1.0 Building Overview

1.1 Site, Architecture, and Construction

The School District of Philadelphia (SDP) originally had employees in four different office locations. The administration had hopes in finding an existing building large enough to join together the employees scattered throughout the city. One of the main objectives was to move everyone into one building where it was easily accessed by both the employees and the public. This was accomplished by choosing a site which is very close to City Hall in downtown Philadelphia. The School District of Philadelphia Administration Headquarters (SDPAH) is now located at 440 North Broad Street.

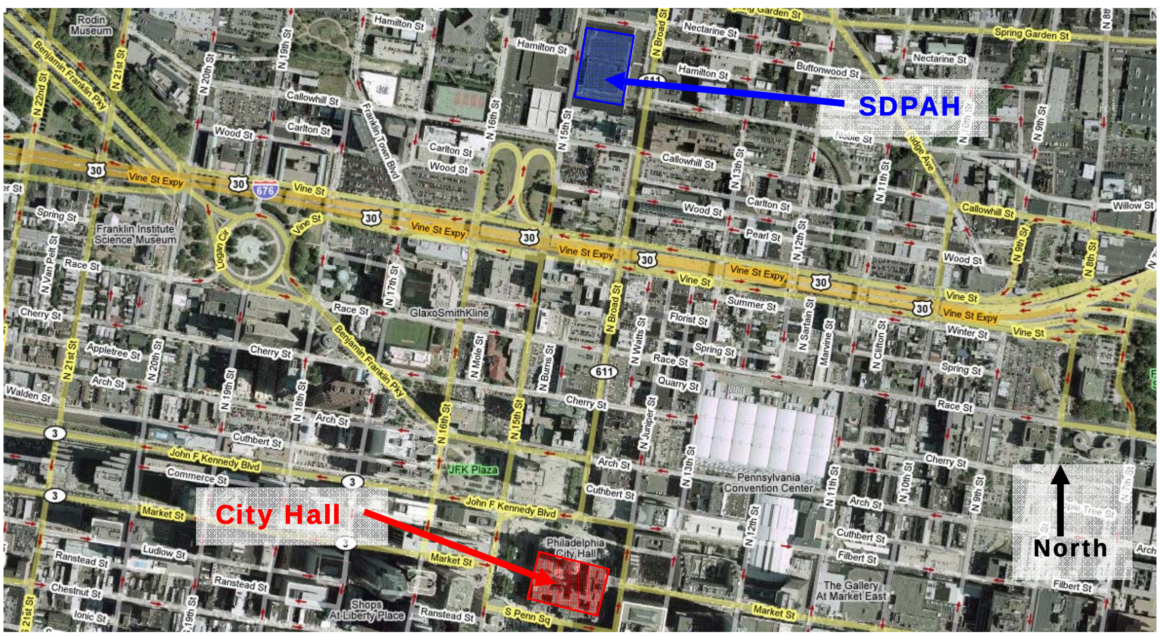

Figure 1.1A Map of 440 North Broad Street, Philadelphia, PA.

The building at 440 North Broad was originally built as a printing facility in 1948. Since then various newspapers and magazines have occupied the building and various additions have been completed. Because the original building was a printing facility, the floor to floor height is larger and helps with some other objectives: visual connectivity, natural light, and employee productivity. Since most would agree that natural light has a big impact on

Figure 1.1B. SDPAH New Atrium Space.

someone's mood and ability to produce, the architects focused on a central atrium space that provided connectivity between both the 15th Street and Broad Street entrances, making the space inviting to workers and guests. As can be seen in Figure 1.1B, the District has occupied the space and made it their own with flags of children and other pieces of artwork. The capped columns were left from construction as an architectural feature possibly to keep in mind the original purpose of the building.

Some of the architectural renovations which affected the engineering disciplines included new core toilet rooms, new elevator shafts, a new 3 story atrium, and new lobbies for the 15th Street and Broad Street entrances. Exterior renovations included new windows, curtain walls, entrances, and re-glazing.

The building footprint is approximately 161,000 square feet (SF) with a total measured gross area of 848,000 SF. It has six floors above grade including the Ground Level and Floors 1 through 5. About 440,000 SF of the gross area is office space (mostly open plan office space) and approximately 50,000 SF is a data center. The remainder of the space is storage area in the Basement Level. The focus of this report will be on the open office space within the building which is on Floors 1, 2, 3, and 5 and the data center on Floor 4.

