Alternative Designs of Mechanical Systems

Final Report

Freetown Elementary School

Glen Burnie, MD

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Architectural Engineering – Mechanical Option

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Freetown Elementary School

Glen Burnie, MD

Owner: **Anne Arundel County Public Schools**

Project Team

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Mechanical & Plumbing Engineer: **James Posey Associates**

Structural Engineer: **Columbia Engineering**

Provided by Anne Arundel Public Schools

Provided by Aerial Photographers LLC

MECHANICAL

Mechanical Room is located in southwest corner of building with two boilers, 2 chilled/heating pumps, and domestic water heater. An air cooled chiller is located outside with a 1500 gallon grease inceptor. Two energy recovery units serves each classroom wing. The school is also equipped with ductless split system units, fan coil units with outdoor air and with conditioned outdoor air. An air source heat pump supplies the Extended Day Program addition to the building.

ELECTRICAL/LIGHTING

Adjacent to the main mechanical room is the electrical room, located in the southwest corner of the building. Freetown Elementary School has a connected load of 1396.1 kVA and a demand load of 1056.9 kVA. Located in the main electrical room is a switchboard with a main breaker of 2000 amps and a voltage of 277/480V 3 phase. Most of the lighting is 277 V with fluorescent, HID, and incandescent types of lights.

CONSTRUCTION

The existing Freetown Elementary School was demolished in order to build the new school and create new sports fields in place of the old school. The new school (83,000 ft^2 was managed through multiple prime contracts with design-bid-build and started construction March 2008, finishing May 2010. The building was divided into three different sections for easier flow of construction. The two wings each being a different section and the gym/cafeteria being another.

STRUCTURAL

The building has a lateral braced frame with cast-in-place concrete columns of varying size. The first floor slab on grade is 5 inches thick with welded wire fabric over 6 mil vapor barrier and 4 inch washed gravel. The second floor slab is 3 inches normal weight concrete with 28 gage galvanized form deck. Steel joists span the classrooms and the corridors.

Matthew Buda — Mechanical Option

http://www.engr.psu.edu/ae/thesis/portfolios/2011/mrb5143/index.html

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1.0 Executive Summary

Freetown Elementary School is an 83,000 square foot building located in Glen Burnie, MD. The existing mechanical system is made up of a chiller/boiler two pipe system. With strong recent pushes towards being as energy efficient as possible, this system will be compared to alternative systems that could replace more efficient equipment or help reduce energy use to cut down on emissions that are effecting the world.

After assessing the existing mechanical system, an opportunity for energy savings exists. The existing chiller EER is rated at 9.4. Alternative system will be analyzed to compare to this efficiency. An opportunity also exists to save on emissions. Freetown Elementary School uses a great amount of electricity which is a carbon intensive energy source.

Applying alternative systems such as a ground source heat pump for the entire building load and solar panels for hot water and space heating, a decrease in energy use and a decrease in emissions will make the system more beneficial.

The ground source heat pump allows for elimination for one of the boilers and using the other existing boiler as emergency backup. The chiller is eliminated because of the ground loop rejects all of the load from the building. The use of a ground source heat pump instead of a chiller allows for an increase in efficiency and decrease in emissions.

The solar panel analysis first started for sizing the entire heating load to be accommodated by the heat gain from the panels. After discussion, the payback would be too long considering it only saved about 500 therms per year which results in only $430 savings a year in natural gas. The first cost of this system is extremely high because of the cost of a solar panel. Then it was determined that the solar panels should be sized to accommodate the domestic hot water load because hot water is used all year round as the space heating is only used in the winter months and would just be useless the rest of the time. The payback period became less but is still extensive compared to the first overall cost of the system.

A breadth topic for lighting was analyzed for daylighting controls. This analysis demonstrated the use of a dimming ballast to adjust to the amount of daylight in a space according to a sensor. The model resulted in energy savings of the lighting but required more energy to heat spaces because of the lowered internal loads. With a greater heating load because of the decrease in internal loads from the lighting, the cooling load decreased because of the decrease in internal loads.

A second breadth of sustainability was analyzed to create a rain water collection system to support the water usage of toilets and sinks in Freetown Elementary School.

2.0 Building Background Design Information

2.1 Building Façades

Freetown Elementary School's façade is mainly made up for 12" CMU's on the interior, 1 ½" rigid cavity insulation, and a running bond face brick on the exterior. On the exterior, there are brick features such as a projected brick medallion and a projected soldier course along the building, as well as stack bonds and rowlocks for different aesthetics for the building.

2.2 Roofing

An important part of the building enclosure is the roof, consisting of tapered polyisocyanurate insulation with ½" perlite cap ¼" per foot minimum for sloping of the roof. Structural steel roof joists are the support for the 1 ½" galvanized roof deck, insulation, and the built up bituminous roofing. The structural steel joists are designed with a net uplift of 12 psf unless the joist span is less than 18'-0", then the designed net uplift is 22 psf.

Above the gymnasium, the roofing is slightly different in the fact that the roof has acoustical roof deck with perforated flat bottom to absorb sound from transferring through. In order to create roof drains, the insulation is tapered. The structural steel joists are designed with a net uplift of 12 psf.

2.3 Architecture

Freetown Elementary school was designed into three different sections of the building with three main corridors throughout the building. Two of these sections are the east and west classroom wings. The eastern wing is primarily kindergarten level classrooms on the first floor. These two wings have a second floor with similar layout for classrooms. A division of these wings allows for a courtyard to allow natural light into every classroom. This division also allows for a computer room and media center. The third section is where the gymnasium, cafeteria, extended day care, and mechanical storage are located. In case of a need for a large gathering, the cafeteria was designed with a stage to transform into an auditorium. If extra seating is still required, the partition between the gymnasium and the cafeteria can slide into storage to open up the space.

Administrative personnel are located at the entrance of the school, functioning as a place to administer visitors and control flow in and out. Also located near the entrance are the nurse's office, the principal's office, and the assistant principal's office. For easy access for music performances, the music room and storage is located behind the stage in the cafeteria in close proximity. Also in relation to the cafeteria, there are restrooms located outside in the corridor.

Every classroom is equipped with its own restroom to prevent kids wandering the halls and allow for more supervision.

Freetown Elementary School's façade is mainly made up for 12" CMU's on the interior, 1 ½" rigid cavity insulation, and a running bond face brick on the exterior. On the exterior, there are brick features such as a projected brick medallion and a projected soldier course along the building, as well as stack bonds and rowlocks for different aesthetics for the building.

2.4 Construction Management

Before constructing the new Freetown Elementary School, the existing school had to be demolished. The new building for the school was built on the existing fields. Freetown Elementary School was broken up into three different sections for construction purposes. Section A is the gymnasium, kitchen, and music rooms. Section B is the media center, the administration offices, and the east classroom wing. Section C is the west classroom wing with the art room on the first floor. Noting from the geotechnical report, mechanical compaction of the existing soil below the building was critical to performance of the building foundations. This compaction was used ten feet beyond the building pad horizontally. The building is constructed under the classification of 2B unprotected, noncombustible.

2.5 Lighting/Electrical

Freetown Elementary School's electrical system is organized by a switchboard located adjacent to the mechanical room in the south west corner of the building. Here a main breaker of 2000amps controls the switchboard and the panel is mostly 277/480 volt - 3 phase/4 wire. 120/208V - 3 phase is also available. The building has a connected load of 1396.1 kVA and a demand load of 1056.9 kVA. A transformer is located just outside of this room on the exterior. Lighting throughout the building is mostly fluorescent and incandescent along with HID lights for the gymnasium and cafeteria.

2.6 Structural

The building has a lateral braced frame with cast- in-place concrete columns of varying size. The first floor slab on grade is 5 inches thick with welded wire fabric over 6 mil vapor barrier and 4 inch washed gravel. The slab is thickened to 6 inches at the mechanical room to hold the load of the mechanical equipment. The second floor slab is 3 inches normal weight concrete with 28 gage galvanized form deck. Steel joists span the classrooms and the corridors.

2.7 Mechanical

The main mechanical room is located in the southwest corner of the building along the perimeter. Two natural gas boilers and an air cooled chiller outside control the loads in the building. Freetown Elementary School is based off a 2 pipe system and has controls set up for changeover from heating to cooling and vice versa. Six rooftop air handling units serve the music rooms, gymnasium, cafeteria, administration offices and the media center. Two energy recovery units serve each of the classroom wings. In addition to the air handling units are six ductless split system units serving smaller rooms such as electrical closets. An air source heat pump is responsible for the extended day program located in the north end of the building near the entrance.

2.8 Sustainability

Two Energy Recovery Units serve the east and west classroom wings. These units allow for energy savings through reusing the warm temperature exhaust air to heat up the incoming cold air. The mechanical system is saving energy on the heating coil loads by using of this waste heat from the building.

An energy management system was also in mind when designing. Boiler rotation is monthly and is adjusted by the owner. Independent schedules of operation for each zone listed in the auto-occupied-unoccupied sequence are for energy management. A master schedule for control of all zones (except RAHU-5) in the event of a snow day is also accounted for.

2.9 Fire Protection

In the gymnasium and cafeteria, a visible and voice signal announces the smoke detection. Throughout the rest of the building, visible and audio signals with three pulses alarm the occupants of the dangers of a fire. Freetown Elementary School is broken up into three zones in controlling the sprinkler system. In case of fire, an automatic wet pipe system is maintained with water supply of 1860gpm by a six inch underground pipe. Sprinklers are set on quick response and are semi-recessed. Dry pendent sprinklers are located in the walk-in freezer and cooler. Two high temperature sprinklers are under the kitchen exhaust hood.

2.10 Transportation

Freetown Elementary School has three stairwells and one elevator with three main corridors. The elevator is located near the cafeteria entrance right off of the main corridor. Two corridors are located on each of the wings allowing students and teachers to reach all of the stairwells and control the flow of the building.

3.0 Design Factors

3.1 Site

Freetown Elementary School location is on the same site of the old school. As you can see from the aerial photos below provided by Aerial Photographers, LLC, The old school was located where the new athletic fields are today. This was done because construction of the new school was being done the same time as the old school was still in session.

Figure 1 – Site of Old School

Figure 2 – Site of New School

3.2 Cost

Freetown Elementary School is funded by the tax dollars or donations of Anne Arundel County. This public school was controlled by the Maryland State Department of Education. The overall project cost was approximately $17 million.

4.0 Existing Mechanical System

4.1 Outdoor and Indoor Design Conditions

Determined in the previous technical report, the design conditions for Freetown Elementary School were assumed to be the same as Baltimore, MD. In Table-1 below, the outdoor values were obtained from the 2005 ASHRAE Handbook of Fundamentals. The indoor values were obtained from the mechanical design documents. All of these values were used in calculating the model computed in Trace in Technical Report #2.

Design Temperatures	
ASHRAE 0.4% Cooling Dry Bulb	93.6 ^oF
ASHRAE 0.4% Cooling Wet Bulb	75.0 ^oF
ASHRAE 99.6% Heating Dry Bulb	12.3 ^oF
Indoor Cooling Dry Bulb	78.0 ^oF
Indoor Heating Dry Bulb	70.0 ^oF

Table 1 – Design Outdoor and Indoor Air Conditions

4.2 Design Ventilation Requirements

By using ASHRAE Standard 62.1, the design ventilation requirements were compared to calculated ventilation rates by the standard. A detailed discussion of the calculations can be found in Technical Report #1. Table-2 shows the results of the analysis, compares the designed to the calculated rates, and whether it complies or not with the minimum ASHRAE standard.

The only air handler that does not meet the required minimum outdoor air rate is AHU-3. In analyzing AHU-3 (serving the cafeteria), the assumption was made that there were around 300 students in the cafeteria at once in three different lunch periods. With this assumption, the calculated outdoor compared to the designed minimum outdoor air was higher, resulting in a non-compliance with the standard. This discrepancy is not an issue as it is very close to the minimum and 300 students is the maximum number that would be at lunch during one period.

System	Calculated Outdoor Air (CFM)	Design Supply Air (CFM)	Design Minimum Outdoor Air (CFM)	ASHRAE 62.1 Compliance
AHU-1	430	1530	600	Yes
AHU-2	232	1530	375	Yes
AHU-3	**2072**	**6000**	**2000**	**No**
AHU-4A	535	7500	2500	Yes
AHU-5	278	3200	700	Yes
AHU-6	824	4680	1080	Yes
ERU-1	4665	8100	8100	Yes
ERU-2	5625	9800	9800	Yes

Table 2 - Calculated vs. Designed Ventilation Rates

4.3 Summary of Major Equipment

Freetown Elementary School was designed with a two pipe changeover system and listed in Table – 3 is the major equipment with its values. Two natural gas fired boilers were placed in the mechanical room for monthly rotation. An air cooled chiller is located outside of the building in the southwest corner near the mechanical room. The domestic water heater is located in the mechanical room and acts as a storage tank.

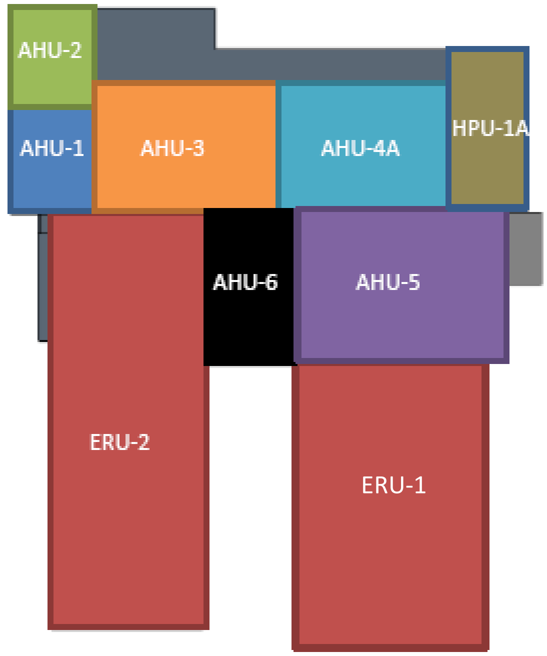

Figure 3 - Zone Diagram for AHU's

RAHU-1, RAHU-2, RAHU-3, and RAHU-4A are constant volume serving spaces such as the music rooms and the cafeteria/gymnasium. RAHU-5 serves the administration section of the school and is a variable volume unit with reheat capabilities. RAHU-6 serves the Media Center and is a constant volume unit with a return air fan.

Two energy recovery units serve the classroom wings. ERU-2 serves the west wing and ERU-1 serves the east wing. These units have DX cooling and contain an air cooled condensing unit.

Summary of Major Equipment				
Equipment	Input MBH	Output MBH	Capacity	HP
Boiler 1	3836	3040	~	90.8
Boiler 2	3836	3040	~	90.8
Air Cooled Chiller	2040	~	400 GPM	~
Domestic Water Heater	399	~	125 Gallon	~

Table 3 - Major Equipment

4.4 Other Equipment Schedules

The air source heat pump is located in the Extended Day Program area. Ductless split systems serve areas such as janitor's office, gym office, telecom, food storage, food prep office and elevator machine room. Two variable frequency drive pumps serve the chilled/heating cycle for pumps P-1 and P-2.

For further information on other equipment refer to Appendix A.

