Mechanical Technical Report 3

Mechanical Systems Existing Conditions Evaluation

Lutheran Theological Seminary at Philadelphia
The New Learning Center

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Executive Summary

The New Learning Center is designed with a mechanical system that heats, cools, and ventilates correctly. Even with a system that is fully functional, there is room for more investigation into more energy efficient or higher thermal comfort systems. The energy consumption and operation of the system are well within code. The system was designed to meet all of the goals, requirements, and objectives set forth early in the process and almost all were met.

When looking to redesign the mechanical system a few issues can be attacked. First of all, humidity control should be addressed in the basement areas. Whether it is another air handling unit to supply previously conditioned the air to the basement or a cooling coil in the supply air path, some sort of dehumidification system should be installed. Second, the rooftop units should be analyzed to see whether it is worth running hot water and chilled water to the units for conditioning. The selection of a different chiller might also need to be analyzed to make the plant efficient enough so the operating costs can outweigh the increased initial costs. Third, the pump sizing in the chilled water distribution loop needs to be addressed. The over sizing of the secondary loop decreases efficiency and increases initial cost and motor power.

The system design successfully maximizes thermal comfort with the adjustable supply air temperatures from the fan coil units. The Direct Digital Control (DDC) system was also the proper choice. A DDC system allows for better network communication and control, less maintenance, higher energy efficiency, and lower operating costs. The thermal comfort and overall humidity control of the building shows that the mechanical system obtained the correct loads, made the correct assumptions, ventilated beyond code, and designed the system properly. By including the enthalpy wheels as an energy recovery portion of the system, the engineer found ways to reduce the initial sizing and cost of the equipment as well as minimize the operating energy and cost.

Overall, The New Learning Center has a properly designed, constructed, and operating mechanical system. All requirements, codes, and objectives seem to have been met. Alterations to the system and equipment may result in a more energy and cost efficient building. In this case, there is always a chance that the system designed and selected may be the best possible system for The New Learning Center.

Building Design Background

The New Learning Center is the most recent construction done on the Lutheran Seminary at Philadelphia Campus. The New Learning Center was designed and built after the last building was deemed structurally unsound and needed to be demolished. The North exterior wall was left standing in its original stone façade form to help the new building tie in with the remainder of the campus.

The New Learning Center is a 4 level building, including a basement. The basement is comprised of the mechanical room, electrical closet, as well as an archive and storage section. The large majority of first floor is comprised of reception halls, lounges, and the kitchen. The second and third floors are made up of classrooms, conference rooms, and offices.

The New Learning Center is one of the main pieces of the campus quadrangle. Aside from the North wall that was left standing, it was designed with a metal clad façade. The first floor is almost entirely glass with an overhang to control direct solar gain into the building. The second and third floors are decorated with a variety of window shapes including diamonds, circles, and rectangles. The typical areas of the building have tile floors with drywall partitions.

There are no site conditions that influenced the mechanical system design. The building is set on a flat site with no large obstruction or shadows cast by landscaping. The mechanical system, however, was designed to work with the neighboring buildings and handle the future expansion of the neighboring library.

Mechanical System Design Objectives, Requirements, and Conditions

There were several design objectives laid out by Paul H. Yeomans, GYA Architects, and the Lutheran Theological Seminary at Philadelphia. First, they wanted the mechanical system that would fit in a small plenum height. The plenum was shallow since they wanted the floors of the building to coincide with the remaining exterior wall that would be integrated with the new design. Design was to create a DOAS with closets for the fan coil units to save space in the ceiling. Second, the owner wanted and energy efficient building. Since the owner of the building would continue to reap the long-term energy savings benefits, their wishes were to have a building that would save them operation costs over time. This was taken into consideration when the enthalpy wheel was installed in the rooftop unit and when the system was designed with variable frequency drives. Third, it was an objective to give individuals the greatest comfort and control possible. They designed the system with thermostats to control the fan coils units for optimal comfort. Finally, the system must be designed to account for the hot water required for all kitchen equipment.

Many of the requirements for the mechanical system of the building were the same as any other building. First, proper amounts of ventilation must be supplied to all zones. The outdoor air must meet or exceed the code set forth by ASHRAE 62.1. The rooftop units were designed to supply the proper amount of outdoor air to the building. Second, humidity must be controlled to eliminate mold, as well as increase comfort and health of the employees. This requirement was addressed by humidity control in the rooftop units equipped with hot gas reheat.

The majority of the indoor and outdoor design conditions were agreed upon early in the design. The outdoor conditions, such as design outdoor air temperature, and humidity conditions are set forth by ASHRAE 90.1. Information such as air contaminant levels are also specified in ASHRAE. The most important indoor condition was the schedules agreed upon by the engineer and owner. To save the most amount of energy, the system needs to be sized and turned on and off depending on assumed occupancy and schedules of the building. With the proper occupancy conditions agreed upon, the mechanical system can be designed for proper ventilation and temperature control.

Mechanical System Summary

The mechanical system for The New Learning Center is designed as a dedicated outdoor air system. The air is then mixed and reconditioned in the fan coil units before being delivered to the zones. It is designed for proper ventilation, heating, and cooling.

Chilled Water System

The chilled water system is fueled by the air cooled chiller on the roof. The chiller is made for low ambient conditions so it is capable for operation during the colder months to cool rooms with high cooling loads. It also has variable speed for low load conditions. The chiller is sized for 150 tons. The water arrives at the chiller evaporator at 42 F and leaves at 56 F.

Hot Water System

The hot water system consists of two gas fired boilers in the basement mechanical room. Each of these boilers is designed for 1250 MBH. This hot water is run through variable speed pumps to fan coil units and constant volume pumps to the fin tube radiation.

Air Side System

The mechanical system for The New Learning Center is designed as a dedicated outdoor air system. The system is controlled by DDC controls and is all tied back into the main controller. The system has three packaged DX rooftop units with 100% outside air. These units have integral heat recovery through a heat wheel, gas heat, direct expansion cooling, and hot gas reheat. RTU-1 and RTU-2 have 270 MBH of heating capacity and 320 MBH of cooling capacity. The smaller unit, RTU-3, has 90 MBH heating and 100 MBH of cooling capacity. These air handlers feed fan coil units in mechanical closets. The air is mixed within the closet, reconditioned, and then supplied to the rooms. The fan coils are various sizes, all based upon the room or group of rooms that they supply air to. In cooling mode the water is delivered to the coil at 45 F and leave at 55F. When heat is needed the water arrives at the coil at 180 F and leaves at 160 F. All of the fan coils are equipped with a two pipe system for heating and cooling coils.