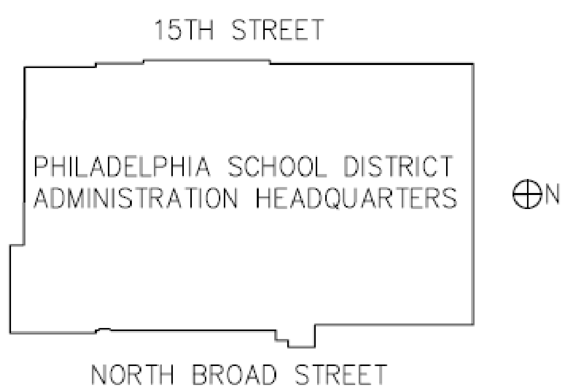

Figure 1.1C SDPAH Footprint.

Construction began on the existing structure in December 2003 with the shell and core mechanical renovation plans by **Cannon Design** from New York City. The shell and core renovation project team included Cannon as the mechanical engineers, **Thorton Tomasetti Group** as the structural engineers, **Gladnick Wright Salameda** as the site/civil engineers, **Turner Construction Company** as the general contractor, and **Hooper Shiles Architects** as the architect. The focus of this report is on the shell and core renovations with the exception of considering Floor 4 as a data center as mentioned above. As of November 2005, the fifth floor fit-out was still being completed. The building fit-out was completed by a different set of designers.

Figure 1.1D. Broad Street Entrance.

1.2 Engineering Overview

In the following paragraphs there are descriptions of the engineering systems currently in the building and the renovations that were implemented. The existing mechanical system description will include a more in depth explanation in the following section.

1.2.1 Electrical Engineering

Electrical Service

The electrical service is a high tension 13,200 volt service. The electrical service enters the building through a 12-way underground ductbank and terminates in a PECO cable vault at the mezzanine level. There are six cables connected to the existing distribution equipment and six designed for future use. The existing cables connected to Main Service 1B didn't have the capacity to accommodate the new loads for renovations. To increase the capacity of the existing service, a parallel set of 15 KV cables (same size, type, length) were installed to the double-end switchgear. Main Service 1B increased to 10MVA with primary select configuration.

Building Power

Existing Substation

An original 1500 KVA secondary unit substation is connected to the Main Service 1B, which steps down the voltage from 13,200 volts to 480/277 volt. This substation serves base building core loads: lighting, general receptacles, and emergency distribution panel. The existing emergency service is connected to a 150 KW diesel generator. The emergency loads are fire alarm, life safety, and passenger elevators PE-1 and PE-2.

New Substation

Power for the 1st through 5th floors office space is distributed from new substations, one substation providing power to the east electric closets and the other to the west electric closets. The two new 3000 KVA 480/277 volt secondary unit substations are connected to a 4000 amp bus duct riser. A 480/277 volt distribution panel and feeder is provided to each mechanical room. The mechanical panel provides power for HVAC equipment on the floor. Improvements on the 1st through 3rd floors include 500 amp, 208/120 volt main receptacle panel and on the 4th and 5th floors 400 amp, 208/120 volt two-section receptacle.

1.2.2 Lighting

Lighting panels are fed from the base building substations at 480/277 volt. Lighting panels for tenant improvements are located such that the maximum branch circuit length will be less than 150 feet. The shell and core design included general lighting provided for base building areas including MEP rooms, toilet rooms, vaults, loading docks, lobbies, entrances, and stair towers.

1.2.3 Plumbing

Domestic Water System

Renovations include a new 4-inch cold water riser to serve the new east end toilets, each riser provided with a 1-1/2-inch valved outlet at each floor for SDP use.

Hot Water System

Hot water for the Base Building core toilet rooms is generated by electric water heaters located above the ceiling of each core toilet room.

Storm Water System

Roof areas are provided with drains connected to leaders and horizontal storm piping to building storm sewers at 15th Street. All horizontal storm piping is insulated to prevent condensation.

Natural Gas

The original 3-inch gas service from Buttonwood Street is capped at the building control valve. This service would be kept open in a case where an alternative design with a gas fired boiler would be chosen.

1.2.4 Fire Protection

Designed for ordinary hazard (Group II) occupancy and complies with the latest Philadelphia Building Code, Fire Department, and NFPA 13.