4.5 Mechanical System First Cost

The mechanical system first cost was approximately $4.1 million. This is 24% of the total cost of the building.

4.6 Schematic of Chilled/Heating Water System

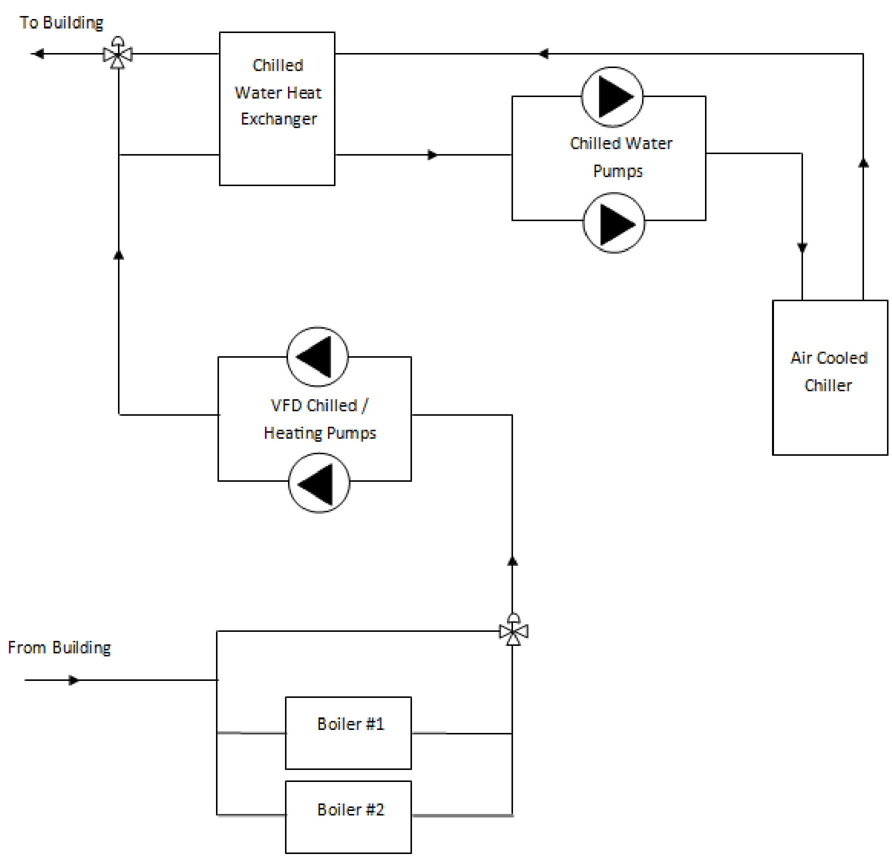

Figure 4 – Chilled/Heating Water System

4.7 System Operation Description

RAHU-1, RAHU-2, RAHU-3, RAHU-4A, RAHUA-6

These air handling units are controlled by the following cycles: Occupied Cycle, Unoccupied Cycle (heating mode), Unoccupied Cycle (cooling mode), Maintenance Cycle, and Safety and Emergency Controls.

Occupied Cycle:

In the occupied cycle, the supply air fan motor is energized and runs continuously.

Heating Mode:

When the system is in heating mode, the following occurrences can happen. If the space temperature is more than 2 degrees F below the heating set point of the room sensor, the face and bypass dampers are positioned to provide full flow across the coil. The outdoor air and pressure release damper remain closed with the return air damper remaining open.

If a rise in space temperature is within 2 degrees F of the heating set point of the room sensor, the face and bypass dampers modulate towards bypassing the coil with the outdoor air and pressure release dampers opening to a minimum position. Return air damper closes proportionally in unison.

The outdoor air damper and pressure release damper modulates toward the open position and the return air damper closes proportionally to maintain the room sensor set point. This occurs if there is a further rise in space temperature after the face and bypass dampers are completely bypassed and a 6 degree F dead band increase is reached.

A low limit sensor overrides the room sensor to prevent discharge air from falling below 55 degrees F. This low limit is locked out when system is in cooling mode.

Cooling Mode:

The air handling unit shall continue in heating mode until the chilled/heating system water temperatures falls below 85 degrees F.

The outdoor air and pressure release dampers close to their minimum position. The return air damper opens proportionally. The face and bypass dampers modulate between full airflow across the coil to full bypass around the coil. This maintains the room sensor set point.

Unoccupied Cycle:

Heating Mode:

The supply air fan motor, face and bypass dampers are placed under control of the night set point of the sensor. Under this set point, the fans will cycle and open the coil face dampers to maintain the set point. The outdoor air and pressure release dampers remain close and the return air damper remain open.

Cooling Mode:

De-energized supply fan motor and closing of the outdoor air and pressure release dampers happen during the unoccupied, cooling mode. However, the return air damper remains open.

RAHU-5

This air handling unit is controlled by the following cycles: Occupied cycle (heating and cooling modes), Zone Reheat Coils, Control of Changeover Between Heating and Cooling Mode, Unoccupied Cycle, Maintenance Cycle and Safety and Emergency Controls.

When the building system is in heating mode, the two position isolation control valves are open. This valve is then close for cooling mode.

Occupied Cycle:

Energizing of the supply fan motor is the beginning stage of this operation. The motor should run continuously and the outdoor air damper is open. A central controller directed through the DDC monitors the supply air temperature and velocity. This controller also modulates the bypass damper to maintain constant supply air flow through the air handling unit.

In order to maintain zone thermostat set points, zone dampers modulate between maximum and minimum flow. The central controller monitors all zone thermostats and dampers. At this point, the system selects heating or cooling operation.

Heating Mode:

Heating is called for from the central controller. It causes a 3-way control valve to modulate to provide heat. A low limit thermostat overrides the central controller and the 3-way control valve to prevent discharge air from falling below a set point set at 55 degrees F.

Cooling Mode:

Cooling is called for from the central controller and closes the 3-way control valve to the heating coil. The cooling system energizes the stages of DX cooling as needed.

Zone Reheat Coils:

If the space temperature sensor is calling for heating and the central controller is calling for cooling, the zone duct mounted temperature sensor modulates 2-way heating control valve to adjust to 90 degrees F.

Changeover between Heating and Cooling Modes:

Monitoring of all space temperatures is done by the central controller. The maximum number of calls for space heating or cooling determines cooling or heating. Changeover occurs when the maximum number of heating requirements outnumbers the cooling requirements by at least two zones. This is also true for cooling requirements outnumbering the heating requirements. If any zone temperature falls more than two degrees below its set point the system goes into heating mode.

Unoccupied Cycle:

The supply air fan motor and 3-way control valve is placed under control of the night thermostat. The outdoor air damper is closed and the cooling system is de-energized. A key operated manual override is located in the principal's office. This places the system in occupied mode for 0-3 hours. The circulating pump for the heating coil is energized when the outdoor air temperature is below 45 degrees F and de-energized when above 50 degrees F. Pump is also energized when the 3-way valve is open to the coil and this overrides any outdoor air temperature.

ERU-1, ERU-2

These air handling units are controlled by the following cycles: Occupied Cycle, Unoccupied Cycle, and Safety and Emergency Controls.

Occupied Cycle:

This unit is energized by the occupied cycle in the direct digital control clock.

Unoccupied Cycle:

The exhaust fan is energized when activated by the ATC system. When it is not energized it operates under the packaged controls.

4.8 Design Heating and Cooling Loads

Technical Report #2 displays a detailed discussion of the assumptions that went into making the energy model for Freetown Elementary School.

Modeled vs. Designed				
	Cooling (tons)		Heating (MBH)	
	Modeled	Designed	Modeled	Designed
AHU-1	5.6	6.5	55	78
AHU-2	4.6	5.2	43	61
AHU-3	30.6	23	214	280
AHU-4A	16.9	29	151	355
AHU-5	8.1	10.3	7	120
AHU-6	14.7	14.6	69	183
ERU-1	77.7	33.1	252	613
ERU-2	83.7	42.2	235	741
HPU-1	7.3	9.6	72	119

Table 4 - Modeled vs. Designed Loads

AHU-1 and AHU-2 were modeled reasonably close to the design conditions. These two air handlers only serve one or two rooms with furniture in it so it was accurate in terms of occupants.

AHU-3 and AHU-4A were difficult to model because of the spaces they serve. These air handlers serve the cafeteria and the gymnasium. In the design documents the occupants per room were not discussed therefore an estimation was made. Originally, the ASHRAE recommended number was used for square foot per person. This called for an approximate 500 people in the cafeteria at once. This number had to be adjusted since there are approximately 768 students in the school (32 classrooms of 24 students each). Assuming three lunch periods, a value for the cafeteria was numbered at 256 students. The values are not near design conditions because the schedule is also assumed constant for all rooms. This causes the air handler to work harder when no one is occupying the cafeteria when lunch is not in session or when the gymnasium is not being used. Another issue arises when the partition located between the gymnasium and cafeteria is removed for assemblies or gatherings. This was not taken into effect when modeling these two air handlers.

AHU-5 was modeled as a variable volume reheat. In the design documents, there is also a bypass damper from the return air stream to bypass the air handling unit to serve the space. This was not available in the systems for the model in Trace. Therefore the heating energy is not a reasonable estimate.

AHU-6 was modeled as a constant volume – non-mixing computer room unit because it serves the media center. In the model, there is a reheat before the room but there is no reheat after it leaves the fan in the design documents so this number is not comparable.

ERU-1 and ERU-2 were difficult to model. They were modeled as a constant volume with mixing, terminal air blender. This does not take into consideration that they are energy recovery units and the model schematic also differs from the design schematic. The model schematic has a reheat and an extra fan before the supply air and room air enter the room. The design documents do not show these two features. The design documents simply have the room air mixing with the supply air before entering the room again. In conclusion, the results calculated were not comparable to the design conditions.

4.9 Lost Usable Space

Freetown Elementary School has a mechanical room that takes up 1200 square feet on the first floor located in the southwest corner of the building. This is 1.4% of the total 83,000 square feet of the building. The air handling units are positioned on the roof top so those did not take up any of the buildings square footage.

5.0 Energy

5.1 Site Energy Sources

The mechanical system in Freetown Elementary School uses electricity for the primary energy source for cooling systems and natural gas for the heating systems. Actual utility bills are not available so it won't be compared to the actual energy use. Baltimore Gas and Electric Company were used for determining rates for both gas and electric. It is assumed that Freetown Elementary School is using this because it is so close to Baltimore, MD. Since the demand load for the building is 1,056.9kW, the 2,000kWh or more in any month option was used for the following rates. This is listed under commercial, industrial, and lighting rates. For gas distribution, the general category was assumed.

Electricity Customer Charge: $17.50 per month
Energy Charge: $0.10 per kilowatt hour per month

Gas Customer Charge: $35.00 per month
Distribution Charge: $0.86 cents per therm

5.2 Annual Energy Use

Energy Consumption: Freetown Elementary School consumes 2,112,000 kWh of electricity and 119,000 kBtu of gas annually based on the model. Below is a breakdown of energy consumption for each category. The main energy consumption is by the air cooled chiller and the boiler (when converted to kWh, it is comparable to the air cooled chiller). Lighting is also a large portion of the energy consumption at peak load.

6.0 Overall System Evaluation

After assessing the existing mechanical system, an opportunity for energy savings exists. The existing chiller EER is rated at 9.4. Alternative system will be analyzed to compare to this efficiency. An opportunity also exists to save on emissions. Freetown Elementary School uses a great amount of electricity which is a carbon intensive energy source.

7.0 Depth - Proposed Mechanical System Redesign

7.1 Redesign Goals

The goals for the redesign of Freetown Elementary School are to reduce energy consumption, reduce emissions, and maintain a comfortable environment for the faculty, staff, and students.

7.2 Preliminary Ideas

To achieve the goals of reducing energy consumption and reduce emissions it is necessary to look at different means of mechanical heating, ventilating, and air conditioning than what is existing in the building. A ground source heat pump will reduce both energy consumption and emissions based on research into the system and case studies done on similar elementary schools in the area.

Another system that is going to be analyzed is the use of a solar photovoltaic system to reduce the energy bill by using the sun's energy instead of the use of electricity from power plants. Solar thermal can also be used to use the sun's energy to heat domestic hot water and hot water coils for space heating.

The final system looked at for an addition to the mechanical system is the use of CO2 occupancy sensors that also are in control of the lighting. These sensors will have better control over the ventilation and make the outdoor air be more related directly to the amount of occupants within certain spaces. These sensors will also be implemented into the lighting, where the lights will alter in relationship with the amount of natural daylight that enters the space through windows.

7.3 Selected Systems

Ground Source Heat Pump

Solar Panels

Indoor Environment Quality Sensors

8.0 Ground Source Heat Pump

A ground source heat pump (GSHP) works by using the constant ground temperature of the earth to either dissipate heat or to collect heat in conjunction with other mechanical equipment.

For cooling, the ground source heat pump works like this: water is pumped through underground piping either distributed vertically or horizontally to collect latent heat from the Earth's constant ground temperature of approximately 55 degrees Fahrenheit, then the water goes through a heat exchanger to pass the heat on to a refrigerant, the refrigerant carries this heat through an expansion valve where it turns to a cold liquid, this liquid then travels to an evaporator where air is cooled, from this stage, the cold liquid turns to cold vapor and travels to a compressor, the compressor turns the cold vapor into hot vapor where the hot vapor goes to another heat exchanger where this energy heats the domestic hot water, the hot vapor continues on to exchange heat with the ground source heat loop and changes the hot vapor to hot liquid starting the cycle from the beginning.

Source: Geo4VA

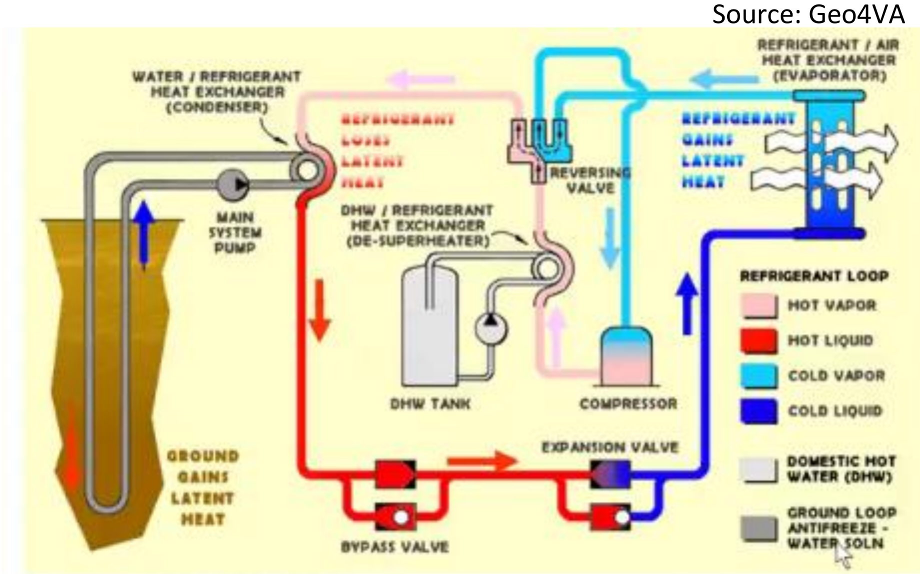

Figure 5 – Ground Source Heat Pump Schematic - Cooling

For heating, the system described above is the same but the opposite. The ground source heat pump works like this: The water is pumped through underground piping either distributed vertically or horizontally to lose latent heat from the Earth's rather constant ground temperature of approximately 55 degrees Fahrenheit. The water then goes through a heat exchanger to get cold vapor as a refrigerant which then goes through the compressor to get hot vapor, this hot vapor passes by the heat exchanger for the domestic hot water and continues on to a heat exchanger for heating of air. The refrigerant loses the latent heat and turns into a hot liquid which travels to an expansion valve to turn into cold liquid and returns to the heat exchanger of the ground loop where it starts the cycle from the beginning.

