The School District of Philadelphia
Administration Headquarters

Mechanical Systems Analysis

Jayme Antolik
The Pennsylvania State University
Department of Architectural Engineering
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Mechanical Option
Advisor: Jae-Weon Jeong

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The School District of Philadelphia Administration Headquarters

Shell and Core Renovations

440 North Broad Street, Philadelphia, PA

Jayme Antolik
Mechanical Option
http://www.arche.psu.edu/thesis/eportfolio/current/portfolios/jla250/


Photo rendering courtesy of Hooper Shiles Architects

Electrical System

– 13,200 Volt service
– Existing 1500 KVA substation
– Existing emergency service is a 150 kW diesel generator
– Two new 3000 KVA 480/277 volt substations

General Building Data

– Size: Gross Measured Area – 848,000SF
Building Footprint Area – 161,000SF
– 8 Total Levels, 6 Stories Above Grade
– Dates of Construction: December 2003 – July 2005
– Cost of Construction: $25M

Structural System

– Original structure is reinforced concrete with brick masonry exterior
– North and South additions: steel frame with concrete slab on metal deck
– Modifications accommodated the new atrium, shafts, stairs and elevators

Project Team

Owner:	**Archon Group**
General Contractor/CM:	**Turner Construction Co.**
Architect:	**Hooper Shiles Architects**
MEP Engineers:	**CannonDesign**
Site/Civil Engineers:	**Gladnick Wright Salameda**
Structural Engineers:	**Thorton Tomasetti Group**

Architecture

– Originally built in 1948 as a printing facility
– 2 major additions on the north (1960s) and on the south (1980s)
– A three story atrium with skylights is a new architectural highlight
– Interior construction: new toilet rooms, elevator shafts, and lobbies
– Exterior wall refurbishment: insulated glass windows, curtain wall systems, and re-glazing
– Roof: Insulated 3-ply modified bitumen system, modified for new roof penetrations

Mechanical System

– Existing: two 15-ton and one 10-ton packaged rooftop unit, electrical cabinet heaters, unit heaters, and strip heaters provide local heat
– New AC Units (with electric heating coil): Seven 80-ton units, five 90-ton units, five 100-ton units
– New exhaust for toilet rooms, elevator machine rooms, and electrical closets
– Four exhaust fans for the atrium provide 20,000cfm each for smoke purge

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Executive Summary

The School District of Philadelphia Administration Headquarters (SDPAH) is an 848,000 square foot (SF) existing building located in downtown Philadelphia. The existing mechanical system is a variable air volume system with parallel fan powered boxes. It utilizes 17 self contained packaged direct expansion (DX) air handling units (each with a waterside economizer) located within the core of the building served by condenser water from a 1500 ton cooling tower located on the fifth floor roof. Each floor has a cooling load of about 300 tons and a heating load of 300 MBH. Due to the nature of the internal loads, the SDPAH requires cooling year round. The proposed idea is to recommend an alternative mechanical system that requires less energy consumption and less first cost compared to the existing system. The primary space analyzed was the office space (425,000SF).

Trace, a building system simulation program provided by Trane, was used to investigate the energy usage of the alternative designs. Three airside systems all with waterside economizers were analyzed within the office space: 1. The current VAV system, 2. A dedicated outdoor air system (DOAS) with VAV as a parallel system, and 3. A DOAS with radiant panels and baseboard heating as the parallel systems. The waterside part of the mechanical system compared the existing DX units to a central water plant with an electric chiller and a gas-fired boiler. The results are summarized in the following table.

	VAV		DOAS/VAV		DOAS/Radiant
	DX-Electric	CHW-HW	DX-Electric	CHW-HW	CHW-HW
Mechanical System Cost	$3,530,000	$4,362,000	$3,565,000	$4,370,000	$4,220,000
Yearly Energy Consumption	$1,849,812	$1,641,585	$1,963,834	$1,676,231	$1,329,330

These results show that in general a central water plant is more costly than packaged units using refrigerant as the primary coolant. Due to the nature of the DOAS/Radiant system, the required equipment size is smaller than that of the other options allowing for smaller first cost (with respect to other central water plant designs) and a lesser cost due to energy use. Because of this energy savings, it is recommended that when an owner wants a central water plant he or she uses DOAS/Radiant as the airside system.

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.

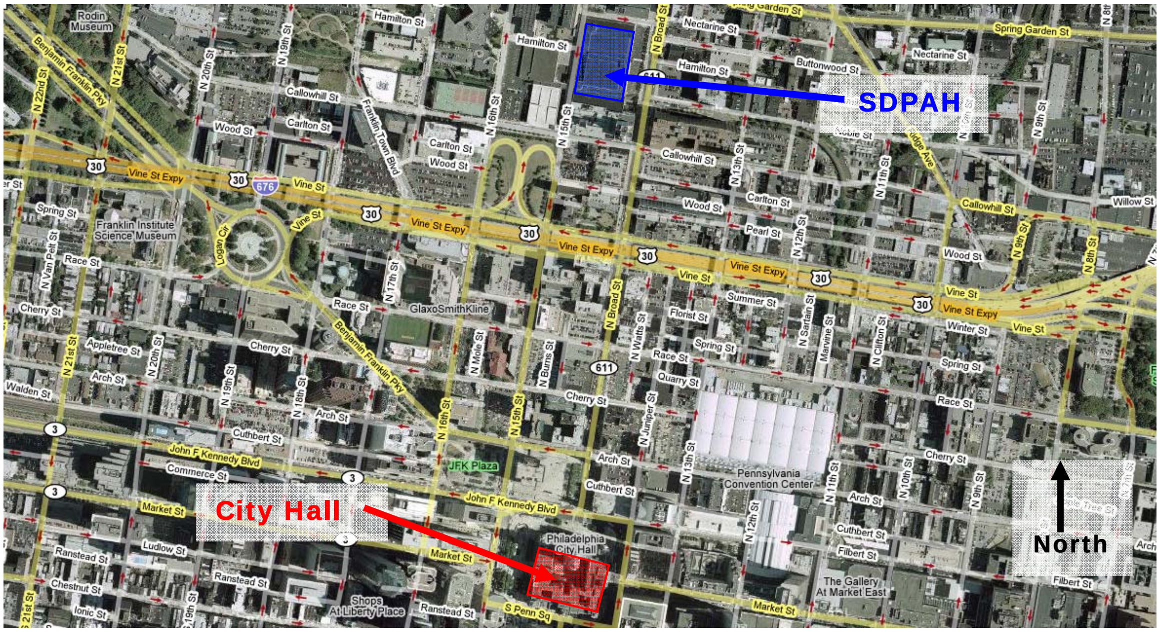


Figure 1.1A Map of 440 North Broad Street, Philadelphia, PA.

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.

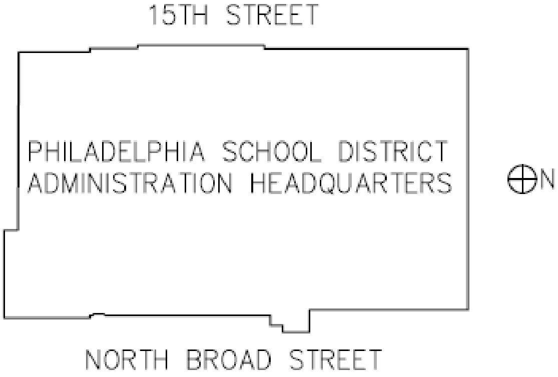


Figure 1.1C SDPAH Footprint.

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.

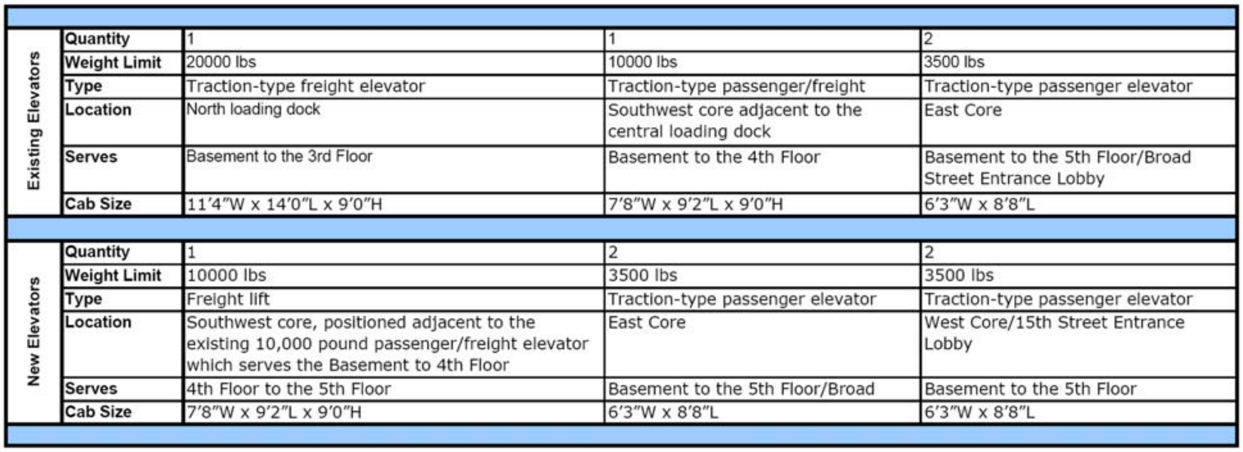
Areas designated for office use have a minimum live load capacity of 125 psf, except a part of the 4th Floor where it is designated to accommodate 100 psf live load.

