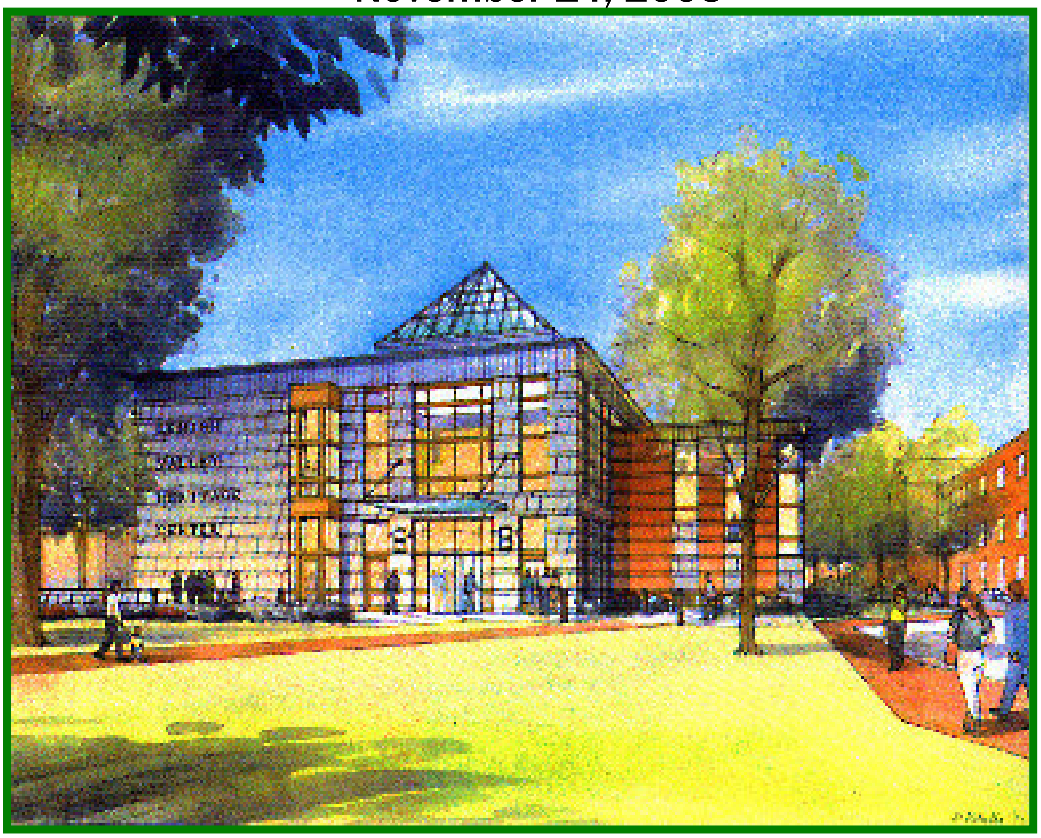
<u>Mechanical Systems Existing Conditions Evaluation</u>:

Mechanical Technical Report 3

Lehigh Valley Heritage Center

November 14, 2003



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Executive Summary

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In this report, the mechanical system of the Lehigh Valley Heritage Center is taken apart and evaluated through its different systems. The mechanical system is comprised of a chilled water loop with a chiller and air cooled condensing units. The chilled water serves the three air-handling-units and the fan coil unit. The condenser, located on the roof, has refrigerant lines running from the fans to the chiller, located in the basement. The hot water hydronic system contains two sources of hot water, two two-thousand MBH natural gas input boilers. The boilers serve the hot water coils to the air-handling-units, VAV boxes, duct coils, fin tube radiators, panel radiators and the fan-coil-unit. The hot water system contains pumps for the boilers, a primary pump and three circulation pumps for the branch circuits.

The air distribution systems are composed of the three air-handling-units, two roof-top-units, fan-coil-unit and an electric cabinet heater, along with the exhaust and outdoor air systems. The main transfer of heat occurs across the cooling coils for the hydronic systems and the electric element for the cabinet heater. The outdoor air fan systems draw in outside air for combustion of the boilers and steam generators and ventilation air for the air-handling-units.

Steam generators are utilized for humidification purposes only. There are two 238 MBH gas input steam generators located in the basement mechanical room that have a two steam injection manifolds that are placed directly in the supply air ducts of air-handling-units one and two. Since the steam is only used for humidification, there is no condensing piping other than the drain on the steam generator itself.

Schematic drawings of these systems were drawn on AutoCAD in a simple, concise manner. The schematics can be found in appendix A on page seven of this report. Please note that most details and information was left off of the drawings for simplification purposes and for clarity of the system design.