Piping for the ground source heat pump can have two different layouts. Depending on how much area one has to work with depends on whether a vertical or horizontal layout works best.

Source: Geo4VA

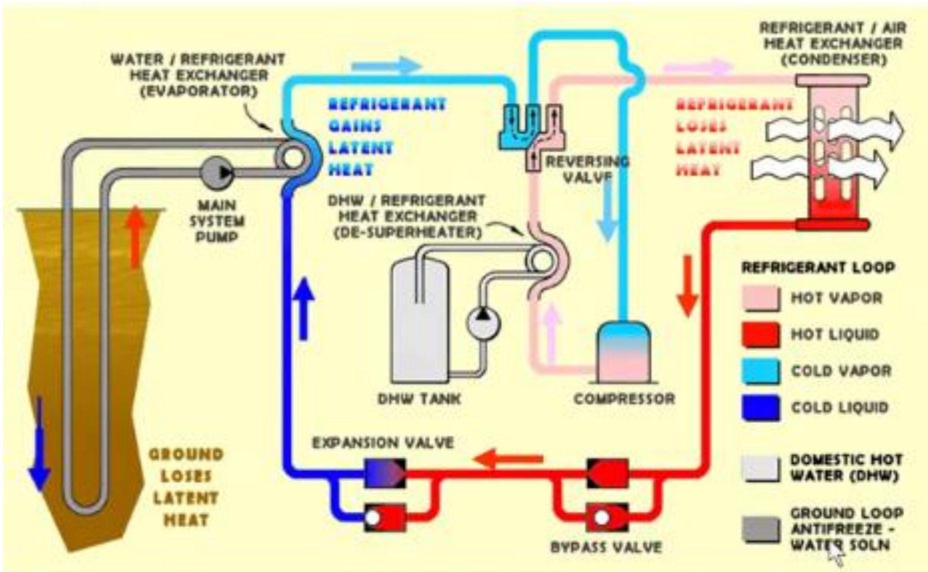

Figure 6 – Ground Source Heat Pump Schematic - Heating

Installing a ground source heat pump in a mechanical system can have its advantages and disadvantages. The following are advantages for a ground source heat pump: no cooling towers or boilers needed therefore system equipment cost is lower, mechanical rooms do not need to be as large, energy consumption is much less than an ordinary system, the earth is used as a thermal reservoir and therefore decreases emissions.

8.1 Vertical Loop

Advantages of a vertical loop are that there is a small cost of grass that needs replanted because of the smaller area and the ground temperature is more constant are greater depths. A disadvantage of a vertical loop is that deeper bore holes are more expensive for drilling.

8.2 Horizontal Loop

The advantage to a horizontal layout for piping for a ground source heat pump is that the drilling for bore holes is less expensive because the depth is much less than that of a vertical loop. Disadvantages of a horizontal loop are ground water temperatures are not as constant of a temperature, a large area to replant grass is more expensive, and the need of more pumping energy.

8.3 Selection - Vertical Closed Loop System

A vertical ground water/glycol loop will be analyzed for Freetown Elementary School because of the constant ground temperature at greater depths meaning the loop will be more reliable and because of the smaller area needed to replant grass considering the need to use the athletic fields for recess during the school year and summer months. A closed loop will be used instead of an open loop.

8.4 Ground Water Temperature

The ASHRAE Handbook of Fundamentals references a figure that gives average ground water temperatures for the United States. Freetown Elementary School is located between the red and blue lines highlighted on the figure. The red line is 54 degrees F and the blue line is 56 degree F. Since the location of the school is between the two, an estimated value of 55 degrees F for the ground water temperature will be used in the analysis of the ground source heat pump.

Source: ASHRAE

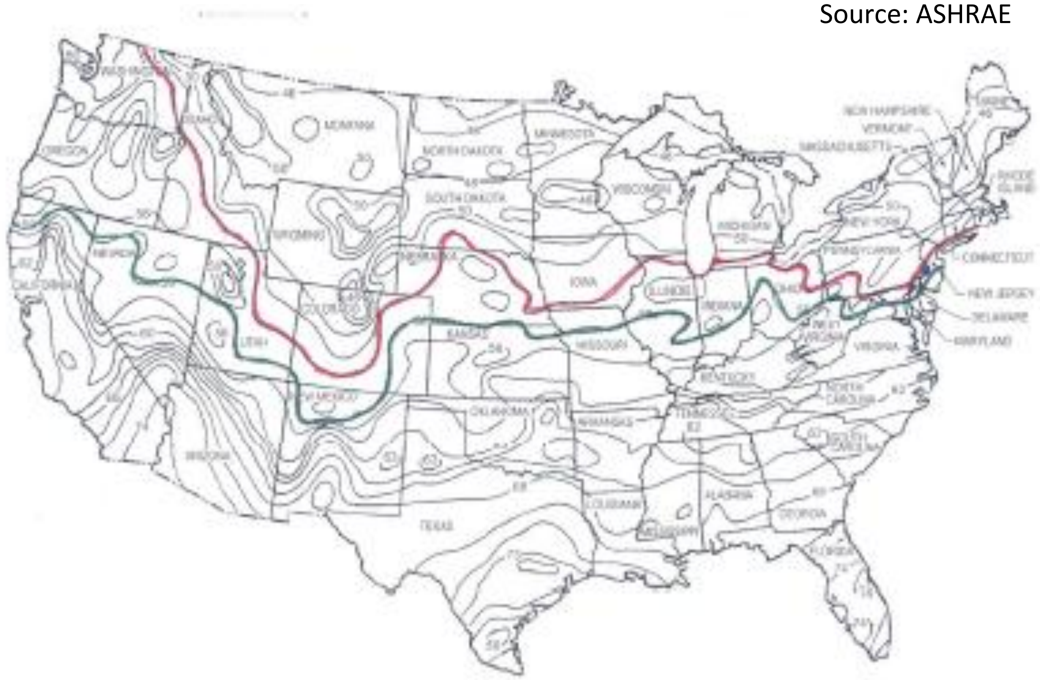

Figure 7 – Ground Water Temperature

8.5 Model – TRACE

In order to convert my original model of Freetown Elementary School from a boiler/chiller system to a ground source heat pump with a boiler back up, a number of components were changed. All the air handling units were changed to water-to-water heat pumps. The pumps were resized using the pump affinity laws. The geothermal loop was modeled with vertical bores with a variable volume loop pump.

Source: TRACE

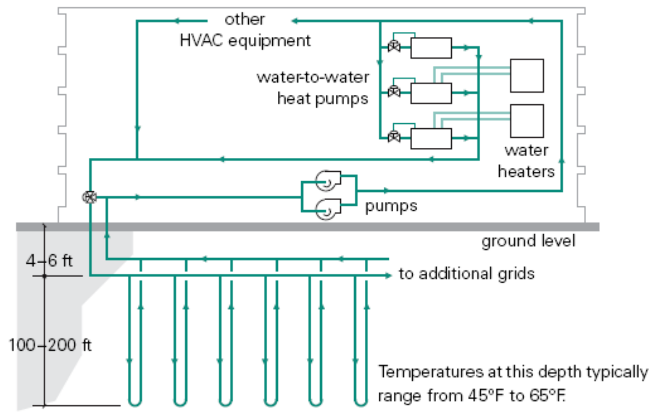

Figure 8 – Ground Source Heat Pump Flow Schematic

8.6 Calculations

The ground loop is sized to handle the peak load either of heating or cooling, whichever is greatest. In this case, the cooling load is greater. The pump was sized according to the cooling load which is 231 tons.

$$Q=500GPM(T_{out}-T_{in})$$

The GPM was determined by the equation above, using Q as the peak cooling load, Tout as the temperature leaving the ground source heat pump system and Tin as the temperature entering the ground source heat pump system. This resulted in a gpm of 342.

$$(Q1/Q2)=(N1/N2)^2$$

$$(H1/H2)/(N1/N2)^2$$

Combining these two equations:

$$(Q1/Q2)^2 = (H1/H2)$$

Using the GPM calculated above and the pump affinity laws, a head loss in ft of water was calculated to input into TRACE for the ground source heat pumps.

8.7 Annual Energy Use

The original model as-designed uses 2,529,487 kWh of electricity and 919 therms of natural gas. This results in a total of 114,845 BTU/ft2 per year. The GSHP model uses 2,231,888 kWh of electricity and eliminates natural gas usage. This results in a total of 100,265 BTU/ft2 per year. This reduction is 13% energy savings.

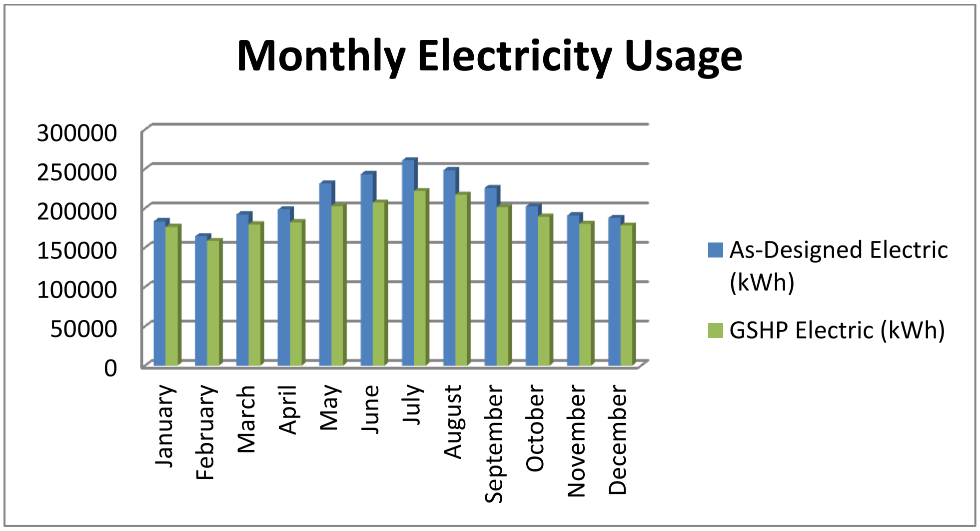

Chart 1 – Monthly Electricity Usage by Ground Source Heat pump

The chart above shows a comparison between the as-designed model and the ground source heat pump model. As one can see, the GSHP model benefits more in the cooling months rather than in the heating months atleast for electric consumption. Overall, the electric consumption is less than that of the as-designed for each month.

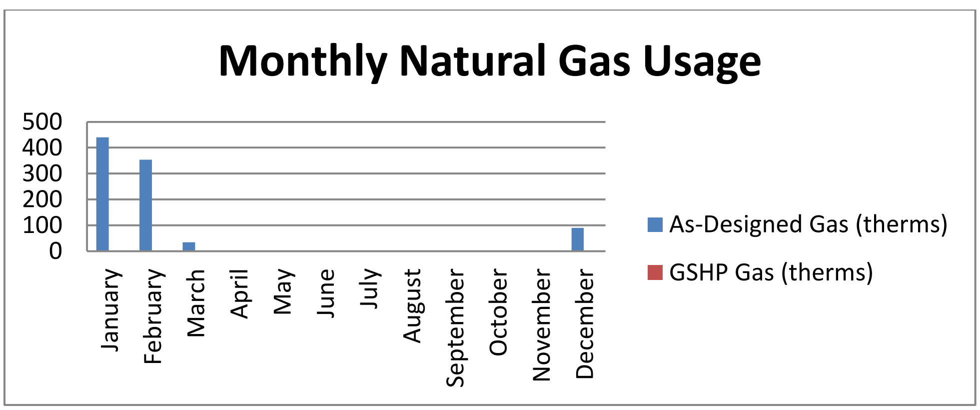

Chart 2 – Monthly Natural Gas Usage by Ground Source Heat Pump

The chart above illustrates the effect of the ground source heat pump has on the existing boiler duties. The existing boiler only operates during the winter months, but with the implementation of a ground source heat pump the existing boiler is no longer needed.

8.8 Cost Savings of GSHP

The original model had a cost of $254,369 per year for utilities, including gas and electric costs. A savings of $30,550 per year was made with the addition of the ground source heat pump. The ground source heat pump utility bill for the year is $223,819.

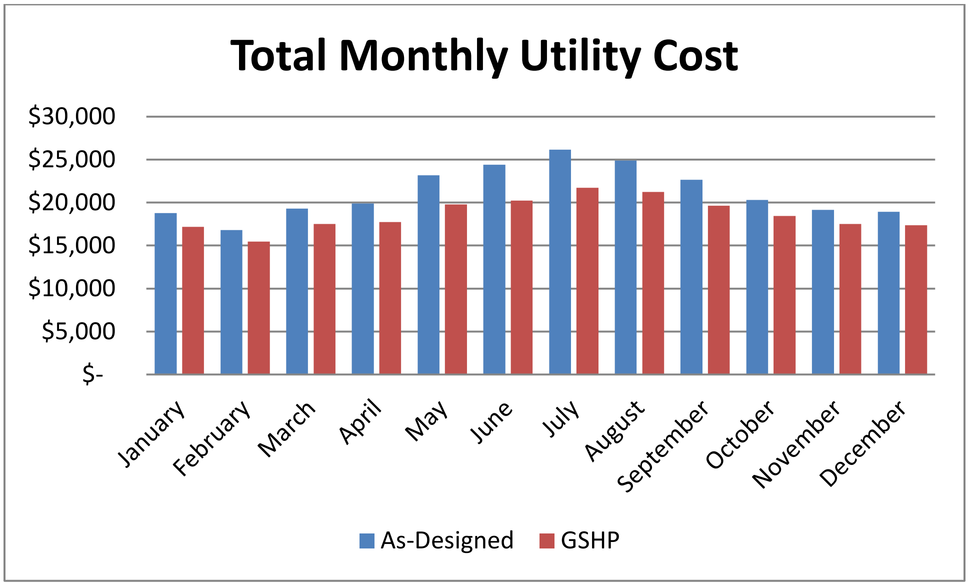

Chart 3 – Total Monthly Utility Cost for Ground Source Heat Pump

8.9 First Cost

A similar project had a cost of $3,500 per 300ft of bore or 2 tons of cooling. Assuming this value includes the pipe, the installation, the grout, the drilling and other miscellaneous items needed, this results in a cost of $406,000 for the bore field. The existing 3040MBH boiler has a cost of $40,600 and the 170 ton chiller has a cost of $72,280. These two values are added to the existing air handler costs totaling $412,080. The first cost of the ground source heat pumps totals to $601,333, with a net first cost of $189,253.