Mechanical System Control Logic

The mechanical system in The New Learning Center is controlled by a BACnet DDC controls with a Building Automation System (BAS). All DDC controls are linked in a contiguous network such that if one control fails, it does not disrupt communication with any other controller on the network. All of the controls are to be wired with 120 VAC emergency power feeds. The BAS must consist of all operator terminals, global controllers, and terminal unit controllers as well as all sensors and software needed to monitor this equipment. The chilled water and hot water systems work along with the airside systems to supply a proper amount of air and maintain comfort in the building.

Water Systems Operation

Sensors for the water system are operated by three switch selectable range sensors. These sensors must have the capability for digital input. There are be two sensors to measure the differential water pressure, each which are accurate to +/- 1% combined linearity, hysteresis, and repeatability.

All valves are operable from 0 – 212 degrees Fahrenheit. The flow type for modulating two way valves are equal percentage. Three way valves have equal percentage control with a modified linear bypass port which will yield 70% of the total flow. These three way valves also have the ability to be used for mixing or diverting.

The operator of the system has many of the system features displayed in real time to troubleshoot and monitor proper operations. The status of the chiller, boilers, and pumps are displayed at the work station. The frequency, voltage, and power of the pumps are also monitored. Sensors also show whether the system is operating correctly by providing pressure differentials, supply water temperatures, and return water temperatures.

The system is indexed to occupied or unoccupied by the BAS. The schedule can be altered for a specified amount of time or changed permanently. The BAS has the ability to be overridden by the operator at any time.

Chilled Water System Operation

The chilled water system operations are monitored and controlled by the BAS. The chiller package is provided with its own controls and safeties. The BAS also has the ability to change the leaving water temperature in the system. The chiller shall be programmed on and off due to the occupancy schedules for The New Learning Center. The chilled water system will be indexed on during occupied mode when the outdoor air temperature reaches 65 F or above. It will also be indexed on when there is a demand for chilled water by any of the fan coil units within The New Learning Center.

To begin operation of the chilled water system, the primary chilled water pump, PCHW-1, is energized first. PCHW-1 is a constant volume pump. Once the differential pressure sensors prove there is flow, the chilled is indexed on. The secondary loop pump, PCHW-3, is then energized as the demand is needed by the fan coils. Differential pressure sensors in the system control the amount of flow to the building by PCHW-3, a variable volume pump. If any of the pumps fail the alarm sounds at the BAS and the chilled water system is de-energized. This is also sensed by the differential pressure sensors within the system. If the chiller package itself is de-energized by any of its own controls or safeties, a trouble signal is sent to the BAS. PCHW-2 is an extra pump that serves as the backup for both pumps. Since it has to have the capability to act as both, PCHW-2 is sized for the maximum possible load and has variable volume control. PCHW-2 requires manual changeover prior to its use and restarting of the chilled water system.

Hot Water System Operation

The hot water system operation is monitored and controlled by the BAS. In case of power failure the hot valves fail open to prevent freezing. The hot waster system is not based on the occupancy schedule, as the chilled water system is, because there may be a heating demand even when the building is unoccupied. The hot water system is indexed to on when the outdoor air temperature drops below 65 F and when there is a heating demand by any of the fan coil units. For the hot water system to be energized, the primary loop pumps, PHW-1 and PHW-2, must first be in operation. Both pumps are constant volume. The flow is proven by pressure differential sensors in the system. The boilers that each of the pumps serve is then indexed on. If the heating demand exceeds the load possible from one boiler, the second boiler is then also energized. If any of the pumps fail in the system the alarm sounds at the BAS and the hot water system is de-energized. The boilers are staged and the gas is modulated to maintain the appropriate temperature in the primary hot water loop. The loop temperatures are controlled by three way modulating valves. The water temperature for the primary boiler loop is always kept at 200 degrees Fahrenheit. There are two secondary loops fed from the primary boiler loop, the high temperature loop and the low temperature loop. Both loops are situated in parallel with the flow and temperature being controlled by three way control valves. PHW-3 and PHW-4 are constant volume. They feed the 200 degree high temperature water to the hydronic radiation. PHW-5 and PHW-6 have variable volume capability. They feed the 180 degree low temperature water to the fan coil units.

Air System Operation

Sensors for the air systems are operated by four switch selectable range sensors for air pressure. The pressure differential sensors are +/- 1% accurate. Humidity sensors are replaceable digitally profiled thin-film capacitive sensors. The humidity sensors are 2% or 3% accurate from 0-90% relative humidity. These sensors have the capability to operate properly for conditions between 0 and 140 degrees Fahrenheit. Resistant Temperature Devices are used as the temperature sensors. Space sensors are equipped with set point adjustment and digital display while public area sensors are not to be adjustable. All dampers and vanes shall be horizontally oriented parallel airfoil blades.

The operator of the system has many of the system features displayed in real time to troubleshoot and monitor proper operations. The status of the rooftop units, fan coils, and supply fans are displayed at the work station. Sensors also show whether the system is operating correctly by providing pressure differential, supply air temperature, return air temperature, as well as zone set and actual temperatures.

Rooftop Unit Operation

The 100% outdoor air rooftop units shall operate continuously when energized by the occupancy schedules. The units are controlled to provide 55 F to 70 F air based on the operation. All units operate with constant volume fans to ensure ventilation of the building. Anytime that the units are energized the enthalpy wheels shall be in normal operation. In case of power failure outdoor air dampers shall fail closed. All plenum zone supply and return air dampers shall fail as is. The cooling and heating coils within the unit are to be regulated by two way control valves to match the proper supply air leaving temperature.

The rooftop unit controls apply a variable supply air temperature based upon outdoor air temperature. When outdoor air temperatures are above 65 degrees, the compressors shall provide 55 degree air temperature. When the outdoor enthalpy exceeds that of the desired internal set point, the unit starts the dehumidification mode. The compressors are again energized and the hot gas reheat conditions the air back to the proper leaving temperature. The hot gas reheat is controlled to provide leaving unit temperature between 60 and 70 degrees. When outside air drops below 65 degrees, the heat is staged to provide leaving air temperature of 65 degrees.

Fan Coil Unit Operation

Fan coil units are used to recondition the air to improve thermal comfort to building zones. The fan coils are equipped with constant volume fans to ensure proper ventilation of all zones. Each fan coil is energized when the rooftop units are, based upon occupancy schedules. If the fan coil is not operating, the chilled water and hot water valves are closed.

The fan coil units have both hot and chilled water coils. These coils are regulated by two way modulating valves to provide the proper amount of heating or cooling load. At no time are both of the coils in operation simultaneously. The valves modulate to provide desired space temperature. In cases which more than one fan coil unit serves the same space the fan coils operate in parallel to produce the desired space temperature.