Control System

Valves controlling the fire protection system are provided with tamper switches and water flow indicators connected to the fire alarm system.

Sprinkler System

The Base Building includes a wet sprinkler system for the Basement and Ground Floor Levels and there is also an existing pre-action sprinkler system located in the basement level. The sprinkler system in the load dock areas remained. Sprinkler protection is in all Base Building areas including mechanical rooms, storage areas, core toilet rooms, utility shafts, and elevator shafts.

Smoke Purge

A smoke purge system is required in the 3 story atrium. The three 20,000 cfm roof mounted exhaust fans with motorized dampers are capable of six air changes per hour.

Fire Alarm System

The fire alarm system is a modular addressable system which is expendable and consists of a central fire command center. The fire alarm systems consists of manual pull stations, elevator recall, sprinkler water flow detection, tenant terminal cabinets, HVAC equipment smoke detection and horn and/or strobe notification.

1.2.5 Structural Engineering

The original structure is in the center of the facility and is a reinforced concrete structure of primarily flat plate floor construction with some beam and slab areas.

The first addition to the north end of the main building occurred in the 1960s and is a structural steel frame with concrete slabs on metal deck. The second addition to the south end of the main building occurred in the 1980s and is a structural steel frame with concrete slabs on metal deck. Other modifications in 2001 include additions to the 2nd and 3rd floors using steel and concrete construction. Over time floor areas were infilled and reinforced to accommodate printing equipment.

Areas designated for office use have a minimum live load capacity of 125 psf, except a part of the 4th Floor where it is designated to accommodate 100 psf live load.

Column extensions and steel roof dunnage were provided to support the new cooling tower. All loads were transferred through the existing column extension.

If an alternative design is proposed where more rooftop mechanical systems will be needed, more structural considerations will be necessary.

1.2.6 Transportation

This table outlines the existing and new elevators in SDPAH. The transportation modes within the building are important to construction crews. Mechanical, electrical, lighting, and other equipment must be moved to the upper floors. *The freight elevators are a vital artery in moving materials throughout the building during construction.*

Existing Elevators	**Quantity**	1	1	2
	Weight Limit	20000 lbs	10000 lbs	3500 lbs
	Type	Traction-type freight elevator	Traction-type passenger/freight	Traction-type passenger elevator
	Location	North loading dock	Southwest core adjacent to the central loading dock	East Core
	Serves	Basement to the 3rd Floor	Basement to the 4th Floor	Basement to the 5th Floor/Broad Street Entrance Lobby
	Cab Size	11'4"W x 14'0"L x 9'0"H	7'8"W x 9'2"L x 9'0"H	6'3"W x 8'8"L
New Elevators	**Quantity**	1	2	2
	Weight Limit	10000 lbs	3500 lbs	3500 lbs
	Type	Freight lift	Traction-type passenger elevator	Traction-type passenger elevator
	Location	Southwest core, positioned adjacent to the existing 10,000 pound passenger/freight elevator which serves the Basement to 4th Floor	East Core	West Core/15th Street Entrance Lobby
	Serves	4th Floor to the 5th Floor	Basement to the 5th Floor/Broad	Basement to the 5th Floor
	Cab Size	7'8"W x 9'2"L x 9'0"H	6'3"W x 8'8"L	6'3"W x 8'8"L

Table 1.2A Existing and New Elevators.

1.2.7 Security

The entire building is secured and protected by a closed circuit television (CCT) and key card access. Access to the building is by card keys and all entrances are monitored by a CCT system reporting to a manned central security station at the Broad Street lobby. All stair towers and elevators are also controlled with card key access.

1.2.8 Lightning Protection

Lighting protection is provided at the medium voltage double-end switchgear as required by PECO. A lightning protection grid is provided on the roof.

1.3 Existing Mechanical System

The existing mechanical system utilizes direct expansion evaporative refrigerant coils in self contained packaged air handling units located in mechanical rooms in the core of the building. Parallel fan-powered variable air volume boxes satisfy perimeter heating needs and are located in the plenum above the spaces they serve. The air conditioning process occurs locally within the air handling units positioned throughout the building. *The following sections give the system details to establish a basis of comparison for alternative systems.*

1.3.1 Air Handling Unit Layout

The existing mechanical system in the SDP's new administration building consists of 17 new self-contained packaged air handling units by McQuay which provide 1500 tons of cooling. Each unit is located within mechanical rooms in the core space of the building. It is important to have a feel for how large the building is and for how much air conditioning each air handler must account for. For reference, a description of the existing air handling units and their nomenclature designations is provided in the following paragraphs. An example of the air handling unit (AHU) designations used in the existing design is 1.3, where 1 is the floor location and 3 is the unit, dedicated to a particular region of the floor.