Component	tons	Existing	Water Source Heat Pumps
ERU-1	51	$ 60,000	$ 52,000
ERU-2	62	$ 70,000	$ 62,858
RAHU-1	7	$ 11,000	$ 9,200
RAHU-2	5	$ 11,000	$ 4,400
RAHU-3	23	$ 32,000	$ 3,075
RAHU-4A	30	$ 45,000	$ 32,800
RAHU-5	10	$ 22,000	$ 11,700
RAHU-6	15	$ 48,200	$ 19,300
	Total	$ 299,200	$ 195,333

Table 5 – First Cost of Water source Heat Pumps

8.10 Payback

The net first cost divided by the savings per year results in a 6.2 year simple payback period.

Existing Equipment	First Cost of GSHP	Net First Cost	Savings/yr
$ 412,080	$ 601,333	$ 189,253	$ 30,550
Payback	6.2		

Table 6 - Payback Calculation

8.11 Emissions

One of the reasons why a ground source heat pump was analyzed was because of the reduction in emissions because of the lower energy usage. The chart below shows a decrease in emission by 13%. A decrease in emissions is very important in controlling the influence the building has on the environment.

Environmental Impact Analysis			
	CO2 (lbm/year)	SO2 (gm/year)	NOX (gm/year)
As-designed	3,305,591	28,210	6,327
GSHP	2,885,957	24,629	5,524
Savings	13%		

Table 7 - Emissions Savings

8.12 Installation

The ground source heat pump system uses high-density-polyethylene piping (HDPE). Grout encases the piping to allow for an increased heat transfer from the piping to the ground. Piping headers should be a minimum 5 ft below grade and spacing between the supply header and return header should be a minimum of 1 ft. The figure shown below illustrates how the pipe is placed in the borehole with the grout filling.

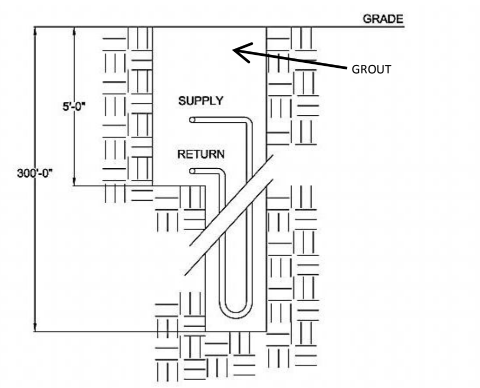

Figure 9 – Detail of Vertical Bore

8.13 Location

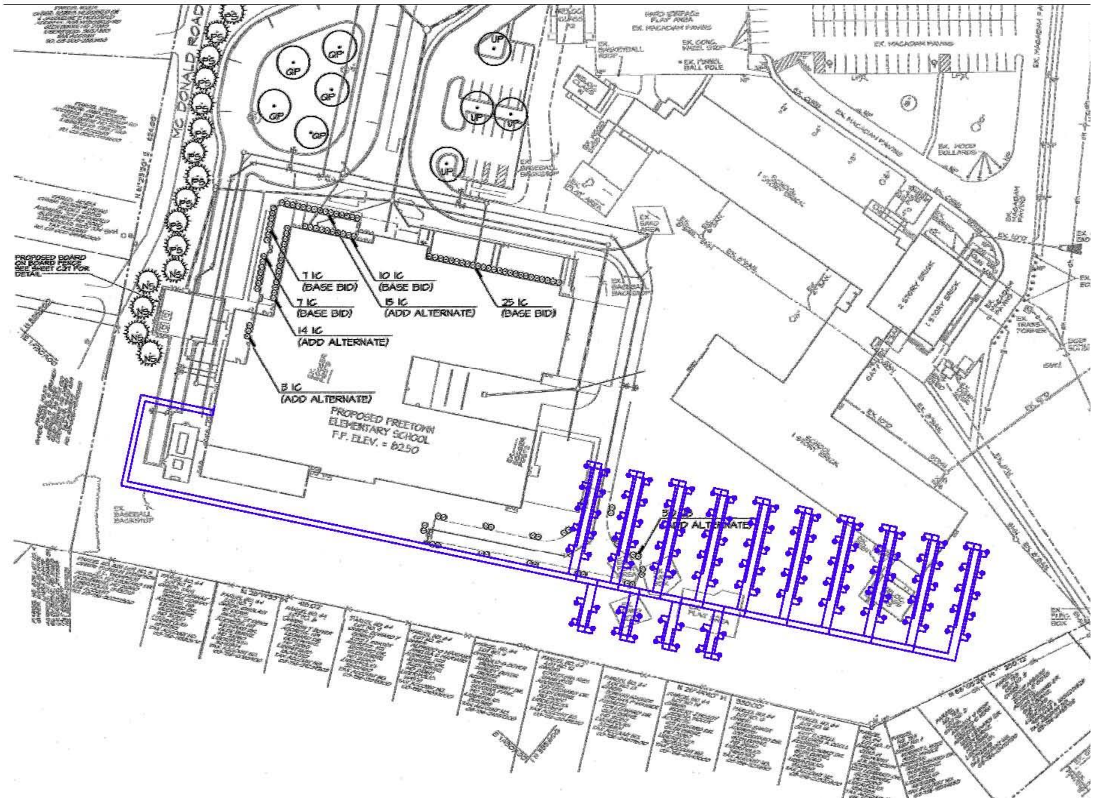

Figure 10 – Layout of Bore field

It is recommended to have a spacing of 20ft between bores to allow for heat rejection and heat extraction of earth around each bore. An estimation of 2 ton per 300ft requires 116 bores at 300ft to take care of 231 tons of cooling, which is the peak load. The peak heating load is smaller than this, which is why the cooling load is used to determine the sizing of the system. The 116 bores will be distributed over 10 branches with 10 bores per branch and 4 branches of 4 bores each.

It is noticed that there is a long pipe run for the supply and return to the bore field from the mechanical room. This is because the bore field could not be placed in any other spot on site because of residential housing just beyond the school limits. There will be some heat loss due to this long length of piping as well as increased pressure head.

9.0 Solar Panels

With the addition of solar panels on the roof of Freetown Elementary School, the building will save energy when it calls for heat. Solar panels allow for a replacement of the boiler or allow for storage for heat, either for space heating or domestic hot water.

9.1 Process

Water is circulated through a piping system. A pump pushes the water up to the solar panels on the roof, once the water gets to the solar panel, the water heats up when it travels through the panel to the top of the panel by conduction.

The solar collector is made up of an absorber plate with a high solar absorptance. A cover has a high solar transmittance to allow solar energy but reduce heat loss through the cover. An insulated housing is on the back of the collector to reduce heat loss through the back.

After the water gains heat through the collector, the water then travels to the storage tank where it exchanges the heat it gained from the solar collector to the storage tank. It then leaves the storage tank and starts the loop over. The heat gained in the storage tank allows for a heat exchanger to take the heat gain to the spaces or domestic hot water in the building.

Source: TRNSED

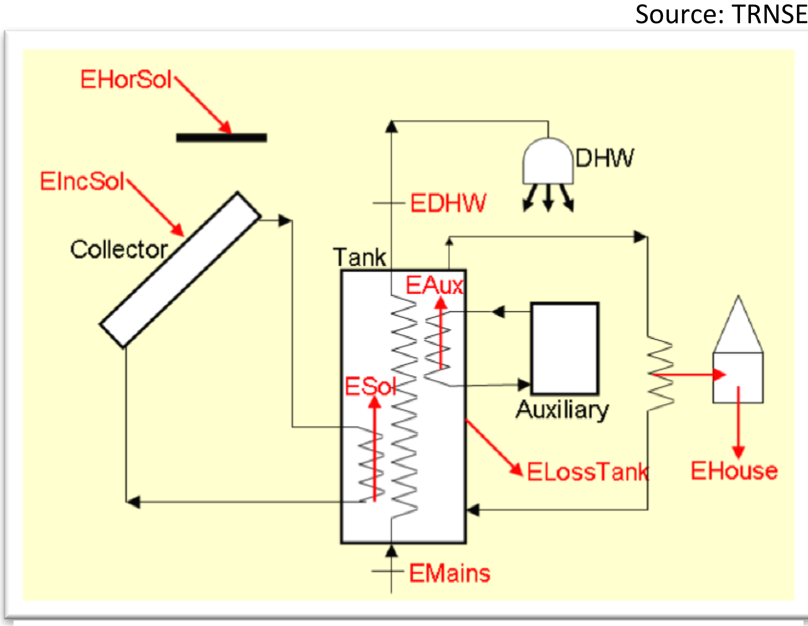

Figure 11 – Solar Panel Schematic

9.2 Selection

There are multiple selections that could be made here: stationary panels, tracking panels, slope of panel, size of panel, azimuth of panel, flat plate collector, concentrating collector, etc. A tracking parabolic collector in a flat plate box with different panel slopes will be analyzed. Since a tracking panel will be analyzed, the azimuth of the panel will be set to zero, which is south. The motor on the panel will track the sun and change the azimuth as the sun changes. This panel will provide heating for hot water between 140 degree F and 250 degree F.

9.3 Panel Care and Maintenance

The SunTrac system has built in protection for power outages, it stops tracking, and therefore no heat is added to the system.

If anything fails, it will most likely be the motor assembly at the bottom of the panel. The motor operates only two minutes per day during the sun tracking. To replace a motor in the field, it is easily switched with a working motor in about five minutes. All electronics are rated at 220 degrees F but only reach 140 degrees F during testing with tube temperatures of 460 degrees F.

The cover on the solar panel uses 5mm tempered low-iron glass to enclose the panels, which keeps the dust and dirt away from the moving parts. The panels are proven to withstand one inch hail stones. The panel box is made up of aluminum and is specified to last beyond 30 years and includes copper tubing throughout the panel. The copper, glass, and aluminum are all 100% recyclable.

Source: SunTracSolar

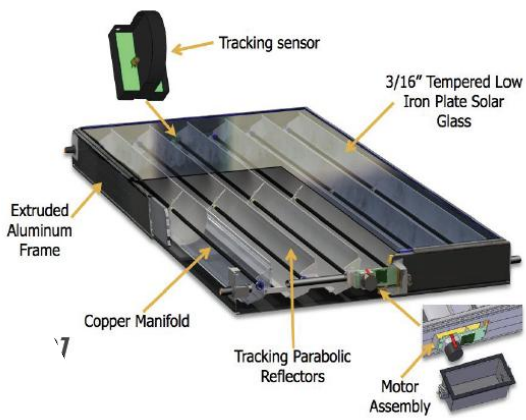

Figure 12 – Solar Panel

9.4 Design and Calculations for Full Heating Load

An analysis will first be done on carrying the full heating load when it peaks. The existing boiler will be used as a backup incase of extreme conditions. According to the Trace model for Freetown Elementary School, the building peaks with its highest demand in January. This peak load will be used to determine the sizing of the system. The building is designed for a typical day in January at 9am when everyone gets to school to have the highest demand of 265,250 Btu/hr and an outside design temperature of 27 degree Fahrenheit. With a basepoint of 65 degree Fahrenheit yields a UA of 3267W/K. This number is too large to model in TRNSED so the UA was divided into 7 parts.

An analysis was done to determine the best ratio of area of collector to storage size of the tank. The best option was a 2 to 1 ratio. The total collector area then resulted in 15,040 ft2. With a solar panel that is 32 ft2, a total number of panels required to accommodate the full load is 471.

Source: TRNSED

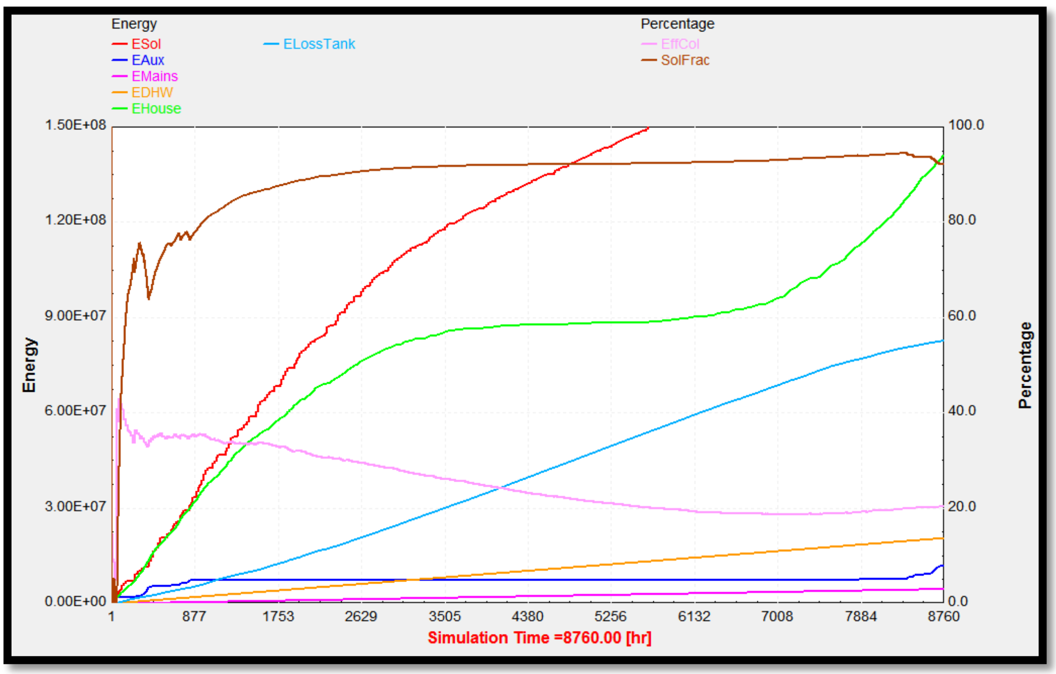

Chart 4 – Results from TRNSED

The chart above shows the amounts of energy that is collected and used throughout the year. “EAux” increases in the winter months which is the beginning of the chart and at the end of the year because of the increased heating load. “EMains” rises first in the winter months because the water needs to be hotter and decreases as the warmer months come and spaces do not need to be as hot. “EDHW” increases constantly throughout the year because it is assumed that the amount of hot water needed for restrooms is consistent throughout the year.

9.5 Layout of Solar Panels

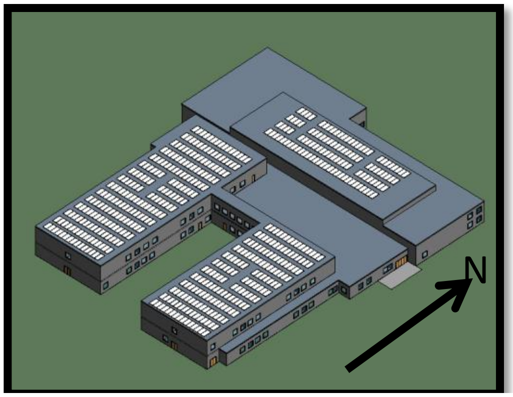

Figure 13 – Layout of Solar Panels on Roof

9.6 Energy Savings from TRNSED

The original model computed in TRACE resulted in 1,222 therms a year with a gas fired boiler. The auxiliary energy needed to cover the heating load with solar panels is 796 therms a year. The difference in the two numbers is what the solar panels can handle on "free energy" from the sun. This energy reduction is 35 %, which is a significant amount.