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.

🟥 AHU 1
🟨 AHU 2
🟦 AHU 3
🟩 AHU 4
🟧 AHU 5

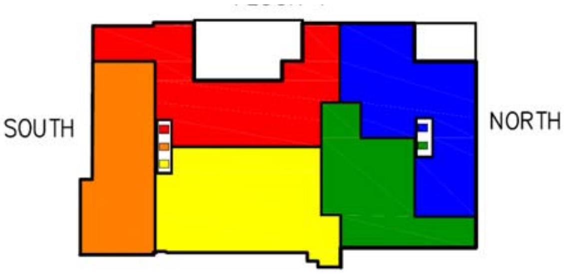


Figure 1.3A. Floor 1 Existing AHU Layout.

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.

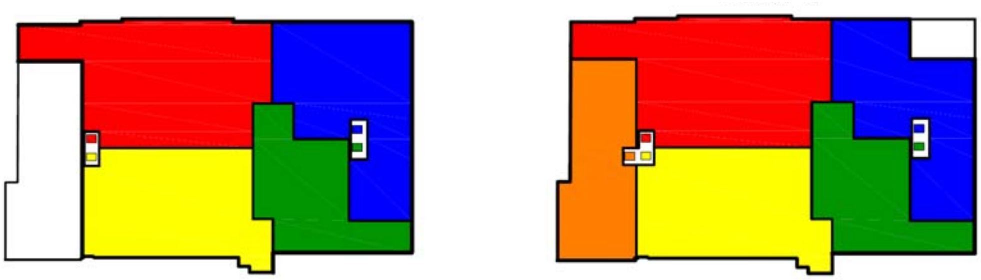


Figure 1.3B Floor 2 and Floor 3 Existing AHU Layout.

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.

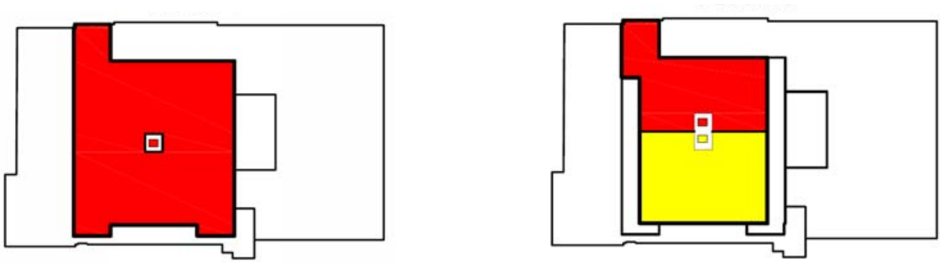


Figure1.3C. Floor 4 and Floor 5 Existing AHU Layout.

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 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.

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.

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	Gas Consumption	Water Consumption	Percent of Total Energy	**Total Source Energy**
	(kWh)	(therms)	(1000 gallons)	%	**(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.

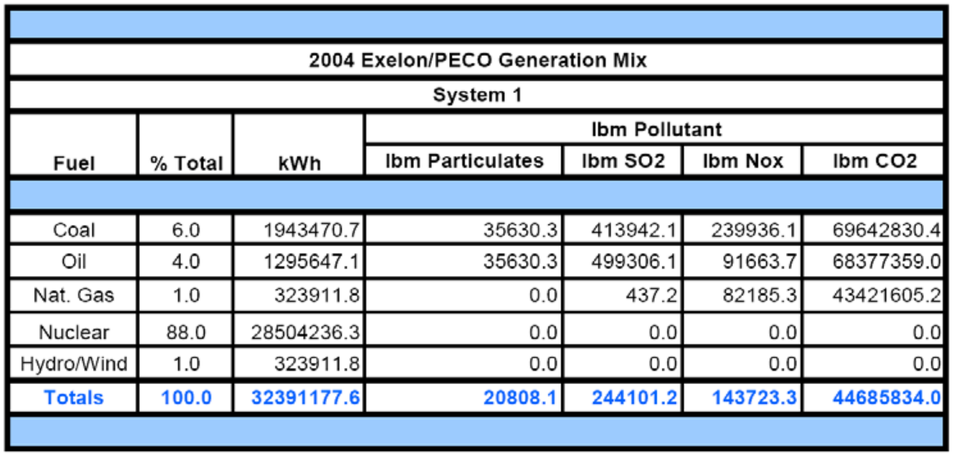
System 1						
	Electric On-Peak			Gas On-Peak	Water On-Peak	
	Consumption	Demand	Total	Consumption	Consumption	Monthly Total
	$	$	$	$	$	$
January	$86,748	$51,369	$138,117	$0	$9,732	**$147,849**
February	$78,598	$51,281	$129,879	$0	$8,753	**$138,632**
March	$86,343	$51,085	$137,428	$0	$11,049	**$148,477**
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

Fuel	% Total	kWh	lbm Pollutant			
			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.

2.0 Depth Work - Alternative Mechanical Designs

2.1 Objectives

The goal of designing alternative systems is to compare energy usage, system costs, emissions, lost rentable space, and constructability. By considering the original concerns of the Philadelphia School District, one final design will be recommended based on the four topics listed above. These comparisons can be used for reference in designing other similar office buildings.

2.2 Overview of Systems

The concentration in the depth work of this report focuses on two concepts. The first is the comparison of two different airside systems: VAV and dedicated outdoor air. The second is the comparison of the existing DX-electric system to a central water plant which supplies cold and hot water to the airside system. In all cases, the fourth floor will be simulated as a constant air volume system. Also, cooling for the atrium and lobbies will not be considered. The analysis will concentrate on open office loads and the energy usage by different systems when used in commercial office buildings. The following five systems will be analyzed:

System 1: VAV with DX coil and electric heating coils
System 2: VAV with chilled water and hot water coils
System 3: DOAS/VAV with DX coils and electric heating coils
System 4: DOAS/VAV with chilled water and hot water coils
System 5: DOAS/Radiant with chilled water and hot water coils

2.2.1 Airside

There will be a comparison of 2 different airside systems. The existing VAV system will be analyzed and a dedicated outdoor air system will be analyzed. The dedicated outdoor air system will be modeled separately with VAV as a parallel system and with radiant panels as a parallel system.

VAV — Systems 1 and 2

The VAV system can exist as a stand alone system as it does currently in the Philadelphia School District Administration Headquarters. Because of the nature of the loads within the SDP building, cooling is needed all year. Depending on the cooling load within each space, a certain quantity of air will be delivered to that space. For heating needs, return air in the plenum will be circulated directly back to the room and heated via a fan and heating coil in the parallel fan powered box.