Supply Fan Operation

The supply fans to the basement operate continuously when scheduled. They are constant volume fans to provide proper ventilation to the storage and mechanical room spaces. The supply fans shall be equipped with heating coils. In the mechanical room, sensors are provided in the duct as well as in the zone. This ensures that the fan is supplying a minimum air temperature to prevent freezing and also attempting to condition the room properly when possible. The sensors trigger the operation of the heating coils to prevent the delivery of sub-freezing temperatures to the interior zones. The supply fans serving the storage areas also have duct sensors to ensure that the fans are not delivering air below freezing. In the case of the storage rooms, the zone sensor then controls the fan coil units to recondition the air.

<u>Design Ventilation Requirements</u>

The analysis of The New Learning Center slightly differs from a more conventional building because of where the mixing occurs in the system. Since the air mixing occurs in the mechanical closets where the fan coils reside, the closets themselves must be analyzed as their or single or multi zone systems. After that is finished, the fan coils can then be traced back to the AHU that serve them. The outdoor air requirement for these AHU's can be determined by the summation of the requirements for their designated fan coil zones.

Upon completion of the calculations, the requirements for the outdoor air delivered by the AHU's are compared to the design conditions. In this case, all of the units supply enough fresh air to meet and exceed code. All three Rooftop Units as well as the basement outdoor air plenum are sized properly. Therefore, the building as a whole has enough outdoor air supplied to properly operate and occupy The New Learning Center. This comparison is shown in brief in Table 1.

Table 1 – ASHRAE 62.1 Outdoor Air Compliance

Room	Calculated Min. OA (CFM)	Design OA (CFM)	ASHRAE 62.1 Code Verification
RTU-1	5995	6225	Verified
RTU-2	3105	6125	Verified
RTU-3	1528	1685	Verified
Basement Plenum	1711	2600	Verified

The analysis in this building is not only done for the AHU's, but also for each individual closet. These closets can be made up of anywhere from one to three fan coil units. There are 26 such mechanical closets in The New Learning Center. There are also 20 such zones that are served by console fan coil units only, all which comply. Of the 26 mechanical closet systems, only 5 do not meet code as the spaces were analyzed with ASHRAE and the assumptions made in this analysis. This does not make the design insufficient, it merely means that different assumptions, decisions, or functions were used in calculation. ASHRAE 62.1 has a chance to leave open the ability to assume various functions of the room depending on the owner's decisions, engineer's previous knowledge of occupancies, and a few other variations.

Two of the closets that were slightly short were in the basement, although the basement as a whole has enough outdoor air supplied. These zones may be short assuming that some of the extra outdoor air will be supplied to the corridor and transferred into the storage areas before being returned. This is not a very critical area since the occupancy of the entire basement is zero.

Two more of the closets that were slightly short of the calculated required outdoor air serve the large lecture space on the first floor. This is a situation that can be treated in several different ways. The large room has folding partitions that can split the room up into three smaller classrooms. If the occupancy and airflow is treated as three separate classrooms, the closets will have plenty of outdoor air. If the calculations are done as one large assembly area, the will be slightly short of the required outdoor air volume.

The final closet that is just shy of the calculated airflow serves a distance learning classroom on the third floor. As with the other space, if the airflow and occupancy is based as a regular classroom, the outdoor air is sufficient. However, if the room is calculated as if it is a lecture classroom, it comes up about 10% short.

Although there are a few discrepancies between the required outdoor air flow showed and the design, it does not mean there were any mistakes during design. With the proper assumptions and owner input, all of these calculations would be sufficient to supply all zones. The evaluation and verification of the Air Handling Units also suggests that the zones were calculated and designed properly. This building would absolutely exceed any code analysis.

Design Heating and Cooling Loads

To design and estimate loads for the Lutheran Theological Seminary at Philadelphia, The New Learning Center, the building needed to be modeled in a building energy simulation program. The program used for the analysis of this report was Trane Trace. The majority of the input data was taken from AHSRAE 90.1. ASHRAE gives the outdoor design conditions, lighting watts per square foot depending on function of the room, sensible load from people, and values of the building envelope. Occupancies for the rooms, schedules of room use, and sensible loads from equipment were taken from the design documents. All of the rooms, windows, exteriors, and other values were entered into the program. All of the rooms were then assigned to the proper system, and then the system assigned to the proper plants.

Upon further inspection, the air handlers were designed conservatively compared to the values given in the simulation. There was more than enough cooling capacity in the air handlers and the fan coils which they serve to cool the zones properly. The ventilation air quantity per square foot is the only place that the designed air handing units fell short of the simulated building. This is not an extremely large problem since all of the zones passed the minimum requirements of ASHRAE 62.1. The results for the cooling and ventilating of the three air handlers and plenum are shown Table 2, 3, 4, and 5.

Table 2 -

RTU-1 and Fan Coils	MBH of Cooling	MBH of Cooling
	Designed Load	Computed Load
Area	13970	13970
Cooling sf/ton	172.83	266.88
Supply Air cfm/sf	1.25	1.15
Ventilation Supply cfm/sf	0.45	0.46

Table 3 -

RTU-2 and Fan Coils	MBH of Cooling	MBH of Cooling
	Designed Load	Computed Load
Area	15723	15723
Cooling sf/ton	244.87	337.69
Supply Air cfm/sf	0.79	0.88
Ventilation Supply cfm/sf	0.39	0.43

MBH of Cooling MBH of Cooling

Table 4 -
RTU-3 and Fan Coils

	Designed Load	Computed Load
Area	6947	6947
Cooling sf/ton	252.80	388.64
Supply Air cfm/sf	1.18	0.78
Ventilation Supply cfm/sf	0.24	0.32

Table 5 -
Plenum and Fan Coils

	MBH of Cooling Designed Load	MBH of Cooling Computed Load
Area	11755	11755
Cooling sf/ton	524.39	636.36
Supply Air cfm/sf	0.64	0.46
Ventilation Supply cfm/sf	0.14	0.22

The next thing that had to be examined was the capacity of the heating and cooling plants. The peak loads of the systems were determined to properly size the chiller for cooling and the boilers for heating. Upon review the chiller was sized almost perfectly for the given building simulation. The two boilers together had more capacity that was needed for the heating of the building. This is due to the fact that the boilers were purposely oversized to be used in heating the future neighboring library as well. The results showing that the equipment is sized properly are in Table 6 and 7.

Table 6 -
Boilers

	Designed Load MBH	Computed Load MBH
Boilers (2)	1800	1648

Table 7 -
Chiller

	Designed Load Tons	Computed Load Tons

Chiller	150	147

This analysis shows that all of the mechanical equipment was designed to meet peak load. There is enough capacity from all major HVAC components to allow this building to function correctly. Extra information about loads and schedules are in Appendix D.