Comparison		Existing Boiler	Solar Panels	Energy Savings
Energy Use	therms/yr	1222	796	35%
Total Charge	$/therm	0.86	0.86	
Monthly Meter Fee	$	35	35	Cost Savings
Total cost	$/yr	1471	1105	25%

Table 8 – Energy Savings

9.7 First Cost

The first cost of the solar system was calculated using RS Means Mechanical Cost Data 2011. A system containing 3 panels and a 120 gallon storage tank costs $6,775. This value includes the circulator, fittings, and labor. Each additional 120 gallon tank costs $1,625. This value was subtracted from the total cost of the 3 panels and storage tank to get $5,150 for just the price of the three panels. This cost estimate boils down to $1,717 per panel. The cost of the panel was rounded up to $2,000 per panel to allow for a better quality panel. With 471panels installed, a first cost of the system results in $942,000.

Solar Panels		
Number of panels	#	471
Footprint required for system	ft2	15,072
Price per panel	$	2,000
Total installed system cost:	$	942,000

Table 9 – Solar Panel First Cost

9.8 Payback

The net first cost of the solar system factors in the reduction of one of the boilers, so there is only one backup boiler. The boiler cost was $40,600. The payback resulted in a very extensive time period so the up front cost would not be worth the initial deficit. This payback period is so long because solar panels are rather expensive still being in the research and development phase. There has been great strides to make solar panels more efficient and have a bigger reduction in first cost. However, this system would not be beneficial to take on the space heating load and domestic hot water loads. The space heating load dominates and is only required four out of the twelve months of the year so in the warmer months, it is barely providing any energy benefits beyond the small hot water load.

Payback		
Net First Cost	$	901,400
Energy Savings a year	therms	426
Cost of therm	$/therm	0.86
Customer Charge	$/month	35
Cost Savings a year	$	786

Table 10 – Simple Payback Period

9.9 Design and Calculations for Domestic Hot Water Load

A similar process was done for sizing of the domestic hot water load. Different sizes of collector area and storage size was evaluated. It was determined that 2, 32ft^2 solar panels are needed to have the best payback period. A more realistic payback period was found for the domestic hot water load but is still quite extensive. However, this system will be used year round as opposed to the previous sizing of space heating and hot water which is mostly used only four months out of the year.

Solar Panels for Domestic Hot Water Load								
	payback	89	109	80	66	50	38	47
	first cost	$ 10,088	$ 12,609	$ 9,079	$ 7,061	$ 5,044	$ 2,522	$ 5,044
	savings	$ 113	$ 116	$ 114	$ 108	$ 100	$ 67	$ 106
	# panels	7	8	6	5	3	2	3
Collector size	ft2	215.2	269	193.68	150.64	107.6	53.8	107.6
Collector size	m2	20	25	18	14	10	5	10
Storage tank	l/m2	20	18	25	25	30	30	40

Table 11 – Solar Panel for Domestic Hot Water Analysis

10.0 Air Quality Sensors

ASHRAE Standard 62.1 has two procedures for calculating ventilation rates. One of the calculations computes based on Volatile Organic Compounds while the other is based on strictly occupancy. The calculation based on occupancy ignores offensive odors and VOC's that are present if CO2 levels are low.

CO2 Occupancy Sensors are vital in reducing the energy used to bring in outdoor air. When measuring CO2 by occupancy sensors that are wired into the HVAC system, there will be a better handle of ventilation administered in the building. Humans give off CO2 when they are exhaling. ASHRAE has standards to apply a certain ventilation rate per occupant for each kind of space. For example, a classroom has a ventilation rate of 10 cfm per person whereas a conference/meeting room has a ventilation rate of 5 cfm per person according to ASHRAE Standard 62.1.

Measuring ventilation rates and altering the mechanical system to serve the rate only when needed can benefit the system. CO2 concentrations should be maintained at or below 1000 parts per million (ppm). If the concentration is 1000 ppm, outside air ventilation should be 15 cfm per person and the differential between the inside and outside should be 650 ppm.

10.1 Volatile Organic Compounds (VOC)

Volatile Organic Compounds are the cause of sick building syndrome. Sick building syndrome is a term used to explain the sickness and comfort effects of building occupants that are linked to time spent in a building and no specific cause can be identified.

The table shown below displays possible VOC's and their source from typical indoor contaminants; such as, humans, office equipment, building materials, furniture, etc.

Source: BAPI

Table 1 Typical Indoor Contaminants (VOCs) and Their Source

Contamination Source	Emission Source	VOC
Human Being	Breath	Acetone, Ethanol, Isoprene, CO_2
	Skin Respiration & Perspiration	Nonanal, Decanal, alpha-Pinene
	Flatulence	Methane, Hydrogen,
	Cosmetics	Limonene, Eucalyptol
Consumer Products	Household Supplies	Alcohols, Esters, Limonene
Office Equipment	Printers, Copiers, Computers	Benzene, Styrene, Phonole
Combustion	Engines, Appliances, Smoke	Unburnt Hydrocarbons, CO, CO_2
Building Materials	Paints, Adhesives, Solvents, Carpets	Formaldehyde, Alkanes, Alcohols, Aldehydes, Ketones, Siloxanes
Furniture	Poly Vinyl Chloride (PVC)	Toluene, Xylene, Decane

Table 12 – Typical Indoor Contaminants (VOCs)

10.2 Indoor Environment Quality Sensors

IEQ sensors are sensors that do not only measure CO2 for ventilation rates but also measures all types of VOC's. Therefore, if a cooking odor has a high concentration a CO2 occupancy sensor will not detect it but the IEQ sensor will and ventilate the kitchen and serving area appropriately. When the sensors measure everything in a space, the output measures the highest concentration of an individual VOC. The sensor takes the measurement and converts it to voltage to send to the mechanical controls. An example of this is if carbon monoxide is measured in the kitchen at 5 ppm and the range of measurement is 0-10ppm, the sensor will read out 50% which converts to 5 volts if it is a 10 volt range. The range for each compound is listed below in the table. This sensor has been optimized for Demand Control Ventilation. A calibration algorithm allows a high correlation to CO2 level and ASHRAE's occupancy –based ventilation rate procedure schedule to ventilate.

Source: BAPI

Table 2 Some Typical VOCs and the Individual Concentrations Needed for 100% output

Compound	Formula	Range	Potential sources of indoor pollutants
Carbon monoxide	CO	0-10 ppm	Car exhaust, fuel-based heating, cooking appliances, smoking
Methane	CH_4	0-200 ppm	Natural Gas
Propane	C_3H_8	0-20 ppm	Fuel-based heating, cooking appliances, cleaners
Ethyl Alcohol	C_2H_6O	0-3 ppm	Cosmetics, cleaners, disinfectants, paints, coatings, breath
Acetaldehyde	C_2H_4O	0-20 ppm	Adhesives, coatings, plastics, lubricants, ripening of fruit, smoking, rosin core solder
Methyl Ethyl Ketone	C_4H_8O	0-20 ppm	Adhesives, coatings, plastics, lubricants
Toluene	C_7H_8	0-5 ppm	Paints, coatings, cleaners, detergents, smoking, polyurethane lacquers

Table 13 – Concentration Outputs

An IEQ sensor will ensure the safety of the elementary schools occupants and reduce energy use when spaces are not used and ventilation is not needed, like the gymnasium and cafeteria.

Source: BAPI

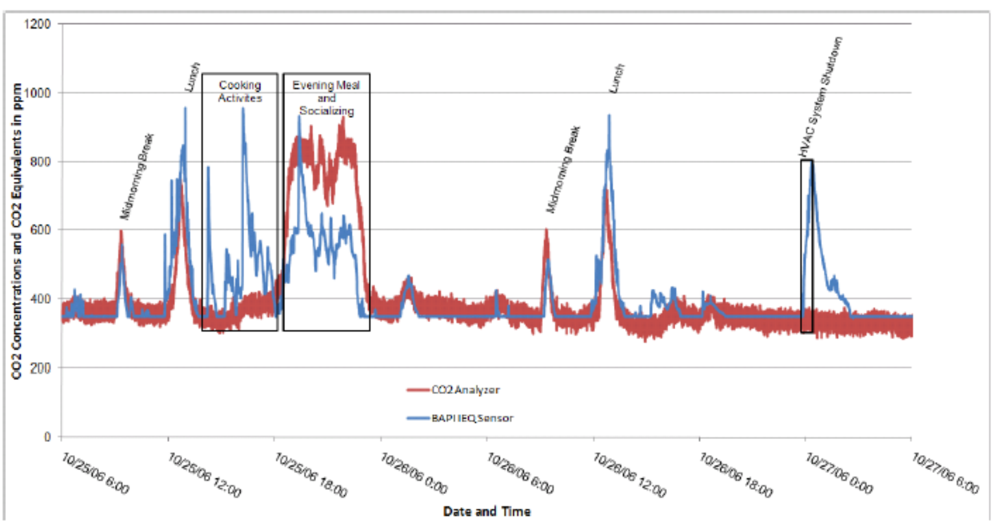

Chart 1: VOCs in a Kitchen and Serving Area
(The red line indicates CO_2 and the blue indicates the output of BAPI's VOC Sensor)

Chart 5 – VOC in Kitchen

The chart above was a study done to compare CO2 sensors to VOC sensors. It shows the correlation in a kitchen and serving area in a cafeteria during 2 days. The red line is CO2 and the blue line is what is read by the IEQ sensor, which includes all VOC's. The two readings were similar during the morning hours when it was occupied, during lunch, and evening meal and socializing. In an elementary school cafeteria, the space may only be occupied during lunch time, school gatherings, and maybe breakfast.

The CO2 reading for both the sensors will be similar during occupied times but what will be different is when the cooking activities happen in the kitchen. The IEQ sensor will pick up offensive cooking odors, which occurs before the space gets occupied leaving a fresh, inviting smell inside the spaces being served. The CO2 sensor will not ventilate when there is only cooking odors and zero occupancy in a space where the IEQ sensor will.

Source: BAPI

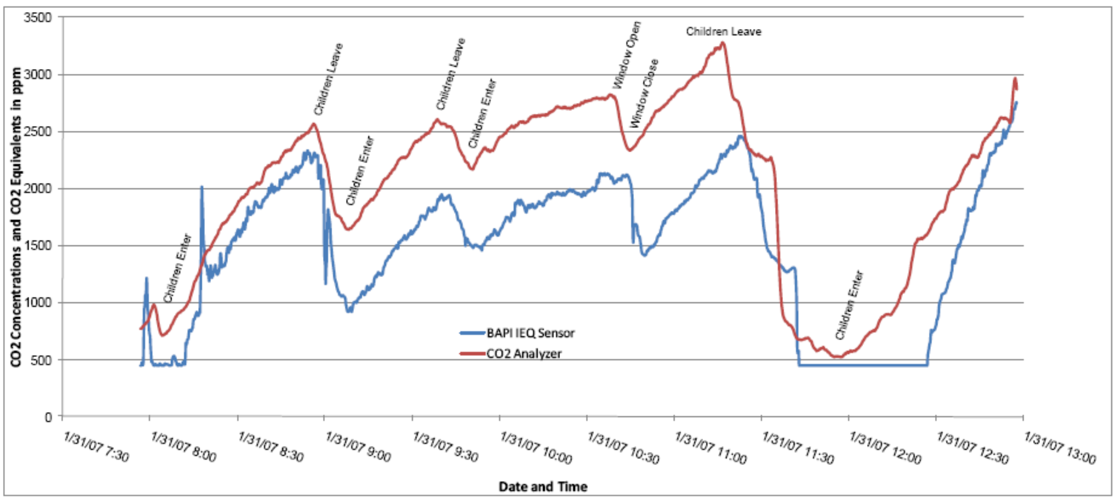

Chart 3: VOCs in an elementary school classroom

Chart 6 – VOC in Classroom

The chart above shows the difference in a CO2 sensor versus a VOC sensor in an elementary classroom with one teacher and 30 students. The IEQ sensor is lower in this case because elementary school children do not wear lotions, colgne and perfume. Although less VOC's show up in this case, the sensor is directly indicating occupancy.

10.3 Placement

In order to diminish the effects of all odors instead of just CO2, IEQ sensors will help eliminate this problem and make the space a better living and learning environment. The IEQ sensors will be placed in each classroom (34), the cafeteria/kitchen (3) and gymnasium (2). This will reduce energy by ventilating only when needed per occupant or when an offensive odor is present.

10.4 First Cost

Each sensor has a cost of $475. A total number of 39 sensors will be placed in the building, having a first cost of $17,575.

10.5 Payback

Although calculating a payback period is hard to determine without proper modeling, according to a study done by Building Automation Products, Inc. "The Building Owners and Management Association stated in a 1999 report that typical building operating costs are 83.3 % personnel salaries, 13.5% rent, 2.1 % repair and maintenance and 1.2 % total energy costs (Heat, Air Conditioning, Lighting, Business Equipment Power, Water Heating, etc)." Therfore, the cost of personnel is the highest expense.

Poor indoor air quality can result in a decreased production as much as six to nine percent, according to Professor Wyon of the Technical University of Denmark's International Centre for Indoor Envinronment and Energy. Numerous studies support Professor Wyon's stand on appropriate ventilation increases productivity. Along with productivity, it increases worker accuracy, increases morale, and decreases health insurance costs from less claims.

Overall, a small increase in total operating costs to allow for appropriate ventilation can increase personnel productivity.

11.0 Lighting Breadth

Occupancy Sensors and Daylighting

In order to reduce electric consumption, the use of occupancy sensors will eliminate the lighting that is not needed at certain times. For instance, the restrooms are not occupied 100% of the school day and would be a waste of energy if someone forgets to shut off the light. With the installation of occupancy sensors for lighting, the system will recognize whether or not light is needed depending on the detection of an occupant in the space.

There are multiple different types of sensors: passive infrared, ultrasonic, and hybrid. All of these options will be explored in Freetown Elementary School. Other features also exist to put better control on the space such as time delays, alerts for shutoff, hard lens, night light, etc.

Source:WattStopper

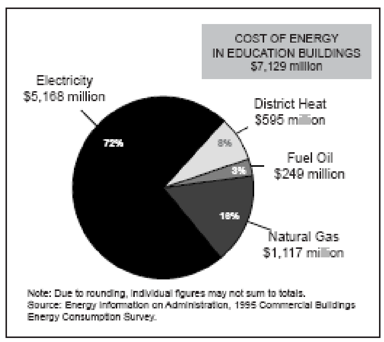

Figure 15 – Energy Usage for Educational Facilities

Electricity is the main energy source in educational buildings. In order to reduce the cost, the use of lighting controls will be installed. Classrooms and offices where a teacher "owns" a space, manual overrides are appropriate. On the other hand, a common area such as a hallway where no single occupant or group is dominant, an automated control works best.

11.1 Advantages vs. Disadvantages

Installing occupancy sensors for indoor lighting has its advantages and disadvantages. One of the major benefits is that they can save you a great amount of electricity which in turn saves money. Lights are only turned on as the occupant needs it. The sensors are also very convenient for occupants. Occupants do not need to search for light switches in the dark. With these advantages come disadvantages like lack of control and unwanted shutoff.