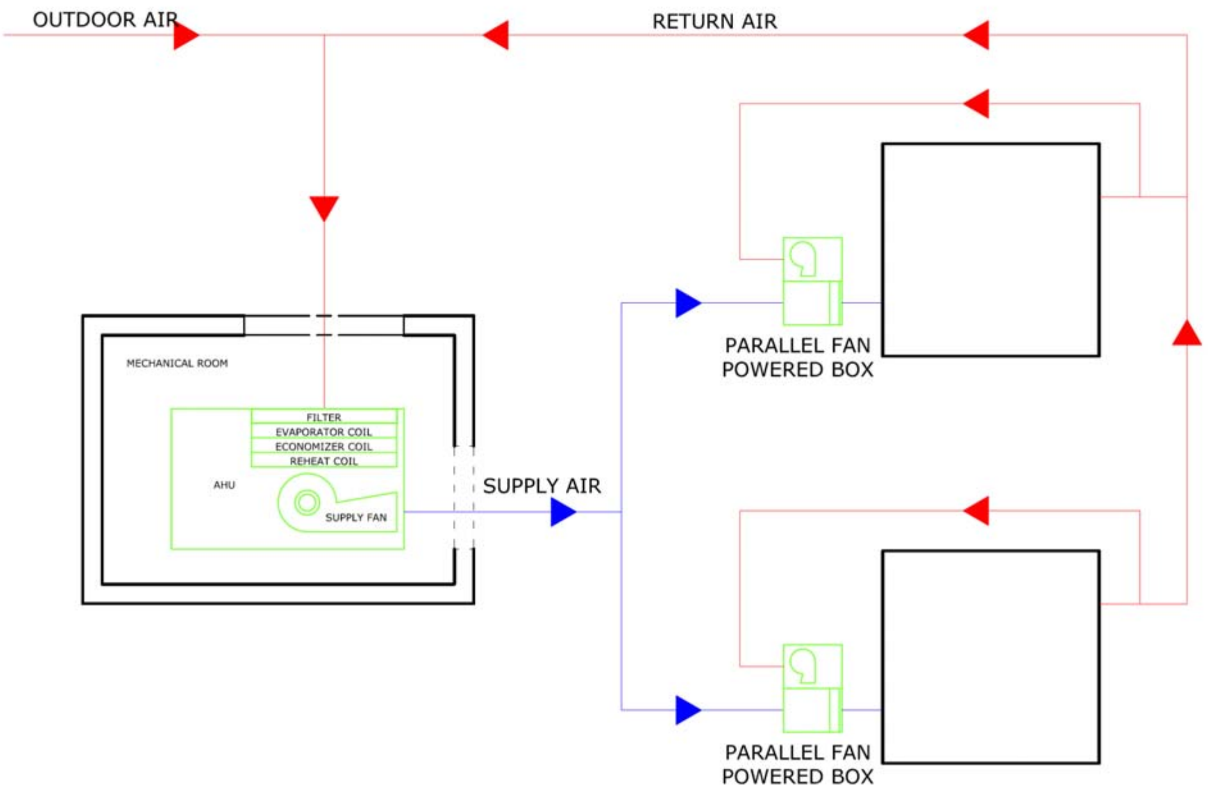


Figure 2.2A. Plan of Airside VAV System.

DOAS — Systems 3, 4, and 5

A dedicated outdoor air system (DOAS) supplies the ventilation requirement for a particular space and is responsible for removing the latent load of that space. It is used with a parallel system which satisfies the rest of the sensible load of the space. In this report two parallel systems will be considered. The first is the existing VAV system with parallel fan-powered boxes. The second is radiant panels used for cooling and radiant baseboard heating. The DOAS in this report uses an enthalpy wheel with an effectiveness of 80 percent. Outdoor air is sent through the enthalpy wheel first. Depending on the season, temperature and humidity are increases or decreased.

During cooling, the enthalpy wheel decreases the outdoor air temperature and humidity by use of heat recovery from the exhaust air stream. The outdoor air is sent through a cooling coil next where its humidity is reduced and its temperature is reduced to 45F. This air can either be reheated to 55F for supply air using a sensible wheel in the outdoor air/exhaust air streams or it can be delivered directly to a space at 45F. The sensible wheel only increases the temperature of the air; it does not alter the humidity of the air. When considering the supply air temperature of the DOAS, it is important to remember that the DOAS is responsible for removing the entire latent load of the space. The supply temperature was determined based on the properties of the parallel systems.

During heating, the DOAS increases the temperature and humidity of the outdoor air by use of heat recovery from the exhaust stream. The enthalpy wheel has the ability to increase the temperature to 58.2F. This can only be done with the VAV system for reasons explained later. With the need for cooling during the winter, the air handling unit does not need a heating coil.

DOAS Analysis

Depending on the parallel system, the conditions of the supply air for a dedicated outdoor air system may be more or less important to control. An analysis was done on the components of the dedicated outdoor air system’s air handling units. The supply air conditions required in this report were not considered in this study. The purpose of this study is to compare the cooling capacity of different configurations with the assumption that the entire latent load is satisfied by the DOAS.

Heat recovery is not a "required" component of a dedicated outdoor air system. A cooling coil can be used to remove the entire latent load of a space; however, this idea is not practical. It requires an enormous cooling coil, has a high first cost, and consumes a lot of energy. Therefore, heat recovery in a DOAS is a must. Heat recovery in the form of an enthalpy wheel, as used in the simulations in this report, reduces the load on the cooling coil. The cooling coil will reduce the outdoor air temperature to 45F and saturated. The remaining option in a DOAS is the use of reheat. This air at 45F can be supplied to the room or it can be reheated to the traditional supply air temperature of 55F. Reheat requires another wheel, a sensible wheel. This component does only sensible cooling or heating. It recovers heat from the exhaust stream to increase the temperature of the 45F air to the supply air requirement. The humidity ratio of the conditioned air does not change as it moves through the sensible wheel. Appendix B provides state point conditions and cooling capacity for the three different cooling models: 1. DOAS with enthalpy and sensible wheel, 2. DOAS with enthalpy wheel, and 3. DOAS without heat recovery. Table 2.2A summarizes the results for space FL-1 NE. The enthalpy wheel only configuration requires the least amount of cooling capacity. The supply temperature for configuration 1 with the sensible wheel is 55F which means the supply air cooling capacity is less than that of configuration 2 which supplies low temperature air at 45F.

		Required Cooling Capacity		
		DOAS	Parallel	Total
		tons	tons	tons
1	**Enthalpy Wheel and Sensible Wheel**	9.33	47.84	**57.17**
2	**Enthalpy Wheel Only**	11.8	36.39	**48.14**
3	**Cooling Coil Only**	153.4	38.64	**192.02**

Table 2.2A. DOAS Analysis Comparison for Space FL-1 NE.

The load across the cooling coil for both cases is the same because the supply air should be saturated in order to satisfy the latent load, but since the air in configuration 2 is heated back to 55F, the parallel system is required to cool more air than the parallel system in configuration 1. By adding another wheel to the outdoor air stream, the first cost of the system will increase on for both the DOAS and the parallel system. The results of this analysis makes the evaluation of reheat seem a little more important when designing the dedicated outdoor air handling unit.

Radiant Panels — System 5

Cooling

The radiant system uses ceiling panels to distribute cooling through radiation. These panels are 2 by 4 foot panels which are similar to 2 by 4 ceiling tiles. Two by 4 foot ceiling tiles are currently installed in the Administration building and were probably a request of the district or a decision made by the architect. These panels would not be complicated to co-exist with the current ceiling layout. Each radiant panel consists of 5 passes of tubing where chilled water is passed through. The heat transfer mechanism of radiation takes over and cools the building spaces.

The radiant panels pose restrictions on the DOAS. No latent load can be left for the radiant panels and the dew point temperature of the DOAS supply air must be lower than the radiant panel surface temperature in the radiant cooling application. The panel surface temperature must exceed the room dew point temperature also. *Both the room dew point temperature and the supply air dew point temperature must be less than the radiant panel surface temperature.* The design room conditions for cooling are 75F and 50% relative humidity. The room dew point temperature that corresponds to these conditions is 55F. The design heating temperature for winter is 70F and 50% relative humidity which correspond to a 50F dew point temperature. The inlet water conditions for these radiant panels must be at least 1 degree above the room dew point temperature. Because the summer conditions control an inlet water temperature of 56F must be used. Therefore, the dew point temperature of the DOAS supply air must be less than 56F. If the occupancy of the space increased, room dew point would increase. This will cause condensation on the radiant panels if air was supplied at 55F and saturated. Using a supply air temperature of 55F would make the chance of condensation more uncertain. Therefore, a supply temperature of 45F will be used to keep the dew point below panel surface temperature. Because the supply temperature is lower than the normal 55F supply temperature, high induction diffusers will be used with the radiant panels. High induction diffusers supply air through a narrow stream at high velocity. The high velocity causes low pressure relative to the ambient room pressure. Because of this pressure differential, room air is drawn into the supply stream where it is quickly mixed within the room. With the DOAS and radiant panels

both the latent and sensible load are satisfied.

Heating

In the winter, the dedicated outdoor air system can supply up to 58.2F air. Because SDPAH requires cooling in the winter, the DOAS must supply at 45 to avoid condensation. The leaving temperature of the enthalpy wheel is controlled by its speed. Therefore, supplying 45F air in the winter is not a problem. For any instances of heating needs, the radiant panel system is supplemented by radiant baseboard heaters along the perimeter of the building. When they sense that the room temperature is below heating thermostat temperature, they will turn on and circulate hot water through finned tubes allowing radiant heating to occur.

VAV — Systems 4 and 5

The cooling supply air temperature in the summer for the DOAS with VAV as the parallel system was also determined to be 45F. For the DOAS/VAV combination the VAV system satisfies the remaining sensible load as does the radiant panels in the previous section. The outdoor air from the DOAS can be mixed with the conditioned air from the VAV unit downstream of the VAV air handling unit. The supply air for the DOAS/VAV system does not have limits on it as it did with radiant panels. This allows the 45F DOAS air to be mixed with the 55F VAV air after both are conditioned. The schematic in Figure 2.2B shows an airside riser diagram for the mixing conditions. The amount of outdoor air being supplied at 45F by the DOAS is small compared to the amount of return air being conditioned to 55F by the VAV system. Because of the ratio of the two supply streams, the supply temperature after they mix is still close to 55F.

During the winter season, the enthalpy wheel increases the temperature and humidity of the outdoor air to 58.2F and 44.2g/lb, respectively. Because all the spaces in the SDPAH require cooling in the winter, this temperature air can mix with the air being supplied by the VAV units. To save energy, the wheel can also be set to heat to 45F where mixing conditions would be very similar to those for the summer. The VAV system has terminal heating at the parallel fan powered boxes. This takes care of any chances of space temperature dropping below heating thermostat temperature.