Controls were also discussed using the schematic diagrams. A basic overview of the systems operating characteristics was given explanation in the paper. The basic settings for the building included a Building Automation System which had two main settings, occupied and unoccupied. The unoccupied mode turned off the outdoor flow rates and the corresponding dampers associated with them. Three way and two way modulating valves controlled the water temperature into the hydronic systems which were monitored by differential pressure valves and thermostats. Low temperature, high temperature and smoke detectors were used in the air systems as safety measures in the events that the coils could freeze, no temperature control or a fire would be the potential hazards respectively. This BAS, incorporated with Direct Digital Control Panels, allows the occupants to determine and solve a problem in the system throughout various points in the system as well as an operator station display.

Throughout the paper the items being discussed includes design requirements, external influences on design, major hardware components, system configuration and operating characteristics. A critique is also given at the end of the paper discussing costs, space requirements, maintainability, environmental control and indoor air quality issues. Please note that some material is referenced from previous technical assignments which can be found on the same webpage as this report.

Design Objectives and Requirements

The Lehigh Valley Heritage Center consisted of two main design objectives. The first is to provide thermal conditioning for a comfortable environment as well as conditioning for human comfort and thermal loading. The second design objective is common for art museums and buildings that store artifacts, which is humidity control for art preservation. The requirements that correspond to these two main objectives are as follows: to provide the minimum, at the very least, of outdoor air quantities to the spaces according to the International Mechanical Code; to keep the spaces at design temperatures and conditions; to satisfy all loads that occur on and within the building; to provide a system(s) that will be able to vary its output according the load factors given at a certain time; to conform to local codes and regulations; to conform to the architect/owner's wishes; and, to allow the building occupant to control the system through an integrated yet simple control system. There are other factors, objectives and requirements that also constrain design conditions throughout the remaining systems of the building and reflect upon the mechanical design which will be discussed later.

Energy Sources and Rates for the Site

The Heritage Center had not been built yet. As of this date, construction has started on the site work, foundation and steel package of the project. No actual rates for the operation of the building exist at this stage because of the new construction. Through some research, potential rates were found for the energy sources of the building. The building will consist of two energy sources: natural gas and electricity. The electricity will likely be supplied by PP&L Co. Referring to technical assignment 2b, the rate of electricity for a mid size, secondary service, GS3 rate building is $0.0775 per kWhr. This value of electricity pricing was given by an employee of PP&L Co. via phone conversation. The natural gas will be supplied by UGI Utilities Inc. A rate of $0.52 per MCF was given via email. This value is new compared to the last submission of technical assignment 2b which gives a rate of $6.23 per Dekatherm of natural gas supplied by PP&L Co. Please note that no percentage due to inflation was given nor was there any demand charges given for the electricity rate.

Influential Cost Factors

The only cost factor that affected design, and is currently affecting the design, is the first cost factor. Minimum first cost is the major influence on design and even redesign when the project cost is exceeded. Although there are some incentives for using natural gas, no utility rebates were determined by choosing to use natural gas for the heating and steam generation systems of the building. According to the engineer, no other cost factors affected the design of the building mechanical system besides first cost.

Site Factors That Influenced Design

There are several on site factors that have influenced the design of the mechanical system. The largest factor that influenced the design is aesthetics. The architect originally did not want any equipment on the roof of the building. The building is proposed to be placed in a large lot that is currently owned by the Lehigh Valley Historical Society. Because of the "openness" of the site, the architect did not want any equipment "distorting" the view of the building as people are walking on site. Originally the building had all of its mechanical equipment in the basement, which consisted of nine air handling units for air distribution. After seeing the amount of space that the air handling units occupied and after several attempts to lay out the building to the architect's desire, an equipment well was placed on the roof for a limited amount of equipment. Another factor that influenced a couple of design parameters was location. The building is being placed in the city of Allentown, which, like many cities, has a higher crime and vandalism rate than the surrounding rural communities. Because of the risk of damaged or vandalized equipment, no equipment was placed on the grounds of the site or anywhere that it could be easily damaged. A second design factor that was influenced by the location of the building was the choice of utilizing natural gas for heating and steam generation. The engineer commented on the fact that natural gas is affordable, readily available and is easy to connect to in the city of Allentown.