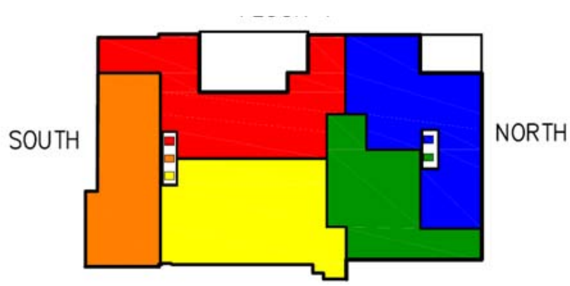

Figure 1.3A. Floor 1 Existing AHU Layout.

Floors 1 through 3 are broken up into north and south sections each with its own mechanical room. The **first floor** has three units in the south mechanical room and two in the north.

Floor 2 has two units in each the south mechanical room and the north mechanical room and the **third floor** has a total of 5 units, three in the south mechanical room and two in the north mechanical room.

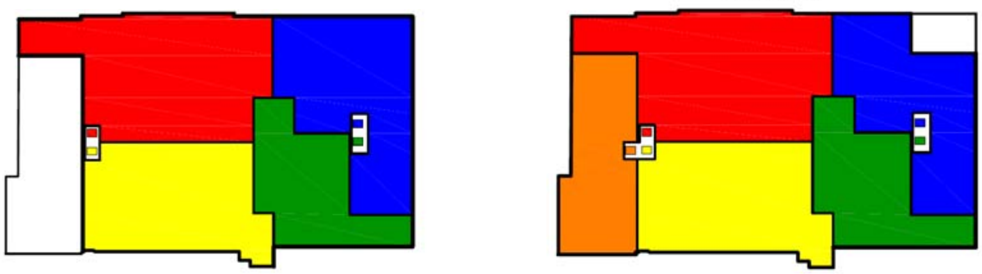

Figure 1.3B Floor 2 and Floor 3 Existing AHU Layout.

Floor 4 was designed to have one air handling unit serving the entire space which was originally thought to be open office. Because this space is currently being used for a data center, the load is higher and will require more conditioning. Two units serve the **fifth floor**, one serving the east wing and another serving the west wing.

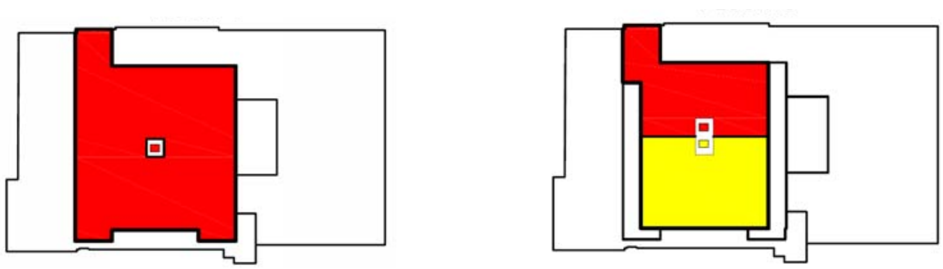

Figure1.3C. Floor 4 and Floor 5 Existing AHU Layout.

1.3.2 Cooling Process

The cooling process occurs locally within each air handling unit (AHU). Hot outdoor air is provided through a shaft by outdoor air fans located on the roof. The outdoor air is mixed in the mechanical room with return air at 75F which enters the mechanical room through a transfer duct from the plenum above the ceiling in the office space. Air first passes through a filter for cleaning. Each unit contains a direct expansion (DX) evaporative refrigerant coil which is used to remove heat from the mixed outdoor air and return air. The process starts as cool refrigerant enters the tubes of the DX coil. As the warm air flows over the coil, the cool refrigerant evaporates as it removes heat from the air. The air is cooled to 55F within the unit and supplied to the building spaces via parallel fan-powered variable air volume (VAV) boxes within the spaces. Spaces are supplied different quantities of air depending on the required cooling loads. After the refrigerant passes through the evaporator coil it is compressed and moved to the condenser where it is cooled by the condenser water. Condenser water is provided at 85F from a 1500 ton two-celled cooling tower located on the roof. Condenser water at 95F is returned to the cooling tower to start the process again. To see the internal layout of the air handler, see Appendix B.