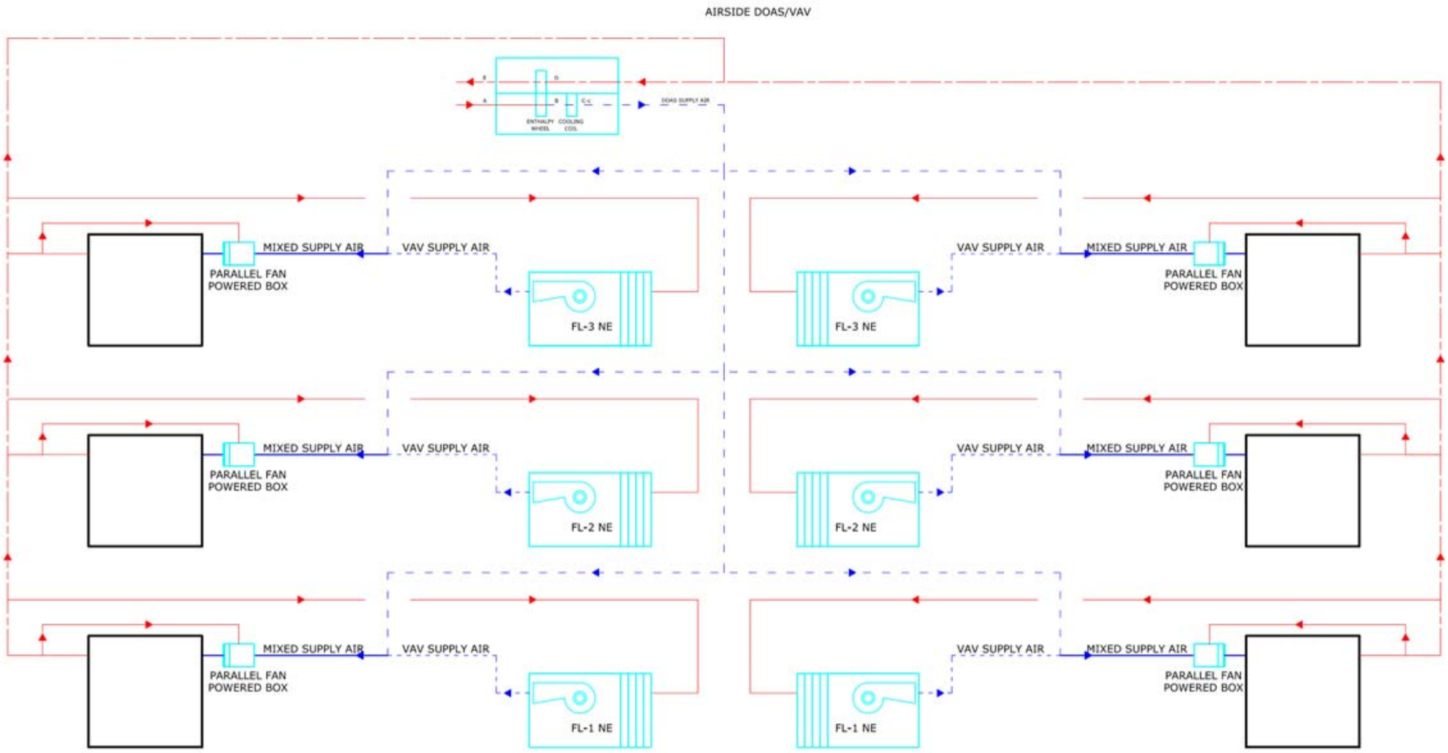


Figure 2.2B. DOAS/VAV Airside Riser Diagram.

CAV—Floor 4

A constant air volume (CAV) system will be used for the fourth floor in all simulations. Floor 4 is known to be utilized as a data center and always has a constant cooling load. Because of this a constant air volume system is the most logical choice.

2.2.2 Water Side

The purpose of comparing the existing DX-electric system to a central water plant is to find yearly energy savings. The current system uses a large quantity of energy (Table 1.3C, Page 19) and a central water plant has the potential to reduce the amount of energy used.

Central Chilled Water Plant

<u>Chiller</u>

In the existing system the refrigeration cycle occurred locally within self-contained packaged air handling units positioned throughout the building using a DX (direct expansion) coil and a waterside economizer coil. An alternative to the existing system is using a central chilled water plant for the main cooling source. For cooling, the refrigeration cycle occurs in a central chiller. A chiller has all of the refrigeration components of the self contained packaged air handling units. Cool refrigerant is passed through an evaporator where it evaporates by taking the heat out of warm water returned from the air handling units or radiant panels. This chilled water is sent to the load and the hot refrigerant vapor passes to a compressor usually at 44F or 45F. A centrifugal compressor is chosen for the models in this report. This compressor has rotating mechanical element that exchanges angular momentum with the refrigerant as it continuously passes through it. The refrigerant at high pressure then passes to the condenser where it will be cooled by water from a cooling tower. The cool refrigerant passes through a pressure reducing element in order for it to enter the evaporator at low pressure. The chiller must be capable of supplying lower temperature water for the DOAS in order to supply 45F air. A heat exchanger must also be used in the application of radiant panels where entering water temperature is 56F. It should be noted that the controls between the chiller and the airside system must be extremely accurate. The focus of this report was on system performance without getting into detail about the system controls.

Cooling Tower

Condenser water from the cooling tower helps to condense the refrigerant after the cooling process. After heat rejection from the refrigerant occurs, heat rejection by the condenser water must occur. After the condenser water leaves the chiller, it is usually 95F. This hot water needs to be cooled again to flow back to the chiller. This occurs by evaporation. The goal is to expose as much water surface area to the air to induce the evaporation process. For the simulation in this report, a "direct induced draft" cooling tower is used. It is direct because the water is in direct contact with the air. It is induced draft because the air is being pulled through the tower by a high pressure water spray instead of blown through, which requires mechanical energy. The induced draft tower is widely used because of its energy efficiency. It uses an axial fan instead of a centrifugal fan. A centrifugal fan requires almost twice as much energy as an axial fan.

Economizer

An economizer cycle is used to model the different systems in this report. A plate and frame heat exchanger can be connected between the condenser water loop and the chilled water loop but the two loops are kept separate. The chilled water loop is connected to the cooling tower loop to transfer heat while the cooling tower loop can bypass the chiller and can provide free cooling to the space when outdoor air conditions are favorable. Favorable outdoor air conditions are typically below 55F.

Central Hot Water Plant

Perimeter heating is needed when the internal load is not large enough to satisfy the perimeter heat losses. Comparisons will be made between the existing electric heating coils and hot water coils served by the hot water plant. A gas fired hot water boiler will be used in the analysis of hot water verses electric heating coils. The boiler will be located on the roof and serve the preheat coils in the AHUs and the coils in the parallel fan powered boxes for the VAV system and the baseboard heaters for the DOAS/Radiant heating system.

2.3 Equipment

The simulations in this report were based on properties of equipment used for each system.

2.3.1 Self Contained Packaged VAV Air Handling Units

The air handling units in the existing system are McQuay self contained water cooled plenum discharge (SWP). The same units were selected for the VAV parallel system in the DOAS application. These units were selected in the existing system for ease of installation and ease of maintenance. The selection of the units depended on the supply air flow for each space and the face velocity of the air across the coil. A small area and high velocity will give a small unit, small cost, and small mechanical room. However, condensate carryover must be considered. As hot air flows over the evaporator or cooling coil, condensate may occur. If the face velocity is too high the condensate will enter the duct system. It may cause damage to the ducts and may threaten indoor air quality. The face velocity rule of thumb of 500 feet per minute (FPM) was used to size the AHUs.

Figure 2.3A. McQuay Packaged SWP Air Handling Unit in Third Floor South Mechanical Room.

Table 2.3A. Sample Schedule of SWP Units on Floor 3 and 5 of DOAS/VAV System.

		DX-Electric Units			
Model		SWP095D	SWP095D	SWP095D	SWP065F
Floor		3	3	3	5
Quantity		2	2	1	2
Nominal cfm		33540	33540	33540	24900
SA cfm		30000	29450	27200	20700
Face Area of Unit	SF	55.9	55.9	55.9	41.5
Maximum Face Velocity	FPM	537	527	487	499
Condenser Flow Rate	GPM	257	257	256	170
DX					
Total Heat Capacity	MBH	638	632	595	429
Sensible Heat Capacity	MBH	656	654	636	454
Economizer					
Total Capacity	MBH	595	584	533	388
Sensible Capacity	MBH	576	563	505	370
Unit Size					
W	IN	84	84	84	81
L	IN	156	156	156	120
H	IN	88	88	88	88

2.3.2 DOAS Units

The dedicated outdoor air system requires the use of an enthalpy wheel. In this case the SEMCO TE3-was selected as the manufacturer for the air handling units. The selection of the units depended on the supply air flow for each space and the face velocity of the air across the coil. Because the DOAS units only supply outdoor air, the total quantity of the air is much smaller than what is being supplied by the VAV units. Thus the location and areas served by these units are different than the VAV units. The building was divided into a North section and a South section, each being served by a DOAS unit sized for the required outdoor air for the spaces within those sections. The face velocity parameter of 500 feet per minute (FPM) was used to size the AHUs.