Outdoor and Indoor Design Conditions

The Heritage Center is located in Allentown, Pennsylvania. According to The ASHRAE Fundamentals Handbook, 2001, the outdoor temperature in winter is five degrees Fahrenheit (DB) and in the summer is ninety degrees Fahrenheit. The design was based on the engineering firm's design standards which are, for summer, ninety-five degrees Fahrenheit (DB) and seventy-eight degrees Fahrenheit (WB). For winter, the standards are zero degrees Fahrenheit (DB). The indoor design standards are seventy-five degrees Fahrenheit (DB) and fifty percent relative humidity for summer periods and seventy degrees Fahrenheit (DB) with a relative humidity of forty percent in the winter time. These design conditions for the interior spaces are for general office areas. For the Heritage Center, there are several spaces that have specific climate control for preservation of artifacts. The Archival Storage, Museum Collections Storage and Negative Storage rooms all require a climate consisting of forty-five percent relative humidity (+/- five percent) at sixty five degrees Fahrenheit (+/- five degrees) dry bulb temperature. The Galleries, Reading Room, Archival Processing and Collections Processing rooms all require a climate of forty-five percent relative humidity (+/- five percent) at seventy to seventy-five degrees Fahrenheit dry bulb temperature. The building also contains a large glass lobby on the northern façade of the building. This large area of fenestration contributes a large load onto the building and has the potential to have condensate form on the glass in the winter. Panel heaters were placed along side of the windows to heat the air close to their surface so as to prevent condensation. The building uses a split portion of air and hydronic systems. Boilers supply the hot water while the chiller and air cooled condenser supply the chilled water. Steam generators provide the humidity control for the various spaces in the building by direct injection of steam into the supply ducts of air-handling-unit-one and air-handling-unit-two. VAV boxes serve as heaters to the spaces they serve. By not heating the air to ninety-five degrees, but to only fifty-five degrees, the boxes are not considered "re-heat" since they are acting as normal, primary heating elements, warming the air to ninety-five degrees. The roof-top-units are DX cooling units with hot water duct coil units located in the supply ducts directly below the units. The duct coil units serve as the heating elements to the outside air as it is entering through the roof-top-unit. These are just some of the equipment used to satisfy the indoor climate requirements.

Design Heating and Cooling Loads

The design cooling load was found to be approximately one-hundred-ten tons. This value was found by adding the cooling MBH's for the roof-top-units, the air-handling-units and the fan coil. These items, except for the DX roof-top-units, are the only items fed by the chilled water loop. The total load in MBH is one-thousand-three-hundred-twenty-four. The design heating load was found to be approximately one-thousand-nine hundred-six MBH. The value for the heating was determined by adding the heating loads for the air-handling-units, VAV boxes, duct coils, FCU, panel radiators, fin tube radiators and the cabinet heater. The heating load was computed over the heating coils of the devices. The values for the coil loads were found in the schedules which can be located in Appendix B.

Schematic Drawings

Schematic drawings can be found in Appendix A on page seven of this report. No schematics were found on the design plans. The schematics are simplified so that the system(s) can be easily understood and can be easily interpreted. The air systems show the air distribution units along with the fans and terminal equipment that branch from the main trunk. The combustion air schematic is very basic. The steam generators are used for humidification purposes only. There is no condensate in the supply duct that will be returned to the system, therefore there is no condensate shown on the schematic. The steam is used to keep the humidity level at the required level of forty five percent. The hot water schematic is condensed for simplicity because of repetition. There are fourteen panel radiators and nine fin tube radiators which were simplified into a single unit drawing to represent one of the groups in a typical application and setup. The drawings were limited in the setup of the controls and how they were linked into the Building Automated System (BAS) and Direct Digital Control Panels (DDCP's). The air separators, balancing valves, butterfly valves and condensate drains of the equipment were left out to make the schematic as simple and clear as possible. The expansion tank was never sized in the plans, but was labeled on a generic isometric of the boiler loop. No domestic water connection to the boilers or steam generators were shown either. All flow rates, temperatures, quantities, etc. that are shown on the schematics were taken directly from the plans.

Schedules

Schedules of major equipment can be found in Appendix B at the end of this report. All information for the schedules was taken from the plans. Some discrepancies were noticed as the schedules were being filled out. One is the fact that the flow rate through VAV 6 is incorrectly labeled in the schedule in the plans. The problem occurred when the VAV box was moved into the main trunk when, originally it was located in a branch off of the main trunk. Some other values were missing off the plans such as the min. outdoor air for the air-handling units.

Description of System Operation

The building is to be supplied with a BAS with a totally integrated system network (ISN). The building will also have DDCP's which will be placed around the building. For the hydronic heating, the BAS controls the water temp. by a linear relationship with the outdoor air. For $0<T_{oa}<60$: $T_{water} = 200 – T_{oa}$. The primary pump to the loop (Pump 3) will turn on either when the $T_{oa}<65$ Fahrenheit or when reheat is required due to dehumidification.