Energy Consumption and Operation Costs

To estimate the yearly energy consumption, operation costs, and emissions, Trane Trace is used to model and simulate the performance of the Lutheran Theological Seminary at Philadelphia. This energy data was based upon the input values from the design loads for the building. All of the mechanical systems, units, and efficiencies were input to make the model as realistic as possible.

The cost of energy was estimated due to the fact that the exact billing information was not made available. Energy companies have varying cost of energy structures, so the information was estimated and simplified for this analysis. The price of the estimated energy is shown in Table 8.

Table 8 – Cost of Energy

	Cost of Energy
Gas	$0.92 / therm
Electric	$0.13 / kWh
Demand	$8.65 / kW

The Lutheran Theological Seminary at Philadelphia requires not only an electric feed, but also gas for the boilers and the roof top units. At times it is good to have two feeds of energy, like in cases when the cost of one type of energy increases vastly. This allows the bills to stay slightly steadier. The problem is that when the cost of one type of energy decreases quickly, the benefits cannot be seen as much. Table 9 shows the breakdown of how much of each energy source is used per year to operate the building.

Table 9 – Energy Consumption per year by Source

Source	Electric kWh	Gas therms	% of Total Energy
Primary Heating	9,038.5	15,388.5	45.0%
Primary Cooling	60,350.3		5.9%
Fans and Pumps	335,730.5		32.8%
Lighting	166,922.7		16.3%
Total	572,042.0	15,388.5	100.0%

As shown in the table, therms is a significantly larger quantity of measure than kWh, greater by approximately ten times. This is the reason for a significantly larger portion of energy consumed by the heating sources than by the cooling. The fact that the building is in a colder climate in Philadelphia, rather than somewhere in the southern United States, also plays a great role in the sizing and energy use.

An extensive energy analysis was not done during the design process for the Lutheran Theological Seminary at Philadelphia. There was no need for simulation since the owner and engineer knew what system they wanted to implement ahead of time. The system for The New Learning Center ties in very well with the neighboring buildings and other buildings on the campus.

Although the energy consumption is good information to have during the design process, there is another reason that the building model is simulated. When performance of a structure is analyzed, it is possible to also figure out the yearly emissions from the operation of the building. Usually the emissions information is broken down into four categories, CO_2, SO_2, NOx, and particulates. The amount of yearly emissions of these pollutants is shown in Table 10.

Table 10 - Emissions

Pollutant	Emissions lbm / year
CO_2	1,001,358
SO_2	4,315
NO_x	2,942
Particulates	367

The yearly operation is not only simulated to figure out the amount of energy and the emissions, but also to simulate the annual cost for the owner. With the knowledge of energy consumption per year, where in the system it is consumed, and the cost per energy unit, it is possible to figure out the cost of each piece of equipment. The cost of operation is modeled after the percentage of energy that is consumed by each of the system components per year. That is the reason for the operation of the heating equipment being the most expensive, while the cooling equipment is the least. The cost breakdown is shown in Table 11.

Table 11 – Cost of Equipment Operation

	Calculated Cost of Operation

Boilers	$34,725.60
Chiller	$4,552.91
Fans / Pumps	$25,311.10
Lights	$12,578.38
Building Operation per Year	$77,168.00
Building Operation per sf	$1.38

Some systems are more energy efficient than others. With the modeling and simulation of a building before design, the engineer can more easily assess what would be the correct system for each building if the construction and initial cost permits. Not only is saving energy good for the environment, it also reduces the amount of emissions and saves the owner money on energy bills for the life cycle of the building. As always though, the most energy efficient system and best design is quite often turned down due to the larger initial cost. One type of building that would usually be willing to pay more for the initial cost of mechanical equipment is a building like this, which the builder will also be the owner until the building is demolished. This is one reason that energy was saved by design methods like the heat recovery wheels installed in the air handling units.

Mechanical System Critique

The New Learning Center is designed to maximize thermal comfort, ventilate properly, as well as being energy and cost efficient. Overall, this was a very sensible design that was implemented. The system seems to be designed in a way that almost all spaces are comfortable and properly ventilated. There have been no complaints yet to suggest that the mechanical system in the building is not operating correctly.

Air System Analysis

The way The New Learning Center was redesigned put the engineer in a bind from the beginning, due to the fact that the plenum heights were very shallow. The system must be selected in a way from the beginning that would accommodate this issue. This is a reason why the engineer elected to design a dedicated outdoor air system (DOAS) in order to reduce duct size. This DOAS system consists of three rooftop units. The rooftop units are made to be energy efficient by the enthalpy wheel included in each unit. The enthalpy wheel helps not only with preheating and precooling, but also helps with controlling the amount of moisture in the air stream. These rooftop units have direct expansion (DX) cooling, gas-fired heating, and hot gas reheat. The hot gas reheat is the hot fluid left after passing through the cooling coil, which makes the reheat essentially free. There is no further energy consumption needed to run the hot gas reheat. With the fact that an air cooled chiller was installed, the use of chilled water in the rooftop units may not save a substantial amount of energy. The difference of efficiency between the boilers and a gas fired unit is also minimal, to suggest that that use of a hot water coil would not save energy either.

Fan coil units are designed to be part of the system for local thermal comfort and control. The temperature of the supply air can be controlled by thermostats to ensure that all occupants are satisfied. The fan coil units are placed in closets due to the lack of plenum space, which was a good design idea by the engineer. The outdoor air is then assumed to be perfectly mixed with the return air to supply the correct amount of fresh air to each of the fan coils. Although this assumption meets code, the outdoor air could have been ducted to the fan coils to insure correct ventilation. The reason it was not ducted was that it was not necessary, it would have increased initial cost, and it would have further cluttered the fan coil closets. The fan coil units are energy efficient with the reconditioning of the air. The use of a central hot water and chilled water plant has a larger initial cost, but the energy savings will make for a short payback period. The assurance that the Theological Seminary at Philadelphia will own and operate the building for a long time makes the higher initial cost worthwhile.

The basement is ventilated by fans that supply minimum outdoor air to the fan coil units. There are also heating coils in the supply air stream that prevents the supply of freezing temperatures to the basement. There is no problem with a lack of ventilation in the basement. The problem with this design is that there is no cooling capacity in the ventilation air streams. Heating and ventilating is all that is required by code, but the lack of cooling ability has a huge effect on humidity control. With no cooling coil, the air can not be dehumidified before being supplied to the fan coils. If there is no cooling load, the space sensors do not properly control the fan coil units to dehumidify the zones properly. This is an issue that should be addressed since humidity problems have already been reported.

The engineer made a good decision by ducting the supply air all the way to the diffuser. With the shallow distance in the ceiling, the plenum could be used as a supply air plenum. However, this would not allow for increased control of thermal comfort in spaces through adjustable thermostats. The plenum is being used in this design as a return plenum, which impacts the zone temperature less than the cavity being used as a supply plenum. Ductwork would be needed for either the supply or return air, so it makes sense to duct the supply air directly to the zone.