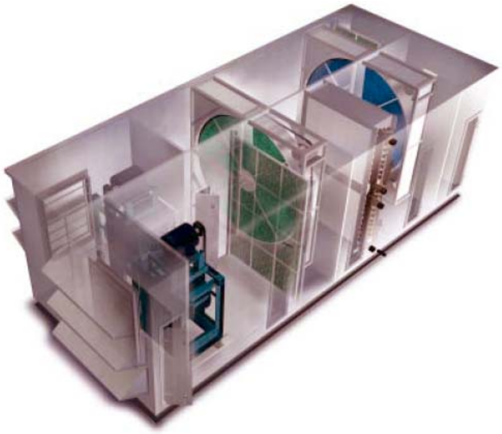


Figure 2.3B. SEMCO Packaged Energy Recovery System, EPC-24/EP-43

	Airflow	Chilled Water	Motor	
			Supply	Return
	CFM	GPM	HP	HP
EPC-24	16150	119	15	15
EPC-43	29100	256	20	20

Table 2.3B. DOAS AHU Schedule.

2.3.3 Enthalpy Wheel

The enthalpy wheel in the SEMCO unit can be individually selected. In this case the EXCLU-SIEVE enthalpy exchanger is chosen. The enthalpy wheel slowly takes the sensible and latent energy from the exhaust stream and shifts it to the transfer core which is made of an aluminum coating with a 3Å molecular sieve desiccant. The energy from the exhaust is transferred to the supply stream saving energy used by traditional systems. This occurs because the air entering the cooling coil after leaving the enthalpy wheel is cooler than it would have been if it skipped the heat recovery process by the enthalpy wheel. The cooling coil is then required to do less work.

In the winter, frost is a possibility on the enthalpy wheel in cold climates. The winter room design conditions are 70F, 50% RH and the winter outdoor air design conditions are 11F, 30% RH. If these two points are connected on a psychrometric chart and the line crosses the saturation curve, then frost may occur. By doing this, it is found that frost does not occur.

When the outdoor air temperature starts to get near the supply temperature an economizer cycle begins. The wheel's speed will slow in response to the set supply temperature. The wheel effectiveness is decreased, however, free cooling is being provided.

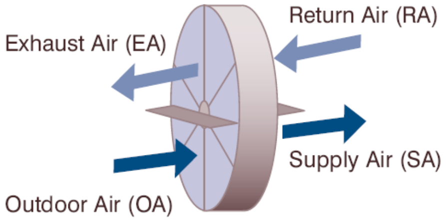


Figure 2.3C. SEMCO Model TE3-24-3Å/TE3-43-3Å

2.3.4 High Induction Diffusers

High induction diffusers must be used to supply low temperature air. Trane was chosen for these diffusers. These diffusers supply air tightly against the ceiling so that it induces the room air into its stream and the two can fully mix.

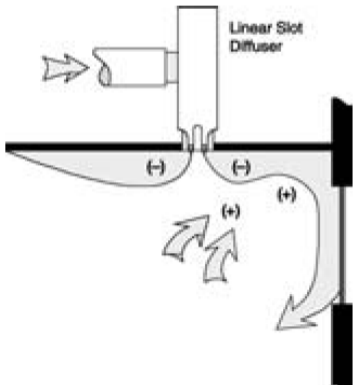


Figure 2.3D. Trane's High Induction Diffuser Performance.

2.3.5 Radiant Panels and Baseboard Heating

Sterling's smooth face linear extrusion radiant panel Type D at 35Btu/SF was used to complete the DOAS/Radiant calculations. The linear extrusion radiant panels will architecturally work with the current ceiling of 2 by 4 acoustic tiles. Sterling's Versa-Line finned tube baseboard radiators were selected for the baseboard heating in the DOAS/Radiant application.

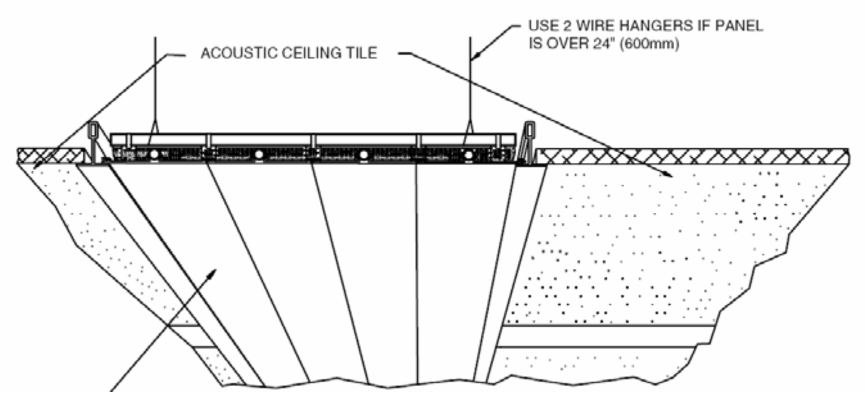


Figure 2.3E. Smooth Face Linear Extrusion Panel Type D by Sterling.

2.3.6 Chillers and Boilers

For purposes of modeling the alternative mechanical systems, the standard chillers and boilers were used from Trace. Two electric centrifugal chillers piped in parallel with variable primary flow characteristics were chosen each with a 0.52 kW/ton rating. The boiler chosen in Trace was a gas-fired 83% efficient boiler.

2.3.7 Pumps

Pumps were sized using Bell and Gossett's VSCS model catalog. Based on the flow and head required for each system the motor horsepower was taken from the pump curves at an average efficiency of about 80%.

2.4 Procedure and Calculations for Alternative Designs

The following sections give the details in designing the alternative systems. The procedure and calculations of the five base systems were described in this section. The fourth floor CAV system design will be described first. Based on the energy consumption of the fourth floor with and without an economizer the main building systems for the other floors will be analyzed with a waterside economizer.

System 1: VAV with DX coil and electric heating coils
System 2: VAV with chilled water and hot water coils
System 3: DOAS/VAV with DX coils and electric heating coils
System 4: DOAS/VAV with chilled water and hot water coils
System 5: DOAS/Radiant with chilled water and hot water coils

2.4.1 New Space Designations

For simplicity of analysis, new spaces designations were created. The general idea of serving five different zones was kept; however, they were squared off from the center of the building so that there are four basic quadrants along with the south wing section. The cardinal directions were used in the designations, which will make it easier to know what unit is serving what space once familiarity sets in with the orientation of the building. “FL-1 NE” is referring to the equipment serving the northeast corner of the first floor. Use Figure 2.4F and this key to correspond with the analysis ahead in this report.

🟥 SW
🟨 SE
🟦 NW
🟩 NE
🟧 T

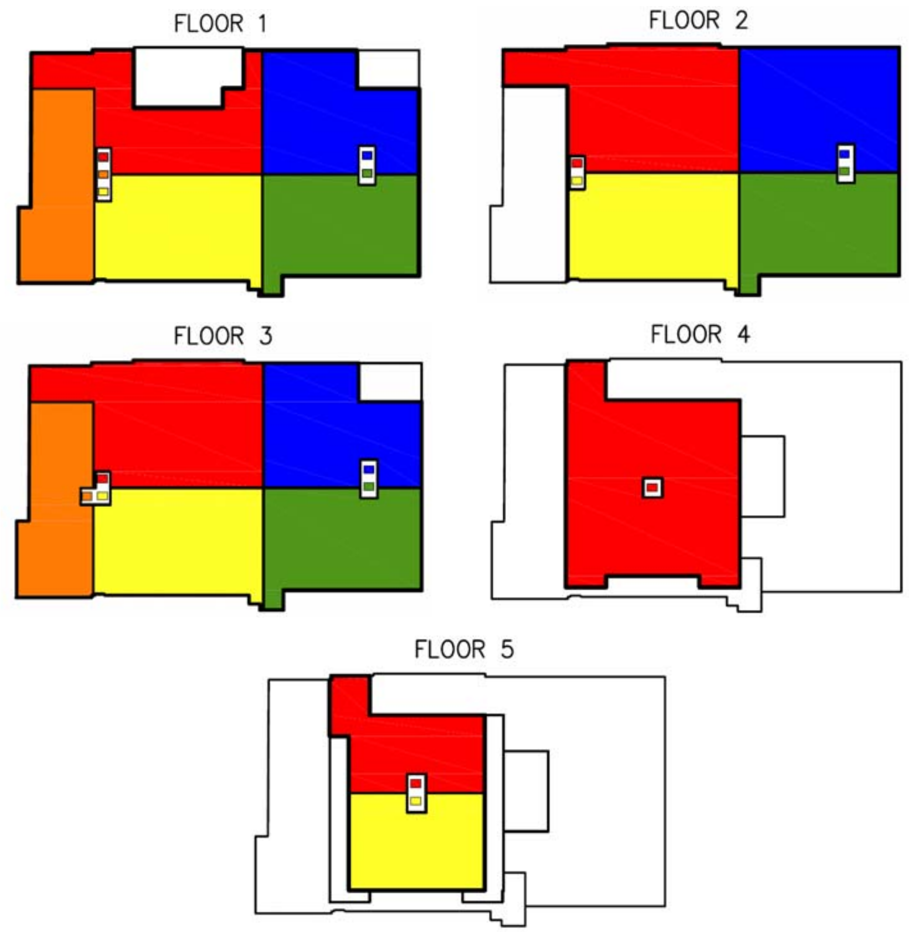


Figure 2.4A. New Service Designation for AHUs.