For the refrigeration cycle, the chillers are on alternating start-ups (first on, first off) so that the wear on the compressors is about equal for each chiller. The system starts and stops the chilled water loop, but an alarm will signal if the unit fails to start up. When the BAS indicates a cooling demand, it switches on the condensing units. In order to assure that the system is operating correctly; flow switches are placed to prove flow, which, if proven, will start up the refrigeration machine as well as the chillers when flow is proven to exist within the chillers. The system will maintain a constant leaving water temp. according to the outside air conditions that require a cooling demand. Temperature control activates the chilled water line when Toa>50 Fahrenheit, through which the refrigerant circuits are to maintain a chilled water temp. of 45 Fahrenheit. If this condition cannot be met, either another circuit must be energized or de-energized.

For the VAV's and AHU's the BAS starts the fan when the building is in the occupied mode. An alarm will sound if the fan fails to start or if the static pressure is too much according the differential pressure controls. When the fan has stopped the VFD should be set to the minimum so as not to burn out when the fan cycles back on. For freeze protection of the coils, there is a thermostat in the duct before the supply fan which has a set point of 37 Fahrenheit. If the temperature of the outdoor air is below the set point, the fan stops and the outdoor dampers close after which an alarm is sounded. For high temperature protection, a thermostat is placed in the return air duct. If the temperature of the returning air was above 300 Fahrenheit, the fan would stop and the outdoor damper would close after, again, an alarm is sounded. For smoke detection, a smoke detector/damper is placed in the return duct and between floor levels and fire rated walls. If any products of combustion are sensed, the fan is stopped and the dampers are closed.

The BAS also controls the mixed conditions of air according to the outdoor air conditions and required ventilation. If the building is occupied, being heated, Toa>Tra, or Hoa>Hra the outdoor air dampers are set to a minimum. When the building is unoccupied, the outdoor air and relief air dampers are closed.

The humidifiers operate continuously for the storage, reading and workrooms, as long as the humidity needs adjustment. Filters can become clogged or dirty and can create a pressure increase or decrease if the filter comes apart. When this occurs, the differential pressure controller will signal an alarm to a DDCP.

The majority of the building is based on occupancy, so the controls are either set to "occupied" or "unoccupied". For the hydronic heating elements and their valves, they are set so that if the building is in unoccupied mode which determines whether the fan will be on or off and consequently the return valve is either closed or open.

For the rest of the terminal units such as the cabinet unit heater, the units are run by the thermostat located in the room. The thermostat can modulate the control valve to determine the correct water temperature entering. This is the case for the panel radiators. For the fan coil unit, if the thermostat called for heating, the chilled water supply would close and the hot water supply be modulated. The same goes for cooling, the hot water supply would shut off, while the chilled water supply would be modulated. Both valves are closed when the unit switches from heating to cooling or vice versa (to prevent thermal shock).

The VAV's and terminal units with hydronic coils are controlled by the BAS which modulates the damper and coil control valve. As far as the outside air intake fans and exhaust fans, they only operate when the building is in occupied mode.