11.2 Variations

Passive Infrared

Passive infrared sensors are sensitive to cross motion and should be put near doorways. These sensors are an electronic device that measures infrared light radiating from objects in the sensors view. Motion is detected when a source with one temperature passes in front of another source with another temperature, such as a human passing by with one temperature being a human and the other temperature being the wall or door. This sensor works by line of sight and is not reliable for motion approaching the sensor. Spaces such as enclosed offices, gymnasiums, hallways, classrooms, media centers, and music rooms are good rooms for this type of sensor. These do not work well in spaces with barriers.

Ultrasonic

Ultrasonic sensors work similar to radar or sonar where radio or sound waves evaluate attributes of a source by echoes. This type of sensor generates high frequency sound waves and evaluates the echoes received by the sensor. The sensor then determines the time interval between sending the signal and receiving to calculate the distance to an object. Motion in the space changes the pattern of the waves, activating the sensor. This type of sensor is sensitive to any motion including inanimate objects and can “see” around barriers. With increased distance of the moving object from the sensor, results in errors with motion detection. This type of sensor works well for restrooms.

Dual Technology/hybrid

Dual technology sensors or hybrid sensors contain both the passive infrared and the ultrasonic components. These have detection by both types of sensors to turn on the lights on but detection by only one to keep them on. This works well to prevent false on/off switching. This can also be combined with a microphone to pick up sounds, which would then be responsive to the sound of typing. This type of sensor is good for large or complex areas and also computer labs, classrooms, or gymnasiums.

11.3 Installation

Installation guidelines are important for placement in order to achieve the best results of an occupancy sensor. Any of these types of sensors should be installed on a vibration free surface and placed above or close to the main areas of activity. An isolated relay enables interfacing with HVAC, BAS, or monitoring system. Sensors should not be installed within 6-8 feet of HVAC outlets or be positioned behind a door. Light level sensors will be used in all spaces that have ample window area to allow natural light into the space during the day hours.

11.4 Typical Elementary Classroom

Control Needs

Automatic switching of lights depending on occupancy. Dimming of fixture row next to the windows based on daylight. Manual switching and dimming of different zones of lights.

With Sensor

LC-100 Intelligent Power Pack, DT-200 Dual Technology Occupancy Sensor and LS-301 Dimming Photosensor. LC-100 easily adjusts dual zone switching and dimming with its dual relay and dual 0-10V dimming outputs. A low voltage momentary switch is connected to dual switch inputs. PIR Coverage 55ft, Ultrasonic coverage 38ft.

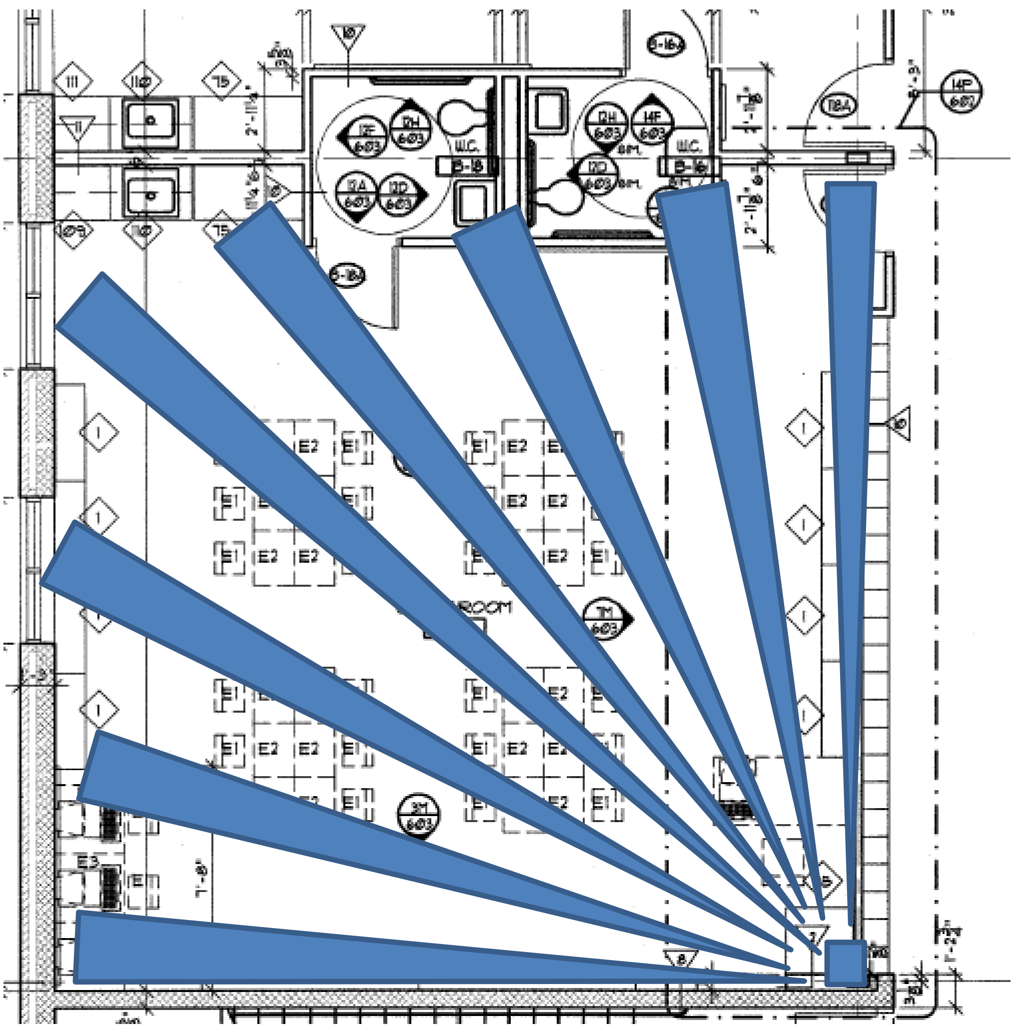

Figure 16

Source: WattStopper

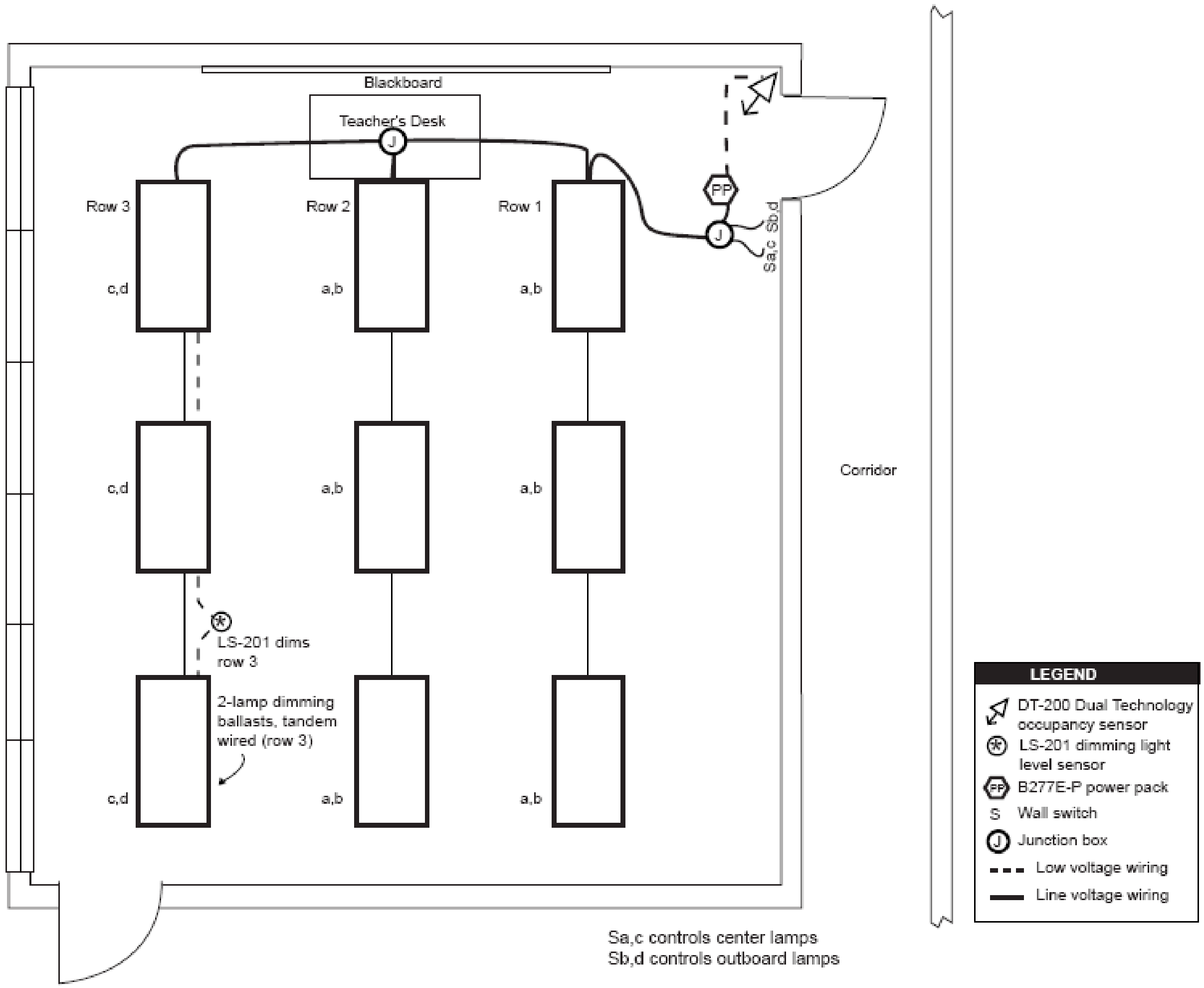

Figure 17 – Typical Layout of wiring

Above is an example of a layout for a classroom with the sensor, powerpack, and switching. The lighting closest to the windows has a 2-lamp dimming balast with tandem wiring to aquire for daylighting controls. The DT-200 has a 18 minute time delay, which is the recommended minimum for classrooms. A minimum of 22 guage wire should be used for low voltage wiring. The LS-201 dimming light level sensor should be mounted between five and eight feet from the window.

11.5 Typical Enclosed Office

Control Needs

Switching control with light level sensing. Sensor should detect small movements such as typing and reading.

With Sensor

WA-200 Automatic Wall Switch Sensor. The WA's SmartSet Technology adjusts the time delay and sensitivity settings.

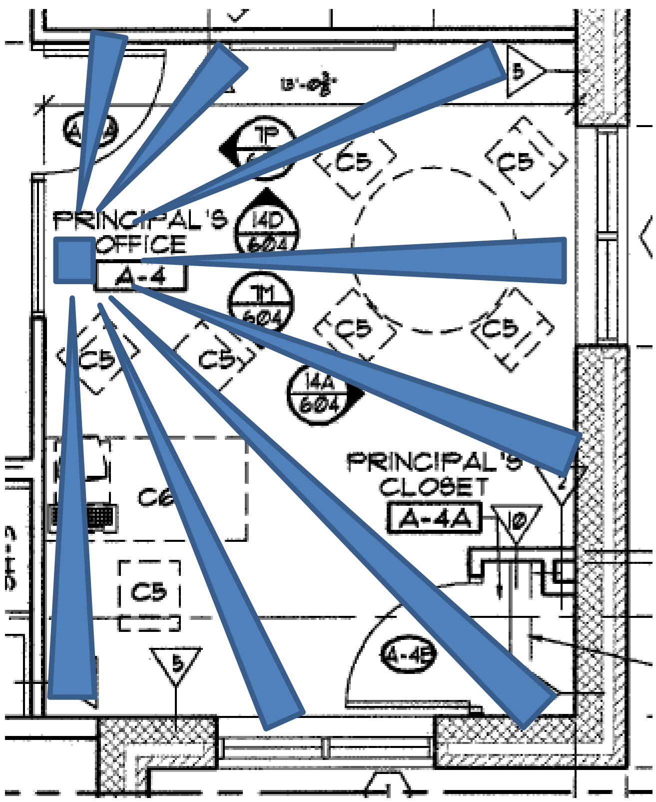

Figure 18

11.6 Conference Room

Control Needs

A sensor with switching for on/off control. High sensitivity for low motion activities and lights capable of remaining off for presentations.

With Sensor

DT-300 360 degrees Dual Technology Occupancy Sensor. Manual off overide. Coverage 40 ft by 40 ft.

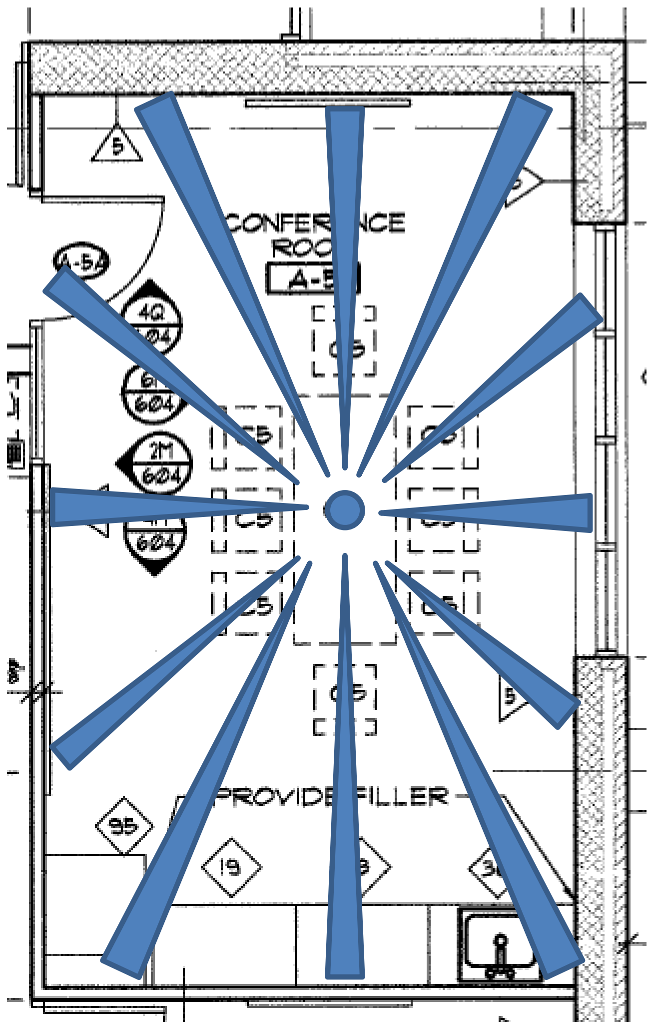

Figure 19

11.7 Restroom

Control Needs

On/off control that can see around barriers.

With Sensor

The UT-355 line voltage, Ultrasonic Sensor.