There will be 16 VAV air handling units in the alternative designs. There will be two DOAS air handling units: One serving the north section and one serving the south section.

2.4.2 Space Loads

Each system was modeled in a separate file using the software Trace by HVAC manufacturer Trane. Spaces were set up in the "Rooms" section of this program according to the floor area served by each air handling unit, the exterior wall, window, and roof areas, the internal load of the building, and other space properties. Once the simulation of the spaces was run, space loads were given. The simulations with VAV as an airside system all had the same space loads because the air handling units where included in the lighting/equipment internal loads. The simulation for the DOAS-Radiant model had slightly smaller space loads because the internal lighting/equipment loads were reduced without the air handling units on each floor. The following tables give each space heating and cooling peak load used in the simulations and calculations in the next sections. It should be noted that the sensible load in winter is a positive value, meaning that cooling is necessary in the winter.

	Cooling		Heating
	Sensible	**Latent**	**Sensible**
	FLOOR 1		
FL-1 NE	517725	20000	346867
FL-1 NW	480276	20000	360694
FL-1 SE	510438	20000	357927
FL-1 SW	428994	20000	386150
FL-1 T	540264	20000	348706
	FLOOR 2		
FL-2 NE	577357	20000	423699
FL-2 NW	555183	20000	435325
FL-2 SE	581823	20000	450197
FL-2 SW	575225	20000	456172
	FLOOR 3		
FL-3 NE	582810	20000	384254
FL-3 NW	609033	20000	385486
FL-3 SE	579808	20000	440467
FL-3 SW	590399	20000	442701
FL-3 T	515911	20000	413353
	FLOOR 4		
FL-4	17202746	0	16812040
	FLOOR 5		
FL-5 E	401390	20000	224655
FL-5 W	418200	20000	226799

Table 2.4A. Space Heating and Cooling Loads with VAV as an Airside System [Btu/h].

	Cooling		Heating
	Sensible	**Latent**	**Sensible**
	FLOOR 1		
FL-1 NE	517725	20000	346867
FL-1 NW	480276	20000	360694
FL-1 SE	510438	20000	357927
FL-1 SW	428994	20000	386150
FL-1 T	540264	20000	348706
	FLOOR 2		
FL-2 NE	577357	20000	423699
FL-2 NW	555183	20000	435325
FL-2 SE	581823	20000	450197
FL-2 SW	575225	20000	456172
	FLOOR 3		
FL-3 NE	582810	20000	384254
FL-3 NW	609033	20000	385486
FL-3 SE	579808	20000	440467
FL-3 SW	590399	20000	442701
FL-3 T	515911	20000	413353
	FLOOR 5		
FL-5 E	401390	20000	224655
FL-5 W	418200	20000	226799

Table 2.4B. Space Heating and Cooling Loads with Radiant Panels as the Parallel System [Btu/h].

2.4.3 Air Properties for Designs

All simulations and calculations were done using the same design air temperatures. The design outdoor air temperatures and properties for heating and cooling based on weather for Philadelphia, PA were taken from ASHRAE Fundamentals. The room air and supply air temperatures and properties were taken as typical design procedure for commercial office buildings. For the DOAS, the supply air temperature was decided to be 45F previously in this report. The following designations are used in Table 2.4C: OA—Outdoor Air, RA—Room Air, SA—Supply Air, DB—Dry Bulb Temperature, RH—Relative Humidity, WB—Wet Bulb Temperature, h—Enthalpy, rho—Density, HR—Humidity Ratio.

Properties	Units	Heating		Cooling		
		OA	RA	OA	RA	SA
DB	F	11.0	70.0	92.0	75.0	55.0
RH	%	30.0	50.0	47.0	50.0	80.0
WB	F	7.2	58.6	75.0	62.4	51.6
h	Btu/lb	3.11	25.3	38.4	28.2	21.1
rho	lb/cf	0.070		0.084		
HR	gr/lb	2.8	54.5	113.5	64.0	52.0

Table 2.4C. Air Properties for Design VAV Conditions.

2.4.4 CAV System

The fourth floor was modeled as a constant volume system. The space loads, room air conditions, and supply air conditions are needed to find the required air flow for the space.

$$CFM_L = \frac{Q_L}{0.68 \cdot (W_{RA} - W_{SA})} \qquad CFM_S = \frac{Q_S}{1.08 \cdot (T_{RA} - T_{SA})}$$

Using the latent load and sensible load equations above, the flow rate can be found. There is no latent load in the space because it is used as a data center and people will not occupy the space for more time than maintenance requires. If there is a case where it is occupied for more than a short time, outdoor air is still supplied based on the floor air requirement. The internal load of the space was 100W/SF which was recommended by a faculty consultant. This is a huge number which can be seen by the sensible load in Table 2.4D.

Floor 4 Design	
Sensible Load	17202.75 Mbh
Supply Air Quantity	799423 CFM
Outdoor Air Quantity	3000 CFM

Table 2.4D. Peak Cooling Design Floor 4 CAV.

Floor 4 was simulated 5 different ways, all with CAV as the airside system. The original DX packaged units were modeled first. The second set of simulations involved the use of an electric centrifugal chiller with an electric boiler and with a gas-fired boiler. The last set of simulations included the use of the electric centrifugal boiler with an economizer and electric boiler and with an economizer and a gas-fired boiler.

The total system capacity is about 1550 tons. By the results of this analysis, it was decided that the systems being analyzed for the open office space will all be modeled with a waterside economizer.

2.4.5 VAV with DX coils and electric heating coils — System 1

A model of the existing system was built in order to have a comparison for the models of the alternative systems. Loads from the model were used to find the supply air quantity. The supply air requirement for each space was used to size the air handler. The total load served by the air handlers were used to size the cooling tower. Heating is provided by parallel fan powered boxes.

Required for Calculations

Space Sensible Loads
Space Latent Loads
Occupancy
Floor Area
Room Dry Bulb Temperature
Supply Dry Bulb Temperature

Calculation Procedure

Cooling Supply Air Quantity

Cooling is needed in both summer and winter for the SDPAH building. In both cases, the required outdoor air quantity should be calculated based on ASHRAE Standard 62.1. For open office space 5CFM/person and 0.05CFM/SF is required. The constant 0.8 is used as a

$$CFM_{vent} = \frac{0.06 \cdot Area + 5 \cdot People}{0.8}$$

This value will be used if it is more than the outdoor air required to satisfy the latent load. The outdoor air required to satisfy the latent load is determined by the following equation:

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

CFM_L is the outdoor air quantity, Q_L is the latent load in Btu/hr, W_RA is the humidity ratio of the room air, and W_SA is the humidity ratio of the supply air. If the quantity required to satisfy the latent load is larger then it is supplied to the space. The rest of the space load, the sensible load, is satisfied by the air quantity calculated by the following equation:

$$CFM_S = \frac{Q_S}{1.08 \cdot (T_{RA} - T_{SA})}$$

The outdoor air and the air that satisfies the sensible load combined is the total supply air to the space. The full spreadsheet of space loads and required supply air quantities is found in Appendix B. This supply air quantity is used to size the air handling unit. A sample selection is provided in Appendix B. It should be noted that during the summer the room air temperature is 75F and humidity ratio is 64 and during the winter the room air temperature is 70 and humidity ratio is 54.5. During the winter a lower sensible load must be met and there is no latent load to be met. The lack of a latent load means that the minimum required outdoor air quantity based on Standard 62.1 must be supplied to the space.

The final cooling capacity for System 1 is 1150 tons.

Sample Calculation for Summer Cooling for FL-1 NE.