Water System Analysis

The schematic design of the chilled water system works well with the operation of the building. The primary loop ensures that the chiller is constantly supplied with the designed 255 gpm to ensure maximum efficiency. The secondary loop is then designed with a variable volume pump to allow for the varying capacity needs of the fan coil units. The problem with the design is that the secondary loop pump is oversized. It needs to be sized with a maximum of 255 gpm but is for some reason sized at the connected load 360 gpm, rather than the block load. This over sizing will affect the initial cost and the efficiency of the motor. The backup pump was also sized to maximum capacity so it could be substituted for both pumps in case of failure or repair, which means this pump is also over sized. Since the chiller plant is already installed to serve the fan coil units, the chilled water could also be supplied to the rooftop units for cooling capacity. Due to the fact that the chiller was selected to be air cooled, the plant may be properly sized for only the fan coils, not incorporating the rooftop units. The cost of piping, freeze protection, pumps, and energy to transport the chilled water might outweigh the benefits of having one way that all of the cooling capacity is supplied to the building. The choice of selecting an air cooled chiller rather than a water cooled chiller also keeps the initial cost low.

The hot water system in The New Learning Center seems to be designed well. The two pumps in the primary boiler loop are constant volume to ensure the boilers receive the designed 120 gpm each, which makes them more efficient and eliminates potential shocking of the boilers. The higher temperature loop is correctly designed with constant volume pumps since the radiation elements it serves have the capability for bypass. The lower temperature loop that serves the fan coil units is designed as variable volume pumps. This is designed correctly since the heating capacity can vary for the fan coil units. Since this boiler plant is already installed, the hot water system could also have been designed to account for hot water heating coils in the rooftop units. Upon further investigation, it seems that the initial design may be better. This redesign would require the initial cost of variable volume pumps to deliver the correct amount of heating capacity to the rooftop units as well as piping. The initial cost may increase as well as the efficiency of the rooftop units varying by such a small amount that the payback period would be nonexistent.

Appendix A

LTSP Chilled Water System Components

Air Cooled Chiller Schedule									
	Capacity	Evaporator				Compressor			
No.	tons	GPM	EWT	LWT	PD	Type	kW	kW / ton	Referig.
1	150	255	42	56	18.4	Screw	188.6	1.273	R - 134a

Split System Air Conditioning Unit Schedule											
	Air Handling Unit					Condensing Unit					
		TOTAL	EAT				Comp	Comp			
No.	CFM	MBH	DB / WB	MCA	MOA	Tag	QTY.	RLA	MCA	Tons	EER
1	750	23.6	80 / 67	1.5	15	CU-1	1	9.6	13	2	10
2-1	600	17.1	80 / 67	1.5	15	CU-2	1	7.8	8.4	1.5	10
2-2	310	11.2	80 / 67	0.8	15						
3-1	310	11.3	80 / 67	0.8	15	CU-3	3	4.8 (EA.)	16.6	3	10
3-2	310	11.3	80 / 67	0.8	15						

LTSP Hot Water System Components

Boiler Schedule									
		Burner			Capacity				Gas
No.	Type	Fuel	HP	MBH	Gross	Net	HP	Fan HP	Volume
1	Forced Draft	Gas	43	1800	1440	1250	43	1/2	728
2	Forced Draft	Gas	43	1800	1440	1250	43	1/2	728

Unit Heater Schedule									
					Fan		Water		
No.	Type	MBH	EAT	LAT	CFM	HP	GPM	EWT	PD
B-1	Horiz Prop	10.1	60	86	350	9 Watt	1.5	200	0.05
1-1	Wall Cabinet	42.1	60	116	685	1/10 & 1/15	6	200	2.25
1-2	Floor Cabinet	35.9	60	125	505	1/10	4	200	1.1
1-3	Horiz Prop	78.4	60	100	1800	1/10	7.9	200	0.36
3-1	Floor Cabinet	34.1	60	122	505	1/10	3	200	0.63
3-2	Floor Cabinet	27.5	60	123	345	1/10	4	200	1

Heating Coil Schedule

No.	Serves	CFM	EAT	LAT	MBH	GPM	EWT	WPD	APD
1	SF-1	1350	10	70	87.5	17.5	200	6.4	0.26
2	SF-2	1310	10	70	84.9	15	200	4.6	0.25
3	SF-3	2350	10	70	152.5	29	20	3.4	0.46

Hydronic Radiation Schedule						
				Element		
No.	Type	MBH	GPM	L (ft)	W (in)	H (in)
1	Base Element	9.6	1	10	3/4	3/4
2	Pedestal	2.9	1	3	3/4	3/4
3	Base Element	1.9	1	2	3/4	3/4
4	Pedestal	3.7	1	4	4 1/4	3 5/8
5	Base Element	6.7	1	7	3/4	3/4
6	Pedestal	9.9	1	7	4 1/4	3 5/8
7	Pedestal	1.9	1	2	3/4	3/4
8	Pedestal	3.7	1	4	4 1/4	3 5/8
9	Pedestal	2.9	1	3	3/4	3/4