Operating History of the System

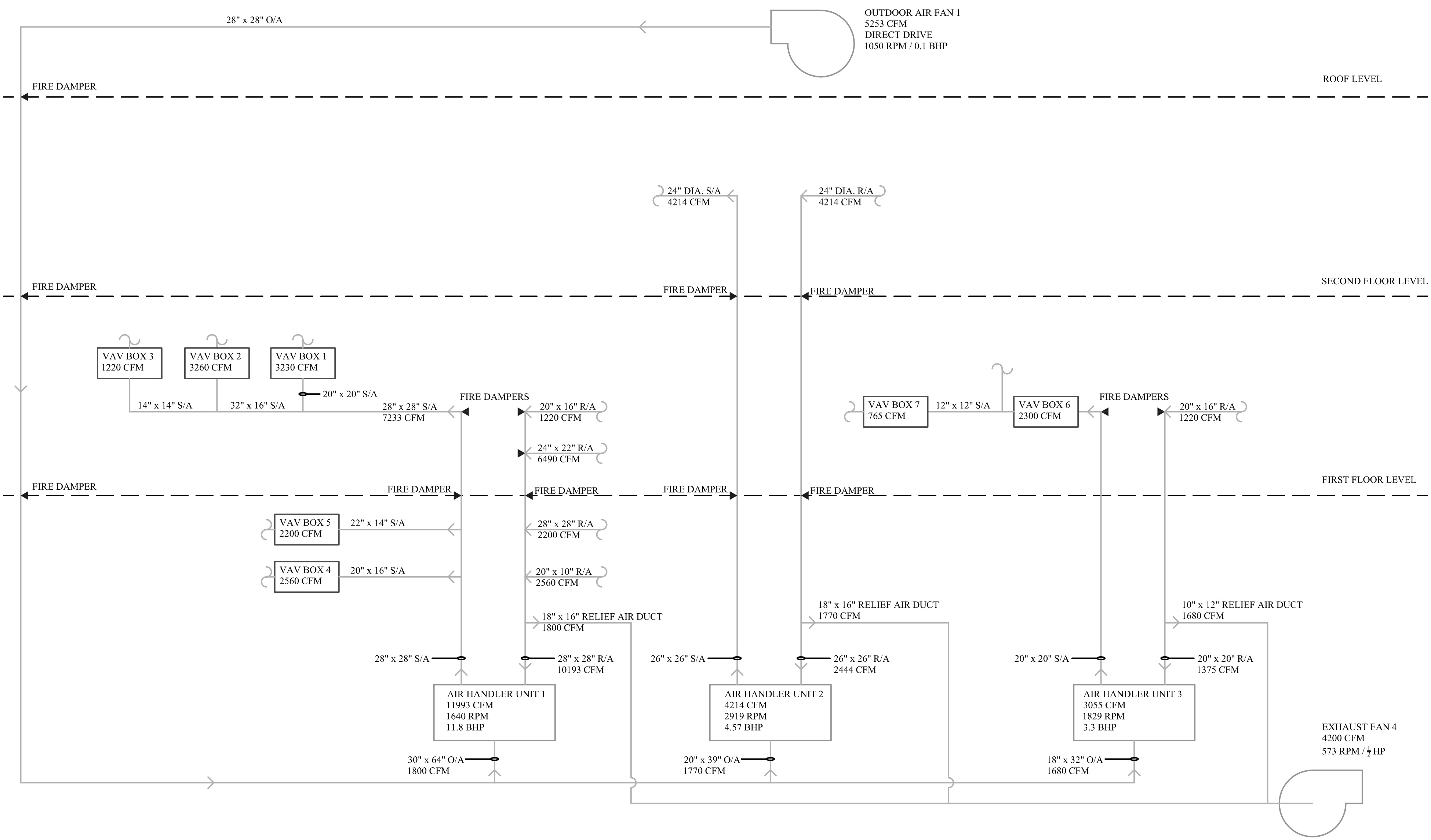
The building is brand new, and under construction as of this date. No information is available for the mechanical operating conditions.

