life of the system. Life-cycle cost analyses are helpful in determining whether a high-performance HVAC system should be selected even though it may have a higher initial cost when compared to other systems, but may result in dramatically reduced operating and maintenance costs. The life-cycle cost analysis evaluated a 25 year time period for each system.

There are numerous costs associated with acquiring, operating, and maintaining a building HVAC system. The following costs were evaluated in the life cycle cost analysis:

- Initial Cost
- Energy Costs, both electric and natural gas
- Operation, Maintenance, and repair costs
- Replacement costs at either 15 or 20 years

Initial system costs were determined for each HVAC system based upon previous project experience and current market conditions. These costs can be found in the system comparison matrix above. Operational expenses for utilities were based on consumption, current rates, and price projections which were supplied by the 7 Group. Operation and maintenance costs for each system were determined by historical data developed by ASHRAE and Barton Associates. Replacement costs for each system were incorporated in the analysis based upon projected system life. The results of the life cycle cost analysis can be seen in the table below. The ground coupled water source heat pump system has the overall lowest operational costs and life cycle costs of the systems evaluated.

Life Cycle Cost Analysis				
HVAC System	**Estimated Probable Construction Cost**	**Annual Energy Cost**	**Annual Maintenance Cost**	**Life Cycle Cost**
Unit Ventilators	$1,550,000.00	$72,281.00	$11,400.00	$3,790,566.00
VAV w/ Hydronic Heat	$1,800,000.00	$56,712.00	$6,600.00	$3,805,440.00
VRV Heat Pump	$1,650,000.00	$40,972.00	$8,650.00	$3,620,169.00
Ground Coupled Heat Pump	$1,767,000.00	$34,622.00	$6,100.00	$3,245,496.00

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Simple Pay Back Analysis			
System Comparison	**Construction Cost Difference**	**Operational Cost Difference**	**Simple Pay Back (years)**
Unit Ventilators Vs VAV	$250,000.00	$20,369.00	12.3
Unit Ventilators Vs VRV	$100,000.00	$34,059.00	2.9
Unit Ventilators VS GCHP	$217,000.00	$42,959.00	5.1