LTSP Air System Components

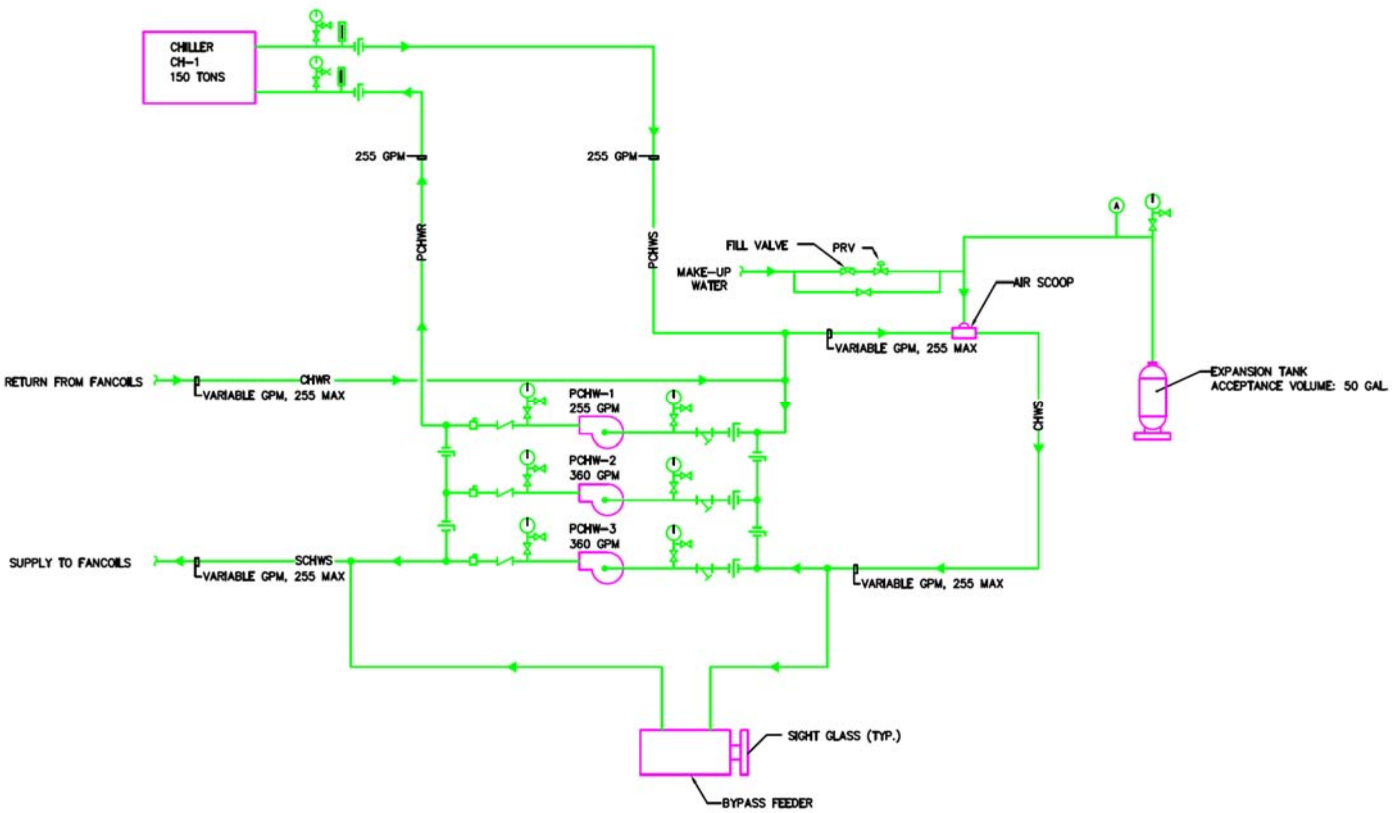
Gas-Fired Rooftop Air Conditioning Unit Schedule																
	Fan				Cooiling Capacity				Heating Capacity					Heat Recovery Wheel		
	Total	OA			Total	Sensible	EAT	LAT		Total	Sensible			Cooling	Heating	
No.	CFM	CFM	ESP	HP	MBH	MBH	DB / WB	DB / WB	Fuel	MBH	MBH	EAT	LAT	LAT	LAT	EER
1	6225	6225	1.5	10	322	200	85 / 71	55 / 54	Gas	270	219	45	77	85	45	10.3
2	6125	6125	1.5	10	320	199	85 / 71	55 / 54	Gas	270	219	45	78	85	45	10.3
3	1685	1685	1.5	3	101	62.9	85 / 71	52 / 51	Gas	90	72.9	25	68	85	25	10.3

Fan Coil Unit Schedule																
		Fan				Cooling Capacity						Heating Capacity				
		Total	OA		Total	Total	Sensible	Water					Water			
No.	Type	CFM	CFM	ESP	HP	MBH	MBH	GPM	EWT	LWT	WPD	MBH	GPM	EWT	LWT	WPD
B-1	Ducted	1215	360	0.25	1/4	43.3	30.4	12.5	45	55	11.2	33.9	1.5	180	160	1.8
B-2	Ducted	1565	360	0.25	1/2	46.7	35.8	8.5	45	55	3.1	50.9	3.5	180	160	9.4
B-3	Ducted	1565	350	0.25	1/2	48.2	36.5	9	45	55	3.6	40.6	1.5	180	160	2.6
B-4	Ducted	1750	120	0.25	1/2	65.4	45.4	16.5	45	55	10.9	65.8	2.5	180	160	2.1
B-5	Ducted	1750	120	0.25	1/2	65.4	45.4	16.5	45	55	10.9	65.8	2.5	180	160	2.1