Critique of System

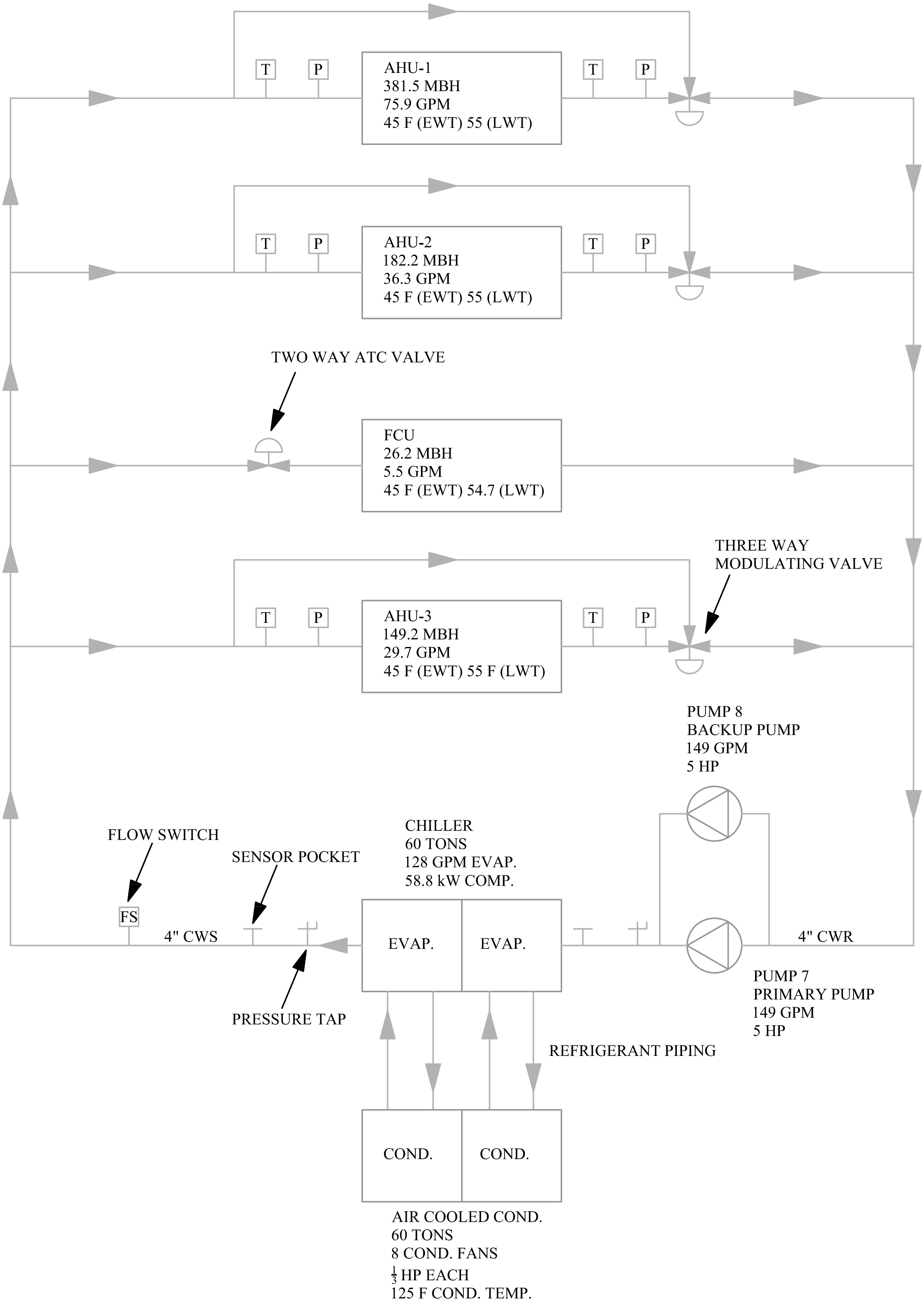
The only cost available to me at this time is the estimated total cost of $5.7 million, which was made back in January. Other cost information was given to the general contractor, but that information is not allowed to be distributed at this time. The same statement above is also valid for the operating cost of the systems. The only data obtainable is from the energy and load analysis performed for technical assignment 2b. The calculated value of the mechanical system is $33,148.00, but this is not totally accurate since it consisted of assumptions for the analysis of the building. I believe the cost of the mechanical system is much greater, probably by a factor of two to four. One way to reduce the cost is to reduce the amount of ductwork in the plenums. The ducts from the roof-top-units are extremely large, plus there seems to be quite a bit of "unused" space in the plenum of the second floor under the high roof. Maintainability and serviceability of the building seems somewhat reasonable. The large pieces of equipment are all accessible with enough clearance to remove the coils, etc. The only problem that I can see is the serviceability of the VAV boxes. Some are close to the walls, and the fact that there are nineteen boxes in the building. The balancing and adjusting of all the dampers and boxes will be tedious and time consuming. Also, the fact that the refrigerant lines are exposed outside on the roof poses a problem too. With exposed piping, there is a chance that the piping could get broken or even perhaps frozen in the winter time. One design parameter that the engineer was faced with was the problem of limited shaft space and the allowance of venting out the walls of the building. Environmental control is another concern with the building. No emissions were found for technical assignment 2b, so no comparison can be made on what the emission rate is and where it lies compared to similar buildings of its size. One thing that can be considered is lowering some of the power densities calculated in technical assignment 2a, that exceeded ASHRAE Std. 90. Another economic factor to be considered is the large glass lobby. A better glazed glass or even perhaps the new smart window technology could reduce the solar load on the building therefore reducing the cooling load and energy consumption on the roof top units. Indoor Air Quality in the building could be a special concern. As mentioned in technical assignment 1, there could be many different artifacts being brought into the museum which also means particulate matter or gasses. Also, the types of chemicals or cleaning processes could require a local ventilation system being placed in the building or perhaps and air cleaner. Also, for being located in the city of Allentown, there is more pollution due to emissions from cars and factories, which could also find its way to the outdoor air intake of the air handling and roof top units.