Figure 1.3D. AHU Air Filter.

Waterside Economizer

The units are provided with a waterside economizer coil. When cooling is necessary in during the heating season and the entering condenser water temperature is sensed to be less set point temperature 55F a waterside economizer control valve is opened for condenser water to enter the economizer coil. The cold water cools the air thus giving “free cooling.” A Freezestat sensor is used to prevent freezing. If it senses potential for freezing the supply air fan turns off and an alarm sounds. The economizer valve is set to fully open and the system remains this way until it is reset.

1.3.3 Heating Process

Heating is usually required in perimeter spaces of open offices where the internal load of the building is not enough to satisfy the heating load requirement. The internal load of the building is due to people, lights, and equipment. For simplicity, it is assumed that the amount of people served by all air handlers in the Administration building is 100. People are a source of heat and contribute to reducing the required heating load. The air handlers used for cooling in the Administration building are located in mechanical rooms within the core of the building and thus contribute to the internal equipment load. The internal load due to lights and equipment is 6 watts per square foot (W/SF). Since the air handlers are located within the core of the building, they are a part of this 6 W/SF and act as a source of heat in the winter. If the internal load is combined and compared to the perimeter envelope load due to exterior window and wall heat loss, it can be found that the internal load is more than enough to take care of the heat losses of the building due to the exterior envelope. In fact, the internal load is so large that cooling is needed even during the heating season. See Appendix A for the sample space and coil load output from Trace, the modeling program used to simulate this system.

During heating season, return air is brought back at 70F and is mixed with cold outdoor air in the mechanical rooms. The return air quantity is much larger than the outdoor air so the mixed air is still warm and must be cooled to the supply temperature of 55F. Possible cold spots along the perimeter must still be accounted for. If the room temperature falls below the room heating thermostat, heating will be required in the parallel fan-powered VAV boxes. In this case, the return air passes through the VAV box and does not go back to the air handler. Warm air from the plenum is passed directly through the VAV boxes for heating by electric heating coils to bring the space temperature above the room heating thermostat again.

1.3.4 Ventilation Analysis: ASHRAE Standard 62.1 Addendum N

Standard 62.1 establishes minimum requirements for outdoor air ventilation within buildings. The original design ventilation airflow quantity was calculated using a rate of 20 cubic feet per minute (CFM) per person in the Trace model. This was based on ASHRAE Standard 62.1 prior to Addendum N. The ventilation actually supplied was 10 percent of the required supply air. New ventilation requirements were calculated based on the new

New Designation	Addendum N Std. 62.1/Latent Load Req.	Actual Occupancy	Existing Designation	Design Occupancy	10% SA	Overdesign Percentage
FLOOR 1						
FL-1 NE	2500	100	1.4	100	2800	12.0%
FL-1 NW	2500	100	1.3	100	2800	12.0%
FL-1 SE	2500	100	1.2	100	2800	12.0%
FL-1 SW	2500	100	1.1	100	2800	12.0%
FL-1 T	2700	100	1.5	100	2800	3.7%
FLOOR 2						
FL-2 NE	2800	100	2.4	100	3150	12.5%
FL-2 NW	2800	100	2.3	100	3150	12.5%
FL-2 SE	2800	100	2.2	100	3150	12.5%
FL-2 SW	2800	100	2.1	100	3150	12.5%
FLOOR 3						
FL-3 NE	2800	100	3.4	100	3500	25.0%
FL-3 NW	2800	100	3.3	100	3500	25.0%
FL-3 SE	2800	100	3.2	100	3500	25.0%
FL-3 SW	2800	100	3.1	100	3500	25.0%
FL-3 T	2800	100	3.5	100	3200	14.3%
FLOOR 4						
FL-4	3000	0	4.1	160	3500	16.7%
FLOOR 5						
FL-5 E	2500	100	5.2	100	2800	12.0%
FL-5 W	2500	100	5.1	100	2800	12.0%

Table 1.3A Ventilation Air Comparison.

addendum. Outdoor air supply is necessary to satisfy the latent load of the space. The latent load removed by the ventilation air quantity calculated based on Standard 62.1 Addendum N should be checked. If it is greater than the latent load of the space then the air from the ASHRAE standard should be supplied.