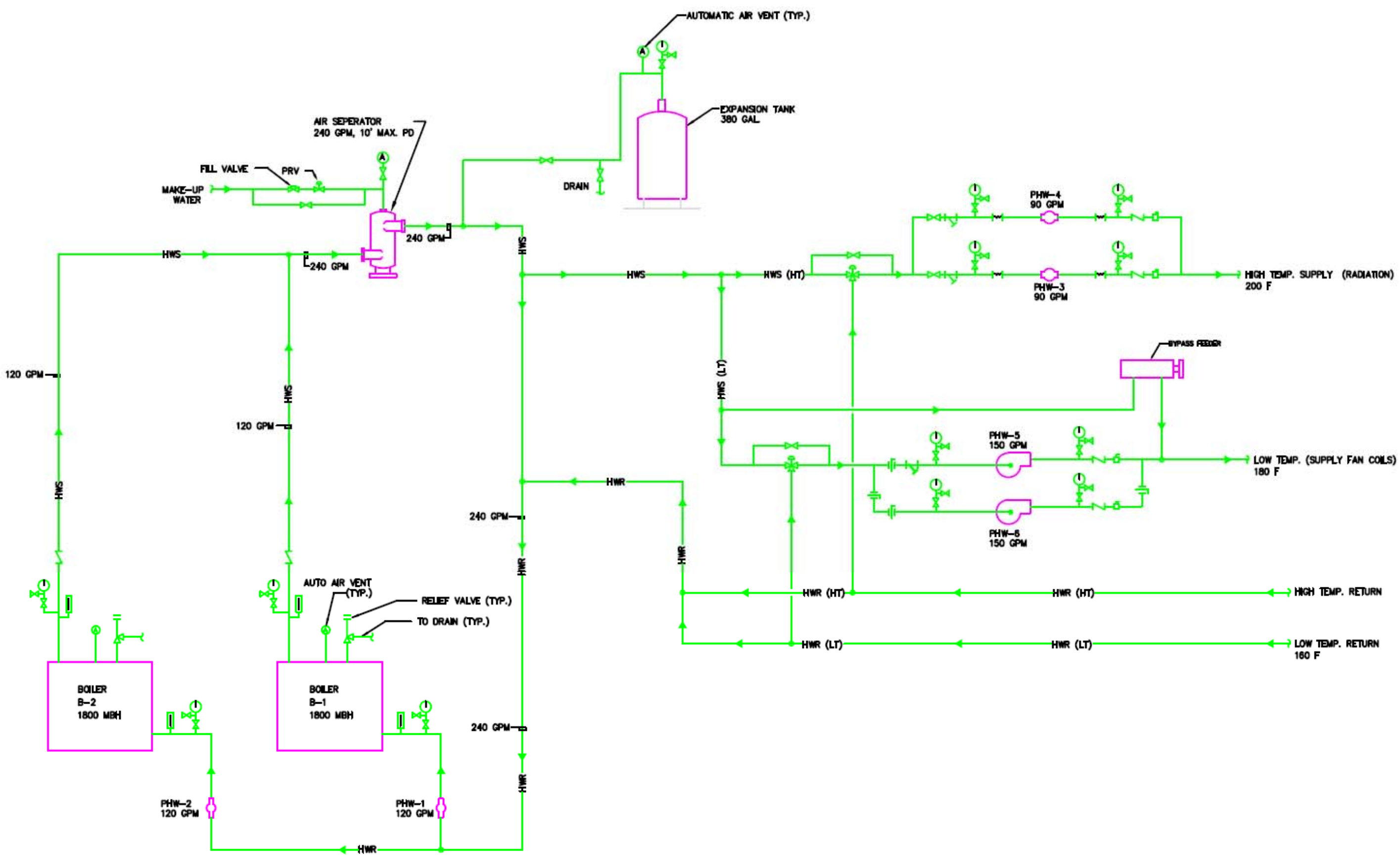
1-1	Ducted	1750	-	0.25	1/2	67.1	46.2	18.5	45	55	13.1	90.8	5	180	160	8.9
1-2	Ducted	1675	-	0.25	1/2	62	42.8	17.5	45	55	10.4	55.1	3.5	180	160	11.8
1-3	Ducted	1565	-	0.25	1/2	55	39.5	14.5	45	55	7.3	50.2	3	180	160	8.4
1-4	Ducted	1565	-	0.25	1/2	55	39.5	14.5	45	55	7.3	50.2	3	180	160	8.4
1-5	Ducted	930	-	0.25	1/4	35.4	24.2	15	45	55	13.4	35.4	1.5	180	160	0.4
1-6	Ducted	930	-	0.25	1/4	35.4	24.2	15	45	55	13.4	35.4	1.5	180	160	0.4
1-7	Ducted	895	-	0.25	1/4	39.2	26.1	8.5	45	55	7.8	28.9	2	180	160	2.5
1-8	Ducted	1750	-	0.25	1/2	70	47.5	24	45	55	19.1	101	8	180	160	21.2
1-9	Ducted	1215	-	0.25	1/4	39.5	28.7	8.5	45	55	6.3	33.9	1.5	180	160	1.8
1-10	Console	385	70	0.05	1/6	13.6	9.6	3	45	55	14.5	18.8	4	180	160	8.4
1-11	Console	235	20	0.05	1/12	9	6.1	2	45	55	10.3	12.2	4	180	160	6.6
2-1	Ducted	1575	-	0.25	1/2	72.2	47.5	16.5	45	55	9.5	48.6	3	180	160	7
2-2	Console	420	80	0.05	1/6	16.3	9.4	9	45	55	13.2	20	4	180	160	12.1
2-3	Console	420	80	0.05	1/6	16.3	9.4	9	45	55	13.2	20	4	180	160	12.1
2-4	Console	420	80	0.05	1/6	16.3	9.4	9	45	55	13.2	20	4	180	160	12.1
2-5	Console	420	80	0.05	1/6	16.3	9.4	9	45	55	13.2	20	4	180	160	12.1
2-6	Ducted	895	-	0.25	1/4	37.9	25.5	7.5	45	55	6.5	23.6	1	180	160	0.8
2-7	Ducted	555	-	0.25	1/4	19.6	14	7	45	55	4.7	12.8	0.5	180	160	0.1
2-8	Console	385	80	0.05	1/6	14.9	10	4	45	55	8.5	18.8	4	180	160	8.4
2-9	Console	385	80	0.05	1/6	14.9	10	4	45	55	8.5	18.8	4	180	160	8.4
2-10	Ducted	930	-	0.25	1/4	33.5	23.4	11	45	55	8.3	35.2	1.5	180	160	0.4
2-11	Ducted	1360	-	0.25	2/5	45.1	32.5	10.5	45	55	8.7	40.1	2	180	160	3.6
2-12	Console	290	20	0.05	1/6	9.2	6.1	2.5	45	55	3	11.8	1.5	180	160	1.9
2-13	Console	290	20	0.05	1/6	9.2	6.1	2.5	45	55	3	11.8	1.5	180	160	1.9
2-14	Ducted	555	-	0.25	1/8	14.3	11.7	2.5	45	55	1	12.8	0.5	180	160	0.1
2-15	Console	290	20	0.05	1/6	9.2	6.1	2.5	45	55	3	11.8	1.5	180	160	1.9
2-16	Console	290	20	0.05	1/6	9.2	6.1	2.5	45	55	3	11.8	1.5	180	160	1.9
2-17	Console	290	20	0.05	1/6	9.2	6.1	2.5	45	55	3	11.8	1.5	180	160	1.9
2-18	Console	290	20	0.05	1/6	9.2	6.1	2.5	45	55	3	11.8	1.5	180	160	1.9
2-19	Console	290	20	0.05	1/6	9.2	6.1	2.5	45	55	3	11.8	1.5	180	160	1.9
2-20	Ducted	1215	-	0.25	1/4	40.3	29.1	9	45	55	7.1	38.5	2.5	180	160	4.3
2-21	Console	290	20	0.05	1/6	9.2	6.1	2.5	45	55	3	11.8	1.5	180	160	1.9
2-22	Console	290	20	0.05	1/6	9.2	6.1	2.5	45	55	3	11.8	1.5	180	160	1.9
2-23	Console	290	20	0.05	1/6	9.2	6.1	2.5	45	55	3	11.8	1.5	180	160	1.9
2-24	Console	245	20	0.05	1/6	10.8	6.8	3	45	55	4.6	12.8	4	180	160	7.9
2-25	Console	290	20	0.05	1/6	9.2	6.1	2.5	45	55	3	11.8	1.5	180	160	1.9
2-26	Console	180	20	0.05	1/12	6.5	4	1.5	45	55	5.4	9.5	3.5	180	160	5.2
3-1	Ducted	1465	-	0.25	1/2	69	44	18.5	45	55	10.2	44.9	2.5	180	160	5.8
3-2	Console	550	80	0.05	1/6	14.1	10.4	4	45	55	4.9	23.5	2.5	180	160	3.8
3-3	Console	550	80	0.05	1/6	14.1	10.4	4	45	55	4.9	23.5	2.5	180	160	3.8
3-4	Console	620	80	0.05	1/6	18.4	13.8	3	45	55	7.1	24.8	2.5	180	160	4.5
3-5	Console	620	80	0.05	1/6	18.4	13.8	3	45	55	7.1	24.8	2.5	180	160	4.5