Appendix A

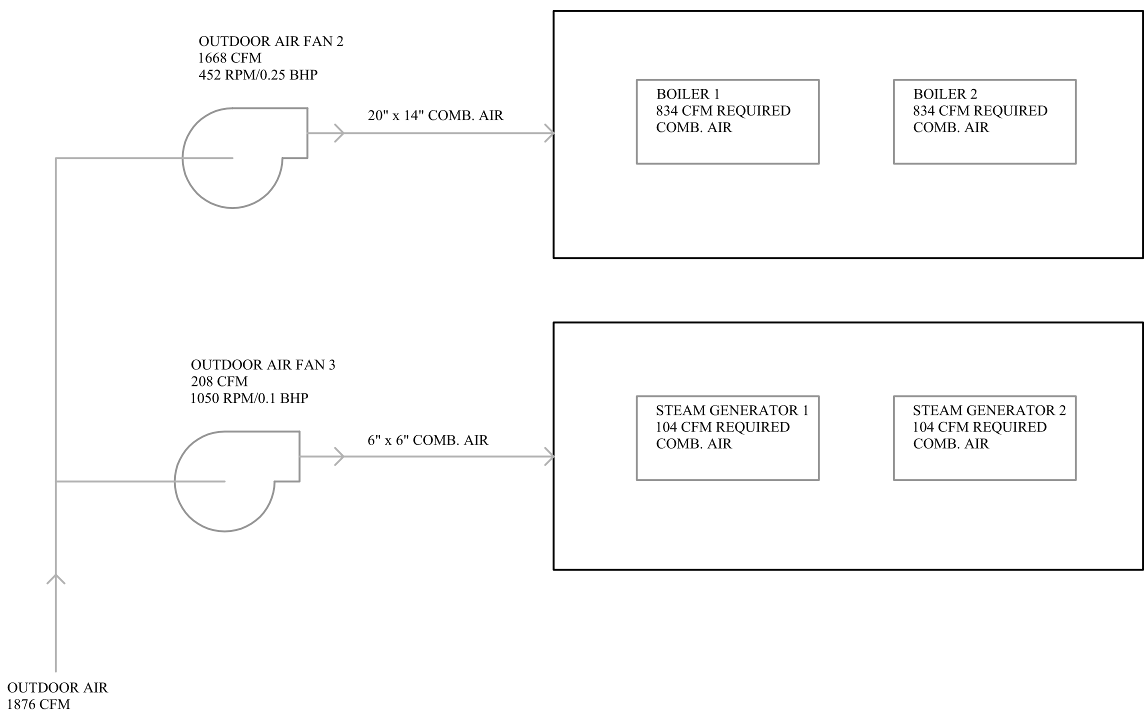
Schematic Diagrams of Mechanical Systems