CFM_vent = (0.06*Area + 5*People)/0.8

CFM_vent = 0.06*25000 + 5*90 = 1950CFM

CFM_L = Q_L/(0.68*(W_RA-W_SA))

CFM_L = 18000/(0.68*(64-52)) = 2206CFM

*2206CFM controls

CFM_S = Q_S/(1.08*(T_RA-T_SA))

CFM_S = 625550/(1.08*(75-55)) = 28961 CFM

CFM_total = CFM_L + CFM_S = 2206 + 28961 = **31167CFM**

2.4.6 VAV with chilled water and hot water coils — System 2

The source of cooling and heating for the VAV system with a central water plant is chilled and hot water. The procedure for finding the required supply airflow for the DX-electric units should be used to find the supply airflow for air handling units being provided chilled and hot water. Because the airflow is the same and the standard face velocity is the same (500FPM) for both cases, the same minimum face area is required. Although the size and flow rate for the coils are not necessary inputs for Trace to do an energy analysis, they are needed for cost analysis. Carrier's Air Handling Unit Builder was used to find the sizes of the coils based on the load requirements, airflow, and the entering air dry bulb and wet bulb temperatures. For simplicity in all selections the entering dry bulb and wet bulb temperatures in the summer were assumed based on mixing conditions to be 76.2F and 63.3F, respectively. In the winter entering dry bulb and wet bulb temperatures were assumed to be 65.7F and 55.3F, respectively. The mixing equation used to find these temperatures was based on the ventilation outdoor air mixing perfectly with the return air from the space.

$$T_{Mixed} = \frac{T_{OA} \cdot CFM_{OA} + T_{RA} \cdot CFM_{RA}}{CFM_{SA}}$$

See Appendix B for full results of the mixing calculations.

The final equipment size for System 2 is 1150 tons, the same as System 1.

2.4.7 DOAS / VAV — System 3 and System 4

SEMCO's packaged energy recovery systems give the choice of cooling with DX or chilled water coils and heating with electric or hot water coils. The load satisfied by the DOAS must be known to do calculations and equipment selection for the parallel system.

Required for DOAS Calculations

Sensible Load	Supply Air Conditions	Room Air Conditions
Latent Load	Outdoor Air Conditions	Ventilation Airflow

Enthalpy Wheel Sensible & Latent Effectiveness

Calculation Procedure

DOAS Cooling Conditions

The first calculation that should be done is the required outdoor airflow. This should be based on ASHRAE Standard 62.1 and on the latent load (Refer to System 1 of the Procedure and Calculations section for more details on these calculations). The larger of the two values should be used in the DOAS calculations. The supply airflow is also what is used to select a SEMCO air handling unit. A sample selection is provided in Appendix B for the North DOAS air handling unit.

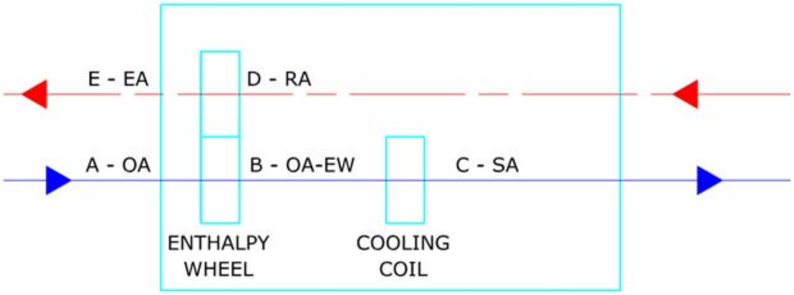


Figure 2.4B. DOAS Air Handling Unit State Points.

Figure 2.4B shows the different state points within the DOAS air handling unit used for the calculation procedure. Outdoor air enters the enthalpy wheel at summer conditions, 92F DBT and 75WBT, an ASHRAE design guideline. From this we can get the different properties of the outdoor air. Supply air conditions were set at 45F and saturated in the previous discussion and the room air conditions are 75F dry bulb and 50% relative humidity. Table 2.4E gives the conditions of the outdoor, supply, and room air.

Property	A - OA - Outdoor Air	C - SA - Supply Air	D - RA - Room Air
DBT [F]	92	45	75
WBT [F]	75	45	62.4
% RH	47	100	50
W [g/lb]	113.5	44	64
h [Btu/lb]	38.4	17.6	28.2

Table 2.4E. Summer DOAS Outdoor, Supply, and Room Air Conditions.

The temperature and humidity ratio at state B governs the effectiveness of the enthalpy wheel. The temperature and humidity ratio at state B can be calculated using the enthalpy wheel effectiveness. The sensible effectiveness can be calculated using the following equation:

$$\varepsilon_{SEN} = \frac{DBT_A - DBT_B}{DBT_A - DBT_D}$$

The effectiveness is assumed to be 0.80, therefore, this equation can be solved for the dry bulb temperature at state B (DBT_B).

$$DBT_B = DBT_A - \varepsilon_{SEN} \cdot (DBT_A - DBT_D)$$

The humidity ratio at state B can be calculated using a similar equation.

$$W_B = W_A - \varepsilon_{LAT} \cdot (W_A - W_D)$$

Building space FL-1 NE will be used to illustrate these calculations.

DBT_B = DBT_A – Eff*(DBT_A – DBT_D)

DBT_B = 92 – 0.8*(92 – 75) = 78.4F

W_B = W_A – Eff*(W_A – W_D)

W_B = 113.5 – 0.8*(113.5 – 64) = 73.9 g/lb

The enthalpy wheel reduces the humidity of the outdoor air by 34.9%.

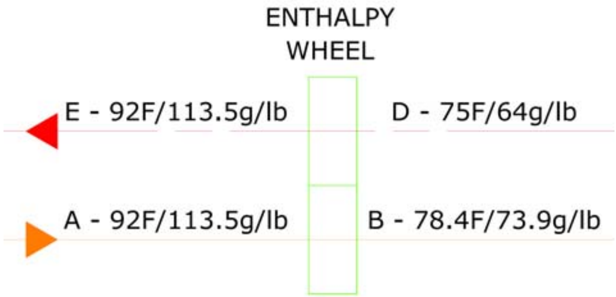


Figure 2.4C. Enthalpy Wheel Effectiveness – Summer.

The dry bulb temperature and humidity ratio reduction at point B will now determine the total cooling coil load. The required outdoor airflow should be used in the following series of equations to calculate the load across the cooling coil.

$$Q_{CC,S} = 1.08 \cdot CFM_{OA} \cdot (DBT_B - DBT_C)$$

$$Q_{CC,L} = 0.68 \cdot CFM_{OA} \cdot (W_B - W_C)$$

$$Q_{total} = Q_{CC,S} + Q_{CC,L}$$

Q_cc,s = 1.08*1950*(78.4 – 45) = 70.340MBH
Q_cc,l = 0.68*1950*(73.9 – 44) = 39.647MBH
Q_total = 70.340 + 39.647 = 109.988MBH = 9.17tons

The total and sensible load across the cooling coil is used to select a coil with Carrier's AHU Builder.

In order to find the parallel system cooling capacity the DOAS cooling capacity must be calculated.

$$Q_{SA} = 1.08 \cdot CFM_{OA} \cdot (T_D - T_{,C})$$

Q_SA = 1.08*1950*(75 – 45) = 63.180MBH

This is where the room sensible load becomes important. The DOAS has satisfied a certain portion of the sensible load (Q_SA) and this can be subtracted from the room sensible load to find the required capacity of the parallel system.

$$Q_{parallel} = Q_{SEN} - Q_{SA}$$

Q_SEN = 625.550MBH
Q_parallel = 625.550 – 63.180 = 562.370MBH

DOAS Heating Conditions

Table 2.4F gives the outdoor, supply, and room air conditions for heating design. Remember, cooling is needed so there is no need for a heating coil within the DOAS unit.

Property	A - OA - Outdoor	C - SA - Supply Air	D - RA - Room Air
DBT [F]	11	45	70
WBT [F]	7.2	45	58.6
% RH	30	100	50
W [g/lb]	2.8	44	54.5
h [Btu/lb]	3.11	17.6	25.3

Table 2.4F. Winter DOAS Outdoor, Supply, and Room Air Conditions.

The same basic equations are used for heating conditions.

$$DBT_B = DBT_A - \varepsilon_{SEN} \cdot (DBT_A - DBT_D)$$

$$W_B = W_A - \varepsilon_{LAT} \cdot (W_A - W_D)$$

Building space FL-1 NE will be used to as an example for the heating calculations.

DBT_B = DBT_A – Eff*(DBT_A – DBT_D)

DBT_B = 11 – 0.8*(11 – 70) = 58.2F

W_B = W_A – Eff*(W_A – W_D)

W_B = 2.8 – 0.8*(2.8 – 54.5) = 44.2 g/lb

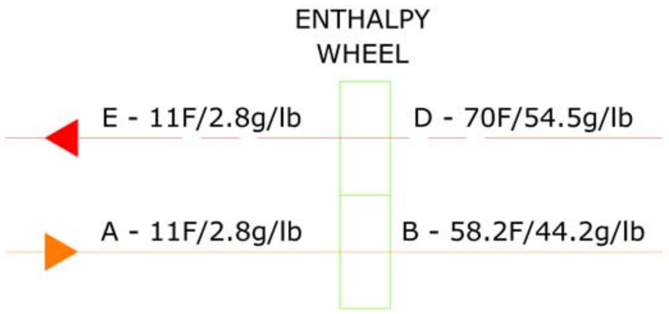


Figure 2.4D. Enthalpy Wheel Effectiveness – Winter.