3-6	Ducted	1700	-	0.25	1/2	78.2	51.1	13.5	45	55	8.2	53.8	3	180	160	10.5
3-7	Ducted	720	-	0.25	1/5	29.6	20.2	5.5	45	55	4	20.4	1	180	160	0.6
3-8	Ducted	290	20	0.05	1/6	9.2	6.1	2.5	45	55	3	11.8	1.5	180	160	1.9
3-9	Ducted	290	20	0.05	1/6	9.2	6.1	2.5	45	55	3	11.8	1.5	180	160	1.9
3-10	Ducted	1180	-	0.25	1/4	35.7	26.7	6.5	45	55	4.1	42.1	1.5	180	160	0.6
3-11	Ducted	1180	-	0.25	1/4	45.1	30.9	16.5	45	55	17.6	55	3	180	160	1.7
3-12	Console	245	20	0.05	1/6	10.5	6.7	2.5	45	55	3.7	10.7	1.5	180	160	1.6
3-13	Console	245	20	0.05	1/6	10.5	6.7	2.5	45	55	3.7	10.7	1.5	180	160	1.6
3-14	Ducted	1215	-	0.25	1/4	38.6	28.3	8	45	55	5.6	29.3	1	180	160	0.9
3-15	Console	550	80	0.05	1/6	14.1	10.4	4	45	55	4.9	23.5	2.5	180	160	3.8
3-16	Console	550	80	0.05	1/6	14.1	10.4	4	45	55	4.9	23.5	2.5	180	160	3.8
3-17	Console	290	20	0.05	1/6	9.2	6.1	2.5	45	55	3	11.8	1.5	180	160	1.9
3-18	Ducted	720	-	0.25	1/5	26.1	18.5	3.5	45	55	2.4	24.6	2	180	160	2.1
3-19	Ducted	515	-	0.25	1/8	17.4	13	2.5	45	55	1.4	15.6	1	180	160	0.5
3-20	Console	290	-	0.05	1/6	9.2	6.1	2.5	45	55	3	11.8	1.5	180	160	1.9
3-21	Ducted	1215	-	0.25	1/4	41.8	29.7	10.5	45	55	8.8	38.5	2.5	180	160	4.2
3-22	Ducted	895	-	0.25	1/4	36.7	25	7	45	55	5.6	30.3	2.5	180	160	3.6
3-23	Console	550	80	0.05	1/3	14.1	10.4	4	45	55	4.9	23.5	2.5	180	160	3.8
3-24	Console	550	80	0.05	1/3	14.1	10.4	4	45	55	4.9	23.5	2.5	180	160	3.8

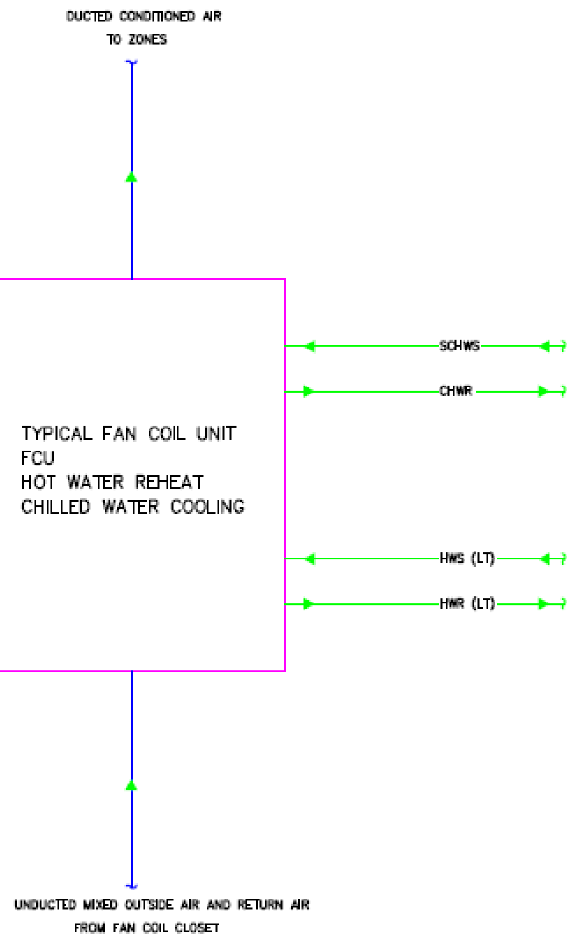
Appendix B



CHILLED WATER PIPING SCHEMATIC



HOT WATER SYSTEM SCHEMATIC



TYPICAL FAN COIL UNIT SCHEMATIC

Appendix C

Chiller COP

COP = Cooling Effect / Energy Input

Cooling Effect = 150 tons = 527.4 kW

Input = 1.273 kW/ton * 150 tons = 190.95

COP = 527.4 kW / 190.95 kW = 2.76

Boiler COP

Boiler Efficiency = Gross Output / Gross Input

Gross Input = 1800 MBH

Gross Output = 1440 MBH

Boiler Efficiency = 1440 MBH / 1800 MBH = .80 = 80%

Table 12 - LTSP WINDOW AREA

Room	Window SF
Basement	0
First Floor	2386
Second Floor	1033
Third Floor	1324
Total Window Area	4743
Total Vertical Wall Area	32623.5
% Fenestration	15%

Appendix D

LTSP SCHEDULES

Office

Function	Hour	% of Usage	Function	Hour	% of Usage
Lights	1	0	People	1	0
	2	0		2	0
	3	0		3	0
	4	0		4	0
	5	0		5	0
	6	0		6	0
	7	10		7	0
	8	50		8	30
	9	100		9	100
	10	100		10	100
	11	100		11	100
	12	100		12	100
	13	100		13	100
	14	100		14	100
	15	100		15	100
	16	100		16	100
	17	100		17	100
	18	50		18	30
	19	10		19	10
	20	0		20	0
	21	0		21	0
	22	0		22	0
	23	0		23	0
	24	0		24	0

School

Function	Hour	% of Usage	Function	Hour	% of Usage
Lights	1	5	People	1	0
	2	5		2	0
	3	5		3	0
	4	5		4	0
	5	5		5	0
	6	5		6	0
	7	10		7	0

	8	10	8	10
	9	80	9	100
	10	90	10	100
	11	90	11	100
	12	90	12	80
	13	40	13	20
	14	90	14	100
	15	90	15	100
	16	55	16	30
	17	5	17	0
	18	5	18	0
	19	5	19	0
	20	5	20	0
	21	30	21	0
	22	5	22	0
	23	5	23	0
	24	5	24	0

Table 13 –
LTSP Load Sources

Source	Sensible Load Btuh
People	250
Personal Computer	1000
Printer	5000
Coffee Maker	3000
Computer Server	3000
Kitchen Eq	As Specified

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