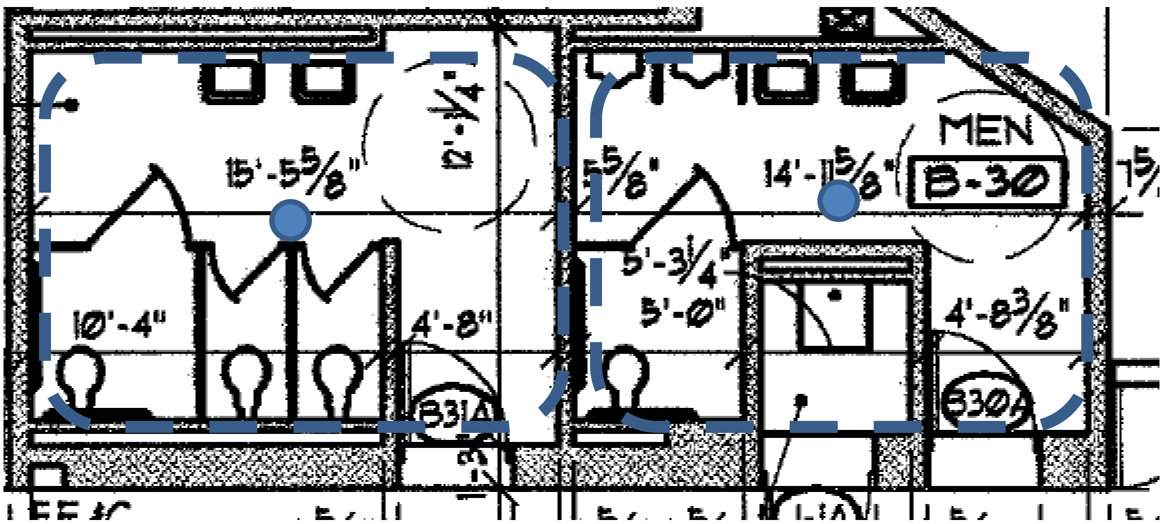

Figure 20

11.8 Typical Hallway

Control Needs

Switching for on/off control and lights turn on when someone enters the hallway from either side or enters from a doorway.

With Sensor

WT-2250 Ultrasonic Sensor

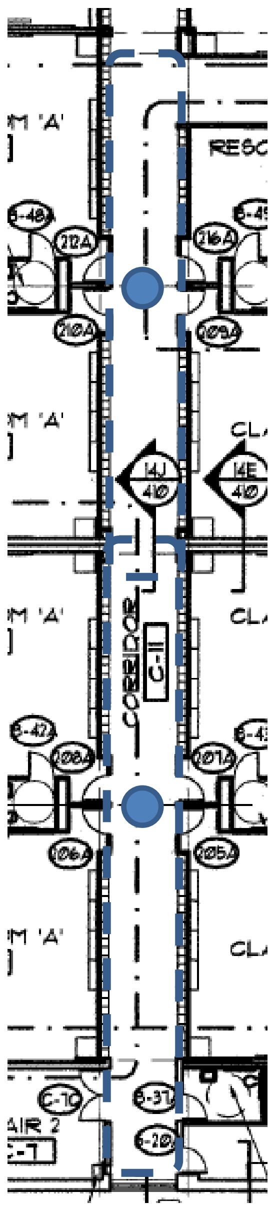

Figure 21

11.9 Media Center

Control Needs

Switching for on/off for variable levels of motion in a large area.

With Sensor

DT-200 and DT-300 dual technology sensors. The DT-200 (passive infrared) is placed in the corner and has a cutoff near the doorway. The DT-300 (360 degree coverage) captures the rest of the space.

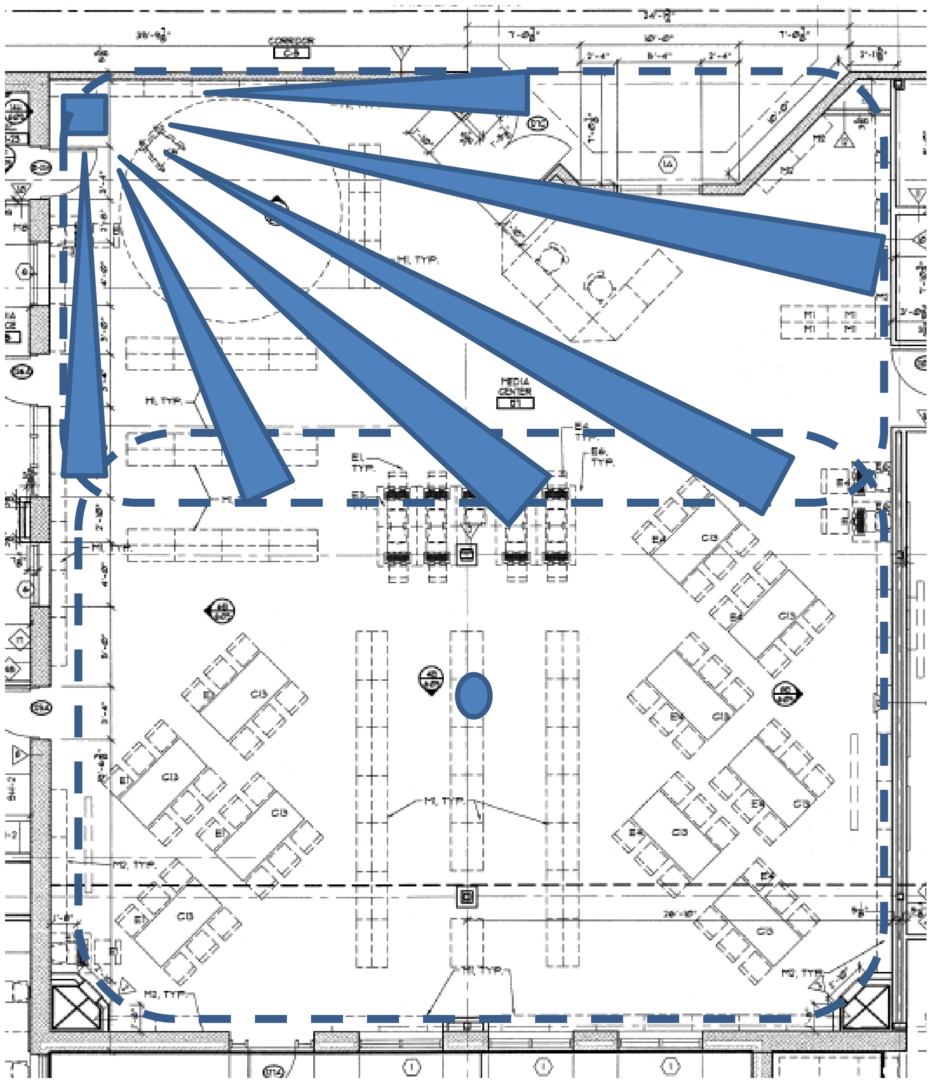

Figure 22

11.10 Model – TRACE

A model was made in TRACE to compare the effects of daylighting controls to the as-designed lighting controls. In TRACE the daylighting controls were made available 100% and a stepped dimmer was applied to spaces that can acquire benefits of daylighting controls.

11.11 First Cost

With estimation from a similar project, an installment of 37 sensors in the classrooms results in a cost of $5644 for the sensors and $1819 for labor. The total first cost of the sensors is $7463. Only this cost is evaluated because only spaces with potential daylighting was configured. The other sensors located in the restroom and gymnasium were not able to be modeled.

11.12 Savings

With the use of occupancy sensors in a classroom, an expected savings range can be between 10-50%. The analysis from TRACE resulted in a 5% total energy reduction or $14,029 per year in utility costs. However, when looking directly at electricity used by lighting, a reduction of energy was lowered by 9%. This reduction in lighting had an effect on the cooling and heating loads because of the decrease in internal loads of lighting.

11.13 Payback

Simple payback is 6 months so this is a very viable option to reduce energy costs while not committing to a huge upfront cost.

12.0 Sustainability Breadth

12.1 Rainwater collection system

An addition of a rainwater collection system will benefit the school because of the resuse of rainwater. Instead of draining the water away, this water can be used to circulate throughout the building. Components that will benefit from this will be the usage of water in toilets and sinks.

12.2 Design

A pressure tank will be used in the rainwater collection system. There is a plastic rubber bladder inside acting like a balloon, to provide water pressure. As the pressure decreases in the tank, the pump turns on to refill the bladder. A pressure sensitive pump is necessary for shut off when a certain pressure is reached.

Using a pressure tank allows for lower powered pumps or low flow rate pumps. Pressure tanks are easy to service, however, occasionally a bladder replacement is required and the entire tank needs to be protected from freezing.

The pressure sensitive pump has little maintenance cost and is easy to install however, they are more expensive. The pump will be placed on the same level as the storage tank. The piping should be a minimum of 1inch diameter to reduce strain on the pump. The collection system will only be on the northern end of the building.

New toilets will be installed with this design to benefit more in the usage of water. Toilets use 1.6 gallons per flush. The urinals will be water free urinals. For sinks in the restrooms a hand sensor will be installed to allow for use only when hands are under the faucet, which reduces water costs greatly, especially in a elementary school setting where children might forget to turn the faucet off. A pump, storage tank, piping, controls and filters are the components needed to install this system.

12.3 Average Monthly Rainfall

With a rule of thumb of 0.625 gallons of water with each inch of rainfall and applying the average monthly rainfall per month of 3.5 inches yields 2.2 gallons of rain. This 2.2 gallons is multiplied by the total collection area of 36,000 results in 79,200 gallons of collection.

12.4 Layout

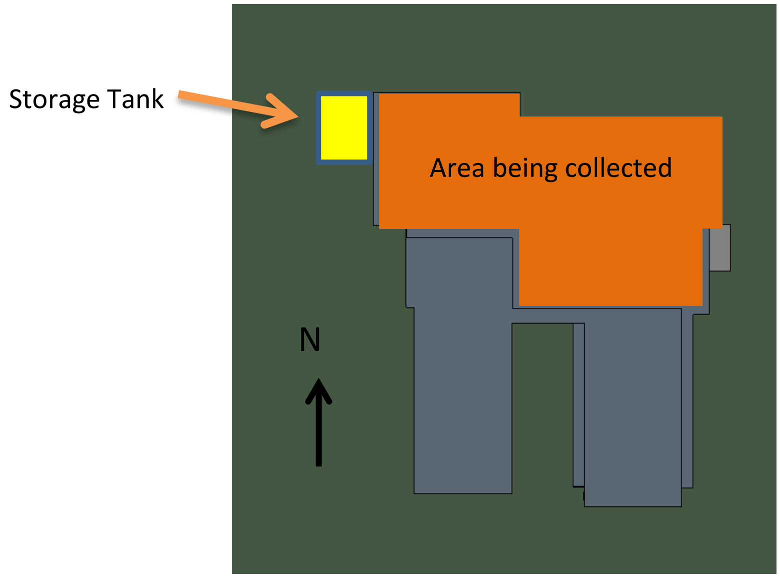

Figure 23 – Rainwater Collection System

The area being looked at for rainwater collection is the northern section of the building. This area equates to approximately 25,000 square feet. All the spouts will be directed towards the north western corner of the building where the storage tankw ill be located. This is a reasonable location because it is in the "back" of the school away from the road and entrance to the east and the athletic fields to the south of the building. Foot traffic is very low so the tank will be hidden from any aesthetic views and away from the students for recess.

12.5 Estimation

An estimation was made for the amount of water used from toilets assuming each student went to the restroom once per day on average and used the sink once for 30 seconds of handwashing. The total amount of gallons per month used is 76,140. This is lower than the total amount collected so the rainwater collection tank is large enough to handle the usage depending on the actual rainfall.

Estimation of water usage for sinks	
gpm	1.5
average time per use (min)	0.5
# of handwashes per day	30
# of sinks	36
gallons per month	24,300

Estimation of water usage for toilets	
gallons per flush	1.6
# of flushes per day	30
# of toilets	36
gallons per month	51,840

Table 14 & 15 – Estimation of Water usage

13.0 Discussion of Results & Recommendations

In conclusion of analyzing a ground source heat pump, solar panels for hot water and space heating, and air quality sensors for my depth topics it is possible to compare each system to the existing system.

The existing system of a boiler and chiller is comparable to the ground source heat pump. The ground source heat pump gives the ability to save energy by using a ground loop to extract heat and reject heat instead of the chiller and boiler. This is a free heat exchanger in context. The differences in cost are that of the pumps and pumping energy for the ground source heat pump as well as the piping and drilling of bores, however the chiller and boiler can be eliminated. This option has a payback period of 6.2 years and saves $30,550 on utility costs per year as wellas saving 13% on emissions.

The solar panel system can relate to the space heating and hot water load for the building. The existing building consumes 1,222 therms a year of natural gas from the boiler and with the solar panel addition there is a 35% energy savings but heating load is not large enough to have an effective payback period. The hot water load is more reasonable because it is able to work year round instead of only during the colder months but still has an extensive payback period because of the large upfront cost.

The air quality sensors allow ventilation for areas that need an improved air quality other from the normal CO2 ventilation. This installment improves the air comfort inside the building which results in less complaints and better production out of the faculty and students.

The daylighting controls and rainwater collection system allow the building to be more sustainable and use less utility. The daylighting controls adjust to amount of sunlight that enters the rooms which saves a sufficient amount of energy out of the lighting load. The use of using rainwater for the building's toilets and sinks decreases the utility cost for water consumption.

Final recommendations that apply to this school to be most cost beneficial are the use of a ground source heat pump, the addition of dimming ballasts for daylighting and the rainwater collection system. These systems will save utility costs, decrease in emissions, and increase the sustainability of the overall building.

14.0 Credits and Acknowledgements

I would like to extend a special thanks to everyone that has helped me throughout this process, the AE faculty, fellow students, family and friends.