If the latent load removed by the ASHRAE standard air is less than that of the space, then the ventilation required to move the space latent load should be calculated using the traditional equation:

$$CFM_L = \frac{Q_L}{0.68 \cdot (W_{RA} - W_{SA})}$$

Table 1.3A gives a comparison of the original design values versus the new values according to ASHRAE Standard 62.1 Addendum N.

1.3.5 LEED Assessment

Leadership in Energy and Environmental Design (LEED) Green Building ratings are meant to encourage sustainable design practices within the construction industry. Points are assigned based on different "green" design categories. Because the Administration building was a renovation project, it received only 6 LEED points in the assessment. Recent research of mine has led to the discovery of LEED Core and Shell Development (LEED-CS). This rating program is currently being developed. It is based on the same categories as new building LEED rating system is: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, and Innovation and Design Process. However, different requirements will be assigned to each subdivision of the categories. Also, it will only evaluate the parts of core and shell design and construction that the owner controls. LEED design was not considered in the original SDP building and was not considered in the design alternatives.

1.3.6 Building Envelope and Lighting Compliance: ASHRAE Standard 90

Standard 90 establishes minimum requirements for the energy-efficient design of buildings (with the exception of low-rise residential buildings). The building envelope consists of the walls, windows, and roof of a building that separates the outdoor environment from the indoor conditioned spaces. Building lighting power requirements are established to keep energy usage to a minimum within the building.

The original mechanical system was modeled using Trane's Trace program. Using the design values obtained from this model, the Administration building complied with walls and window U-values, but not roof values. Due to the addition of the 3-story atrium, the building exceeded the maximum roof percentage for skylights as well.

Also taken from the Trace model was the lighting power density, 6 watts per square foot (W/SF). This value did not comply with Standard 90. However, this value is a combination of lighting and equipment. Because my original analysis was based on the shell and core renovations, specific lighting power density of the fit-out (what is actually in the space now) was not known. Comparing the design values to the requirements in Standard 90 is not accurate. The air handling units chosen for the design are in mechanical rooms in the core of the building. Floors 1 through 3 have two mechanical rooms each. There are two mechanical rooms totaling 2500 SF on each the first floor and third floor. The second floor has two mechanical rooms totaling 1900 SF. One mechanical room on the fourth floor totals 635 SF and one on the fifth floor takes up 1250 SF of its floor area. The internal load may have been design at 6 W/SF due to the heat given off by these mechanical rooms with the air handling units in them.

1.3.7 Lost Rentable Space

All building systems require the usage of rentable space. Depending on the type of systems within the building, the amount of lost rentable space may vary. Each building system (mechanical, electrical, and plumbing) contributes to this lost space. For the School District's building, the total lost rentable space amounts to 5.68% of the total floor area with mechanical rooms amounting to 2.27% of the total building floor area. Total unusable space is 27,916 square feet of 491,658 square feet between floors 1 and 5. One of the many objectives for the alternative designs is that the lost rentable space will be reduced. In some cases this objective is met and in others it is not.

1.3.8 System First Cost

For most owners, the first cost of the mechanical system is given the most attention. Some of the more energy efficient systems may be overlooked because of their higher first cost. Essentially, these more efficient systems will save money on operating costs in the long run. A strong analysis of first cost and operating cost should be done before selecting a system. Maintenance is also a cost concern. Ease of maintenance is a priority amongst building owners and may relate to the system's first cost. The School District of Philadelphia wanted a system that could be maintained easily and could be mainly be done by their employees. The electric system implemented in the Administration building is small in first cost and easy to maintain, but pricey in operating costs. See Table 1.3B for the SDP building mechanical system first cost. (Operating cost/energy utilization will be discussed in the following section.) This first cost estimate is straight from the guaranteed maximum price bid. This includes mechanical costs for the entire building mechanical system and will be modified for the analysis in this report.

Equipment	$2,963,000.00
Equipment Premium	$60,000.00
Sheetmetal/Air Distribution Systems	$948,000.00
Testing Existing DX Units	$5,000.00
ATC/BMS	$250,000.00
Insurance	$198,500.00
Hoisting	$32,000.00
Total	**$4,456,500.00**

Table 1.3B Existing System First Cost.