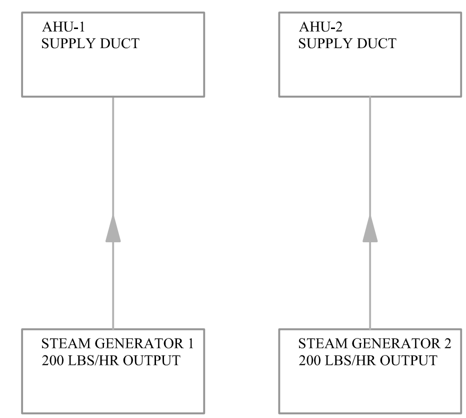
AIR HANDLING UNIT SCHEMATIC



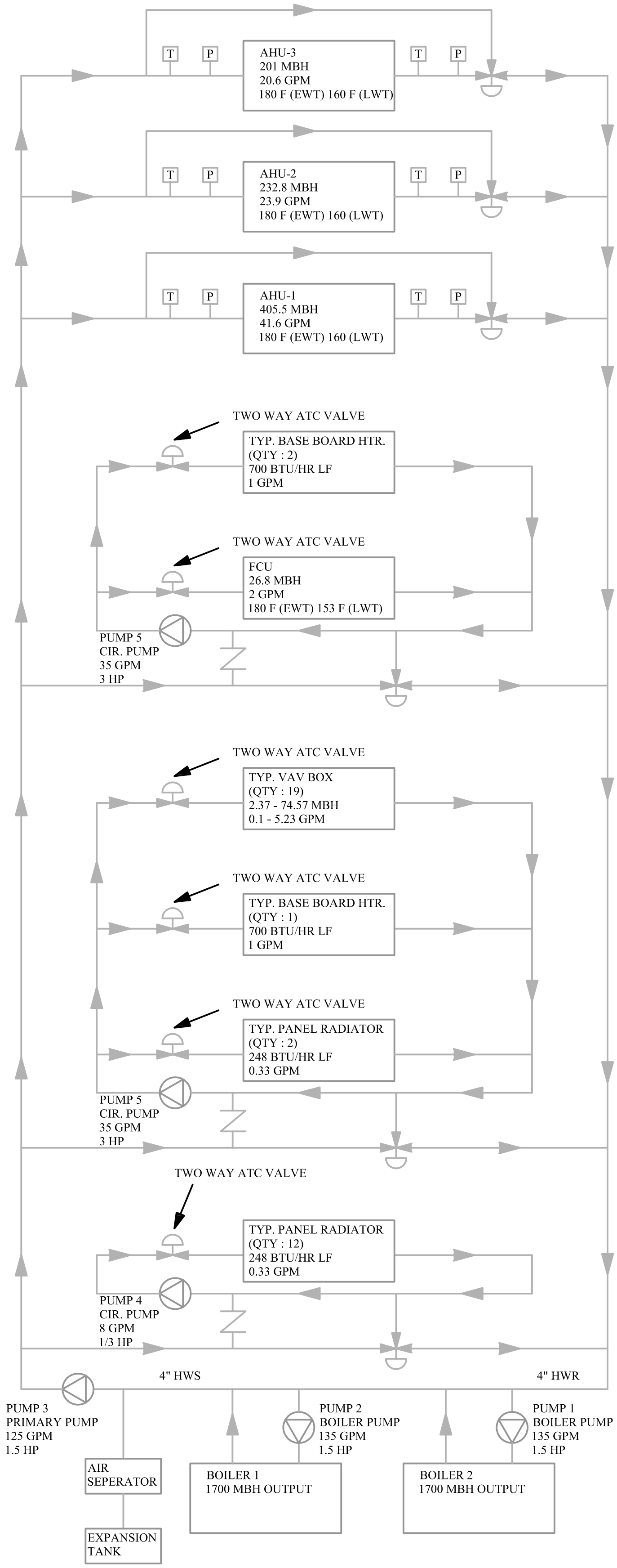
CHILLED WATER SCHEMATIC DIAGRAM



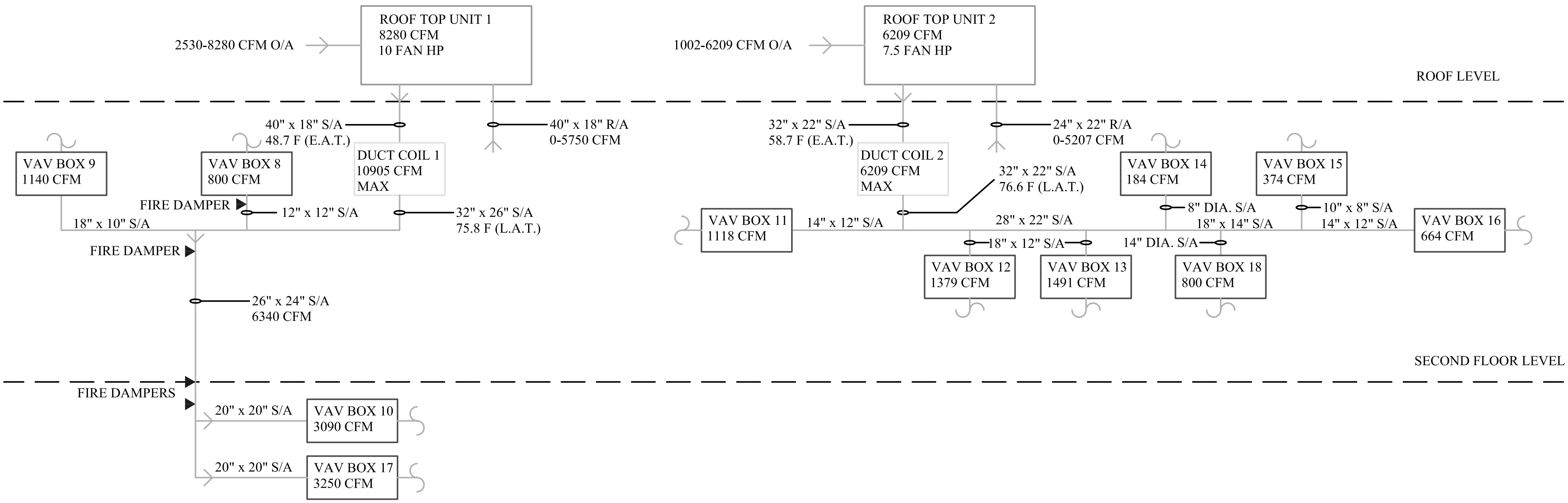
COMBUSTION AIR SCHEMATIC



STEAM GENERATOR SCHEMATIC DIAGRAM



HOT WATER SCHEMATIC DIAGRAM



ROOF TOP UNIT SCHEMATIC DIAGRAM