A special thanks to:

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Matt Tressler, McClure Company

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2009-2010 Senior Thesis Reports

Appendix A – TRACE RESULTS

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

------ Monthly Energy Consumption ------

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 1 **Model**													
Electric													
On-Pk Cons. (kWh)	183,529	164,353	192,201	198,419	231,337	243,373	260,842	248,340	225,968	202,375	190,969	187,780	2,529,487
On-Pk Demand (kW)	283	287	292	323	439	449	459	446	445	327	307	295	459
Gas													
On-Pk Cons. (therms)	440	353	34	0	0	0	0	0	0	1	2	90	919
On-Pk Demand (therms/hr)	3	2	0	0	0	0	0	0	0	0	0	1	3

Energy Consumption		
Building	114,845	Btu/(ft2-year)
Source	342,212	Btu/(ft2-year)
Floor Area	75,973	ft2

Environmental Impact Analysis		
CO_2	3,305,591	lbm/year
SO_2	28,210	gm/year
NOX	6,327	gm/year

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 2 **GSHP**													
Electric													
On-Pk Cons. (kWh)	176,276	158,520	179,681	182,249	202,942	207,019	222,086	217,417	201,192	189,500	180,026	178,082	2,294,989
On-Pk Demand (kW)	247	248	268	285	327	354	365	398	352	287	275	254	398

Energy Consumption		
Building	103,100	Btu/(ft2-year)
Source	309,332	Btu/(ft2-year)
Floor Area	75,973	ft2

Environmental Impact Analysis		
CO_2	2,967,550	lbm/year
SO_2	25,325	gm/year
NOX	5,680	gm/year

Project Name: Freetown Elementary School
Dataset Name: Real GSHP.trc

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Alternative - 2 Monthly Energy Consumption report Page 1 of 2

MONTHLY ENERGY CONSUMPTION

By ACADEMIC

------ Monthly Energy Consumption ------

Utility	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Alternative: 3	**Lighting Control**												
Electric													
On-Pk Cons. (kWh)	177,544	159,833	183,021	184,046	211,534	222,603	240,485	231,754	213,423	195,224	184,788	180,866	2,385,121
On-Pk Demand (kW)	289	281	291	310	382	407	429	431	391	305	301	296	431
Gas													
On-Pk Cons. (therms)	631	501	59	8	0	0	0	0	0	3	14	176	1,392
On-Pk Demand (therms/hr)	4	4	1	0	0	0	0	0	0	0	0	1	4

Energy Consumption		
Building	108,982	Btu/(ft2-year)
Source	323,409	Btu/(ft2-year)
Floor Area	75,973	ft2

Environmental Impact Analysis		
CO_2	3,136,849	lbm/year
SO_2	26,770	gm/year
NOX	6,004	gm/year

Project Name: Freetown Elementary School
Dataset Name: Real GSHP.trc

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Alternative - 3 Monthly Energy Consumption report Page 2 of 2

ENERGY CONSUMPTION SUMMARY

By ACADEMIC

	Elect Cons. (kWh)	Gas Cons. (kBtu)	% of Total Building Energy	Total Building Energy (kBtu/yr)	Total Source Energy* (kBtu/yr)
Alternative 1					
Primary heating					
Primary heating		91,913	1.1 %	91,913	96,750
Other Htg Accessories	8,531		0.3 %	29,118	87,362
Heating Subtotal	**8,531**	**91,913**	**1.4 %**	**121,030**	**184,112**
Primary cooling					
Cooling Compressor	497,239		19.5 %	1,697,077	5,091,742
Tower/Cond Fans	56,171		2.2 %	191,711	575,191
Condenser Pump			0.0 %	0	0
Other Clg Accessories	876		0.0 %	2,990	8,970
Cooling Subtotal....	**554,286**		**21.7 %**	**1,891,779**	**5,675,903**
Auxiliary					
Supply Fans	313,440		12.3 %	1,069,772	3,209,637
Pumps	88,296		3.5 %	301,355	904,155
Stand-alone Base Utilities			0.0 %	0	0
Aux Subtotal....	401,737		15.7 %	1,371,127	4,113,792
Lighting					
Lighting	1,331,041		52.1 %	4,542,843	13,629,891
Receptacle					
Receptacles	233,892		9.2 %	798,274	2,395,061
Cogeneration					
Cogeneration			0.0 %	0	0
Totals					
Totals**	**2,529,487**	**91,913**	**100.0 %**	**8,725,052**	**25,998,756**

* Note: Resource Utilization factors are included in the Total Source Energy value.
** Note: This report can display a maximum of 7 utilities. If additional utilities are used, they will be included in the total.

Project Name: Freetown Elementary School
Dataset Name: Real GSHP.trc

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Alternative - 1 Energy Consumption Summary report page 1

ENERGY CONSUMPTION SUMMARY
By ACADEMIC

	Elect Cons. (kWh)	% of Total Building Energy	Total Building Energy (kBtu/yr)	Total Source Energy* (kBtu/yr)
Alternative 2				
Primary heating				
Primary heating	4,985	0.2 %	17,015	51,049
Other Htg Accessories	3	0.0 %	11	34
Heating Subtotal	**4,989**	**0.2 %**	**17,026**	**51,083**
Primary cooling				
Cooling Compressor	327,849	14.3 %	1,118,948	3,357,180
Tower/Cond Fans		0.0 %	0	0
Condenser Pump		0.0 %	0	0
Other Clg Accessories	216	0.0 %	736	2,209
Cooling Subtotal....	**328,065**	**14.3 %**	**1,119,684**	**3,359,389**
Auxiliary				
Supply Fans	281,318	12.3 %	960,138	2,880,701
Pumps	115,685	5.0 %	394,832	1,184,614
Stand-alone Base Utilities		0.0 %	0	0
Aux Subtotal....	397,003	17.3 %	1,354,970	4,065,316
Lighting				
Lighting	1,331,041	58.0 %	4,542,843	13,629,891
Receptacle				
Receptacles	233,892	10.2 %	798,274	2,395,061
Cogeneration				
Cogeneration		0.0 %	0	0
Totals				
Totals**	**2,294,989**	**100.0 %**	**7,832,797**	**23,500,738**

* Note: Resource Utilization factors are included in the Total Source Energy value.
** Note: This report can display a maximum of 7 utilities. If additional utilities are used, they will be included in the total.

Project Name: Freetown Elementary School
Dataset Name: Real GSHP.trc

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Alternative - 2 Energy Consumption Summary report page 1

ENERGY CONSUMPTION SUMMARY

By ACADEMIC

	Elect Cons. (kWh)	Gas Cons. (kBtu)	% of Total Building Energy	Total Building Energy (kBtu/yr)	Total Source Energy* (kBtu/yr)
Alternative 3					
Primary heating					
Primary heating		139,243	1.7 %	139,243	146,571
Other Htg Accessories	9,763		0.4 %	33,322	99,977
Heating Subtotal	**9,763**	**139,243**	**2.1 %**	**172,565**	**246,548**
Primary cooling					
Cooling Compressor	474,454		19.6 %	1,619,313	4,858,424
Tower/Cond Fans	53,728		2.2 %	183,373	550,173
Condenser Pump			0.0 %	0	0
Other Clg Accessories	876		0.0 %	2,990	8,970
Cooling Subtotal....	**529,058**		**21.8 %**	**1,805,675**	**5,417,567**
Auxiliary					
Supply Fans	313,452		12.9 %	1,069,813	3,209,759
Pumps	88,469		3.7 %	301,945	905,926
Stand-alone Base Utilities			0.0 %	0	0
Aux Subtotal....	401,921		16.6 %	1,371,758	4,115,685
Lighting					
Lighting	1,210,486		49.9 %	4,131,390	12,395,408
Receptacle					
Receptacles	233,892		9.6 %	798,274	2,395,061
Cogeneration					
Cogeneration			0.0 %	0	0
Totals					
Totals**	**2,385,121**	**139,243**	**100.0 %**	**8,279,661**	**24,570,268**

* Note: Resource Utilization factors are included in the Total Source Energy value.
** Note: This report can display a maximum of 7 utilities. If additional utilities are used, they will be included in the total.

Project Name: Freetown Elementary School
Dataset Name: Real GSHP.trc

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Alternative - 3 Energy Consumption Summary report page 1

Geothermal Energy Transfer Summary

By ACADEMIC

Geothermal Plant - Ground-Source Heat Transfer

Alternative: 2 - GSHP
Plant: GSHP

Year: 1

Month	QExtracted from Geothermal Loop ton-hrs	kBtu	kWh	QRejected to Geothermal Loop ton-hrs	kBtu	kWh	Heat Rejected to Auxiliary Cooling peak tons	ton-hrs	kBtu	kWh	Heat Supplied from Supplemental Boiler peak MBH	ton-hrs	kBtu	kWh	Compressor Energy kWh
Jan	2,037	24,448	7,163	-17,410	-208,923	-61,214	0	0	0	0	0	0	0	0	10,184
Feb	1,137	13,644	3,998	-15,532	-186,378	-54,608	0	0	0	0	0	0	0	0	8,746
Mar	6	73	21	-29,086	-349,036	-102,267	0	0	0	0	0	0	0	0	13,233
Apr	0	0	0	-43,609	-523,303	-153,326	0	0	0	0	0	0	0	0	20,718
May	0	0	0	-70,410	-844,916	-247,558	0	0	0	0	0	0	0	0	36,025
Jun	0	0	0	-84,010	-1,008,115	-295,375	0	0	0	0	0	0	0	0	45,487
Jul	0	0	0	-97,547	-1,170,566	-342,973	0	0	0	0	0	0	0	0	55,169
Aug	0	0	0	-88,844	-1,066,130	-312,373	0	0	0	0	0	0	0	0	50,500
Sep	0	0	0	-70,818	-849,817	-248,994	0	0	0	0	0	0	0	0	39,660
Oct	0	0	0	-42,394	-508,727	-149,056	0	0	0	0	0	0	0	0	22,583
Nov	0	0	0	-35,053	-420,640	-123,246	0	0	0	0	0	0	0	0	18,494
Dec	144	1,728	506	-23,058	-276,694	-81,071	0	0	0	0	0	0	0	0	12,036
Annual	3,324	39,893	11,688	-617,770	-7,413,245	-2,172,061	0	0	0	0	0	0	0	0	332,834

Project Name: Freetown Elementary School
Dataset Name: Real GSHP.trc

TRACE® 700 v6.2.6.5 calculated at 05:46 PM on 04/04/2011
Geothermal Plant report page 1 of 2

Economic Summary

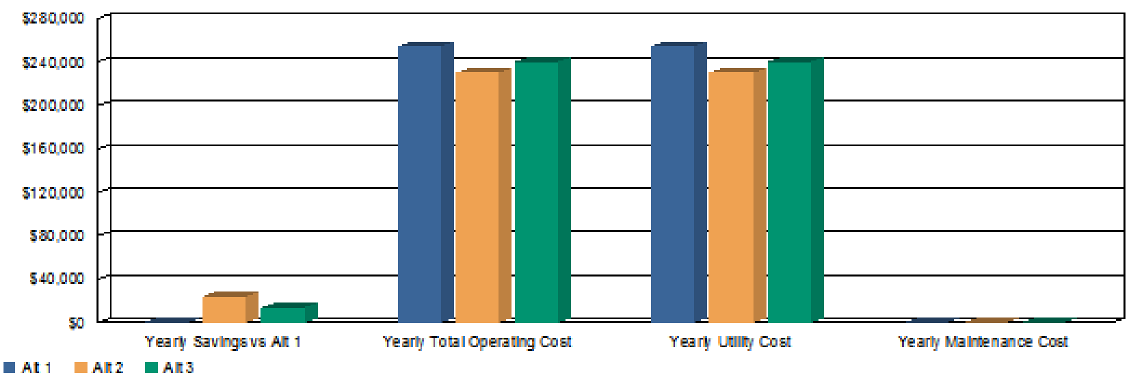
Project Information

Location	Glen Burnie, MD	Study Life:	20 years
Project Name	Freetown Elementary School	Cost of Capital:	10 %
User	Matt Buda	Alternative 1:	Model
Company		Alternative 2:	GSHP
Comments	TRACE 700 v6_2 - gbXML imported on Thursday, October 21, 2010 at 02:29 PM	Alternative 3:	Lighting Control

Economic Comparison of Alternatives

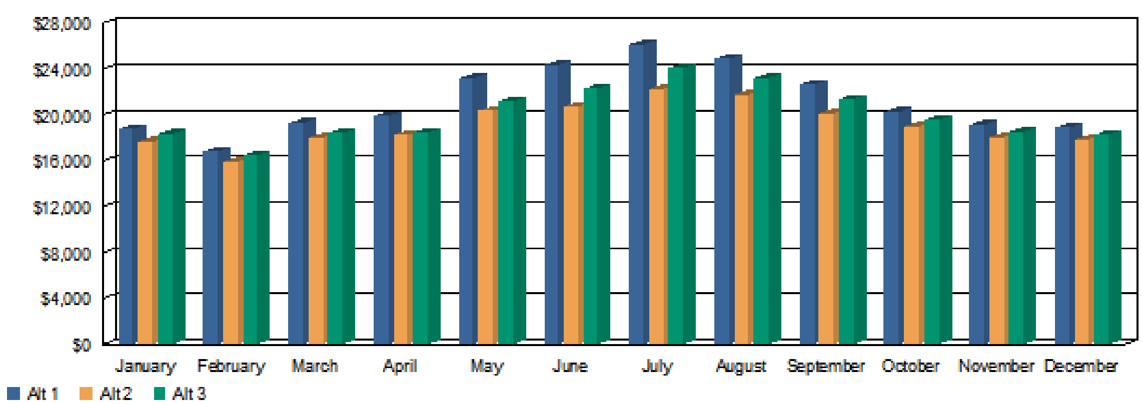
	Yearly Savings ($)	First Cost Difference ($)	Cumulative Cash Flow Difference ($)	Simple Payback (yrs.)	Net Present Value ($)	Life Cycle Payback (yrs.)	Internal Rate of Return (%)	Life Cycle Cost
Alt 1 vs Alt 2	-24,240	0	-484,805	No Payback	-206,371	No Payback	Does Not Payback	0.00
Alt 1 vs Alt 3	-14,030	0	-280,592	No Payback	-119,442	No Payback	Does Not Payback	0.00
Alt 2 vs Alt 3	10,211	0	204,214	No Payback	86,929	No Payback	1,000.0	0.00

Annual Operating Costs



	Yearly Savings vs Alt 1	Yearly Total Operating Cost ($)	Yearly Utility Cost ($)	Yearly Maintenance Cost ($)
Alt 1	0	254,369	254,369	0
Alt 2	24,240	230,129	230,129	0
Alt 3	14,030	240,340	240,340	0

Monthly Utility Costs



Project Name: Freetown Elementary School
Dataset Name: Real GSHP.trc

TRACE 700 6.2.6.5
calculated at 05:46 PM on 04/04/2011

January	Typical Weather (°F)		Design	
Hour	OADB	OAWB	Htg (Btuh)	Clg (Tons)
1	31.1	27.7	-27,944	0.0
2	29.4	26.0	-47,856	0.0
3	27.9	24.6	-46,295	0.0
4	26.7	23.4	-61,310	1.5
5	25.8	22.7	-56,882	11.4
6	25.3	22.0	-71,716	24.1
7	25.1	21.9	-67,403	32.8
8	25.6	22.6	-127,167	4.8
9	27.1	24.3	-179,818	0.1
10	29.4	25.8	-142,654	1.8
11	32.2	27.8	-128,204	6.4
12	35.3	29.9	-78,169	11.3
13	38.1	32.0	-34,392	15.6
14	40.4	33.7	-18,110	19.0
15	41.9	34.9	-14,529	21.0
16	42.4	35.2	-13,995	23.2
17	42.2	35.2	-16,285	22.5
18	41.7	35.4	0	12.7
19	40.8	35.1	0	12.7
20	39.6	34.4	-724	12.9
21	38.1	33.5	-953	15.1
22	36.4	32.5	-1,287	16.2
23	34.7	30.8	-2,035	18.4
24	32.8	29.3	-2,681	18.8

August	Typical Weather (°F)		Design	
Hour	OADB	OAWB	Htg (Btuh)	Clg (Tons)
1	70.6	61.7	0	87.7
2	69.0	60.5	0	85.2
3	67.6	59.6	0	83.2
4	66.6	58.8	0	81.7
5	66.0	58.6	0	80.5
6	65.8	58.6	0	79.9
7	66.4	59.1	0	83.6
8	68.0	60.1	0	101.9
9	70.6	61.2	0	163.8
10	73.7	62.4	0	181.4
11	77.0	63.3	0	195.4
12	80.1	65.2	0	207.3
13	82.6	66.4	0	217.0
14	84.2	67.2	0	225.7
15	84.8	66.9	0	230.8
16	84.6	67.2	0	182.2
17	84.0	67.0	0	210.1
18	83.0	66.9	0	184.0
19	81.7	66.6	0	166.6
20	80.1	66.6	0	146.9
21	78.2	66.5	0	128.4
22	76.3	65.6	0	114.9
23	74.3	64.4	0	105.4
24	72.4	63.1	0	98.0