1.3.9 Energy Utilization and Cost

The energy use of the SDPAH is based on the energy consumption obtained from the Trace model. Because the system in the Administration building uses DX cooling coils and electric heating coils, all energy consumption is due to electricity. Table 1.3C gives the energy consumption for the analysis of the existing system that was completed in this report.

System 1	Electric Consumption (kWh)	Gas Consumption (therms)	Water Consumption (1000 gallons)	Percent of Total Energy %	**Total Source Energy (kBtu/yr)**
Primary Heating					
Primary Heating	1209479.5	0.0		3.7	**123851.0**
Primary Cooling					
Cooling Compressor	5206464.0			16.1	**533143.2**
Tower/Cond Fans	420212.0		25396.4	1.3	**43029.8**
Condenser Pump	1205839.1			3.7	**123478.2**
Other CLG Accessories	876.0				**89.7**
Cooling Subtotal	6833391.1		25396.4	21.1	**699740.9**
Auxiliary					
Supply Fans	2062867.0			6.4	**211238.1**
Circ Pumps					
Base Utilities					
Aux Subtotal	2062867.0			6.4	**211238.1**
Lighting/Equipment					
Lighting/Equipment	22285440.0			68.8	**2282034.3**
Totals	32391177.6	0.0	25396.4	100.0	**3316864.3**

Table 1.3C Energy Consumption by Existing System.

1.3.10 Operating Cost

The operating cost of the existing system is directly proportional to the energy used. PECO's energy rates were used to find the operating cost of the mechanical system. A hypothesis for a result of this report is that the energy and operating cost of the systems with a central chilled and hot water plant will be less than that of the all electric existing system.

System 1						
	Electric On-Peak			Gas On-Peak	Water On-Peak	
	Consumption	Demand	Total	Consumption	Consumption	Monthly Total
	$	$	$	$	$	$
January	$86,748	$51,369	$138,117	$0	$9,732	**$147,849**
February	$78,598	$51,281	$129,879	$0	$8,753	**$138,632**
March	$86,343	$51,085	$137,428	$0	$11,049	**$148,477**
April	$83,678	$51,077	$134,755	$0	$11,942	**$146,697**
May	$85,556	$53,245	$138,801	$0	$14,156	**$152,957**
June	$96,157	$55,333	$151,490	$0	$15,524	**$167,014**
July	$102,654	$56,647	$159,301	$0	$17,629	**$176,930**
August	$99,425	$55,178	$154,603	$0	$16,066	**$170,669**
September	$92,724	$53,102	$145,826	$0	$13,939	**$159,765**
October	$85,818	$50,677	$136,495	$0	$12,245	**$148,740**
November	$82,858	$50,670	$133,528	$0	$11,063	**$144,591**
December	$86,267	$50,943	$137,210	$0	$10,281	**$147,491**
Totals	**$1,066,826**	**$630,607**	**$1,697,433**	**$0**	**$152,379**	**$1,849,812**

Table 1.3D Existing Mechanical System Operating Cost.

Electricity is one of the most costly sources of energy that can be used if it is bought from a public utility. It takes the use of many sources to make electricity and the efficiency of transmitting it is so poor that the cost is high. Using a central chilled water and hot water plant may be more energy efficient and may operate at a smaller cost.

1.3.11 Emissions

Exelon, the parent company of PECO, uses nuclear power to make electricity which reduces emissions by a great degree compared to coal and oil. Emissions from electricity depend on the amount of electricity consumed by the systems of the building. Exelon uses a mixture of energy sources to make electricity which is done efficiently with nuclear power.

2004 Exelon/PECO Generation Mix						
System 1						
			lbm Pollutant			
Fuel	% Total	kWh	lbm Particulates	lbm SO2	lbm Nox	lbm CO2
Coal	6.0	1943470.7	35630.3	413942.1	239936.1	69642830.4
Oil	4.0	1295647.1	35630.3	499306.1	91663.7	68377359.0
Nat. Gas	1.0	323911.8	0.0	437.2	82185.3	43421605.2
Nuclear	88.0	28504236.3	0.0	0.0	0.0	0.0
Hydro/Wind	1.0	323911.8	0.0	0.0	0.0	0.0
Totals	**100.0**	**32391177.6**	**20808.1**	**244101.2**	**143723.3**	**44685834.0**

Table 1.3E Emissions due to the Existing Mechanical System.