Appendix B gives a sample selection of the North DOAS air handling unit.

Parallel VAV

The design procedure for System 1 and 2 in the Procedure and Calculations section is used to calculate the supply air required for the parallel VAV system. The supply air for System 3 and 4 is less than that supplied by the existing case. The percent reduction can be found in Table 2.4G. Using the new supply air quantity, McQuay units were selected for the parallel VAV application. A sample selection can be found in Appendix B.

Space	Supply Air		Percent Reduction
	Existing	System 3 / 4	
FLOOR 1			
FL-1 NE	28000	25200	**10.00%**
FL-1 NW	28000	25200	**10.00%**
FL-1 SE	28000	23750	**15.18%**
FL-1 SW	28000	23750	**15.18%**
FL-1 T	28000	27300	**2.50%**
FLOOR 2			
FL-2 NE	31500	28500	**9.52%**
FL-2 NW	31500	28500	**9.52%**
FL-2 SE	31500	29000	**7.94%**
FL-2 SW	31500	29000	**7.94%**
FLOOR 3			
FL-3 NE	35000	30000	**14.29%**
FL-3 NW	35000	30000	**14.29%**
FL-3 SE	35000	29450	**15.86%**
FL-3 SW	35000	29450	**15.86%**
FL-3 T	35000	27200	**22.29%**
FLOOR 5			
FL-5 E	28000	20700	**26.07%**
FL-5 W	28000	20700	**26.07%**

Table 2.4G. Supply Air Reduction for Parallel VAV System.

The total supply air for the DOAS/VAV system is that provided by both the DOAS and VAV units. These two air streams are mixed after both have been conditioned. The following equation was used to find the supply air temperature for the mixed air:

$$SAT_{Mixed} = SAT_{VAV} \cdot \frac{CFM_{VAV}}{CFM_{TOTAL}} + SAT_{DOAS} \cdot \frac{CFM_{DOAS}}{CFM_{TOTAL}}$$

SAT—Supply Air Temperature, CFM—Cubic Feet per Minute

See Appendix B for the mixed air calculations.

The final equipment size required by SDPAH for System 3 and 4 is 1236 tons.

2.4.8 DOAS/Radiant with chilled water and hot water coils — System 5

Because the latent load of the space remains the same as the systems change, the dedicated outdoor air design procedure remains the same for all three dedicated outdoor air systems.

Required for Radiant Panel Calculations

Calculated Parallel System Capacity
Panel Entering Water Temperature
Panel Sensible Load Absorption Capacity

Calculation Procedure

Panel inlet water temperature must be at least one degree above room dew point temperature. Room design dew point is 55F, therefore the water temperature must be at least 56F. Using Sterling's design procedure, the estimated temperature rise is 10F—leaving water temperature is 66F. Half of the temperature rise is added to the entering water temperature to find the mean water temperature, which is 61F. The difference between the room dry bulb temperature and the mean water temperature, 14F, is used to find a set of panels that will work with out design. If we restrict the ceiling to 50 percent coverage by radiant panels then the capacity of the panel per square foot can be calculated.

$$\text{Area}_{\text{panels}} = \frac{\text{Area}_{\text{ceiling}}}{2}$$

$$Q_{\text{perSF}} = \frac{Q_{\text{parallel}}}{\text{Area}_{\text{panels}}}$$

Using FL-1NE as an example:

Q_perSF = 436725Btu/hr ÷ 12500SF = 34.938Btu/hr per SF

Panel selection C at 35Btu/SF will work. Using 2 by 4 panels each panel will remove 280Btu/hr. Dividing the total parallel load by the capacity of the panel will give the number of panels for the space.

Panels = 436725Btu/hr ÷ 280Btu/hr / Panel = 1560 Panels

Optimizing the pressure drop, capacity, and flow rate for a circuit will give the absorption,

pressure drop, and flow per circuit. See Appendix B for the results of this optimization. In space FL-1 NE, 1GPM was chosen as the flow rate because the pressure drop for higher flow rates were more than tripled that of the 1GPM flow. This corresponds to a pressure drop of 6.8 FT WG per circuit and absorption of 5000Btu/hr per circuit. The number of circuits can be calculated by dividing the total parallel load by 5000Btu/hr. Eighty eight (88) circuits will be needed for this space. Now the radiant ceiling panels can be laid out.

A circulation pump will be assigned to each space, increasing the required pumping energy. To counterbalance this increase in energy, the fan energy will be decreased tremendously since there are only two DOAS air handling units.

The final equipment size required by SDPAH for System 5 is 840 tons.

*All system calculation spreadsheets can be found in Appendix B.

2.5 Results and Recommendations

An analysis on the fourth floor CAV system was completed first to find the savings potential of an electric centrifugal chiller with and without an economizer and to find the savings potential of a gas-fired boiler compared to an electric boiler. The result of the analysis on the fourth floor data center helped to do analysis on the rest of the building spaces. A final recommendation will be made based on energy usage, system costs, lost rentable space, and constructability.

2.5.1 Floor 4 Results

The fourth floor was simulated as a traditional CAV airside system with different waterside systems. The purpose of this analysis was two-fold. The first purpose was to find an energy efficient system that can be useful for the fourth floor's application. The second purpose was to choose what systems the office spaces would be modeled with based on the results from Floor 4's simulations. The full results are detailed in Appendix B. The total energy savings of using a central chilled water and hot water plant can be seen in Chart 2.5A. The base case is the packaged McQuay SWP units. Not only does this system use a lot of energy, 6074637.7 kBtu/yr, but it would require a large amount of floor space to put the units. For data centers, usually air is pushed through underfloor air distribution. The floor panels are perforated and air can be circulated within the electrical and data equipment. Special structural designs should be considered for this system.

From Chart 2.5A, it can be seen that a chiller saves about 350 kBtu per year. Implementing a gas-fired boiler increases this amount by about 6 kBtu per year and using a plate and frame heat exchanger adds another 6 kBtu per year of savings. For the analysis of the office space, it was decided that an electric water cooled chiller with an economizer and a gas-fired boiler would be the basis of comparison to the existing system on the water side of the system.

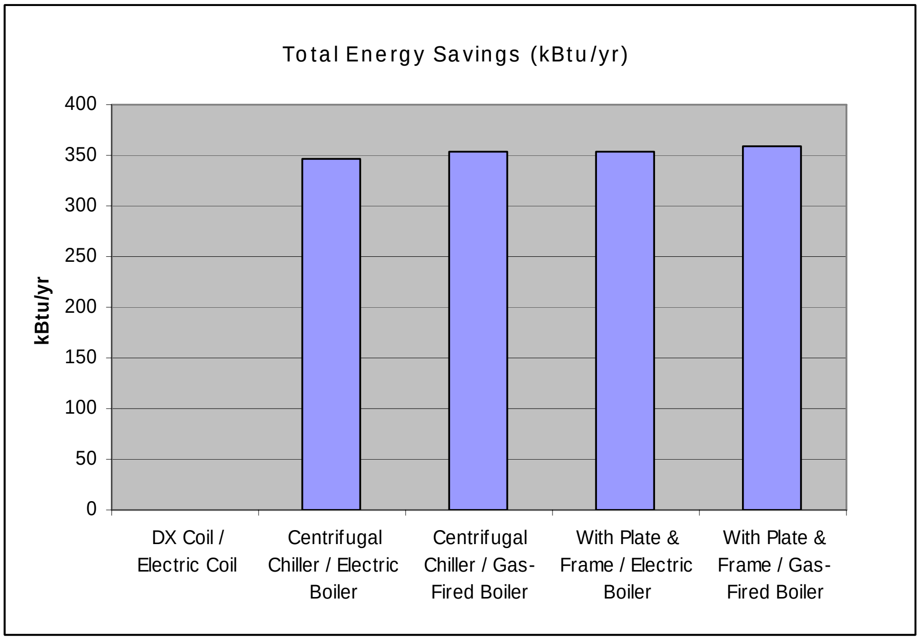


Chart 2.5A. Total Energy Savings Using an Electric Centrifugal Chiller—Floor 4.

2.5.2 Energy Usage and Cost

A good argument for choosing a particular system is yearly energy cost. The total source energy consumed per year by each system is given in Chart 1. "Source" means the part of the mechanical system using energy. The energy represented in this chart includes all forms of energy used in the systems (electric, gas, and water). The values are in MBtu/year—million Btu/hr per year. Compressor energy, the tower fan energy, and the condenser pump energy are all included in the "Primary Cooling" category. It was expected that the DX/Electric systems would use more energy, thus cost more to operate. It was unknown exactly how much more energy the DX/Electric systems would require. System 1—VAV with DX and electric coils and system 3—DOAS/VAV with chilled and hot water coils utilize the largest kW per ton which is why they use the most energy in the end. The systems using VAV as the primary system or as a parallel system require the most fan energy and the radiant system uses the most pumping energy.

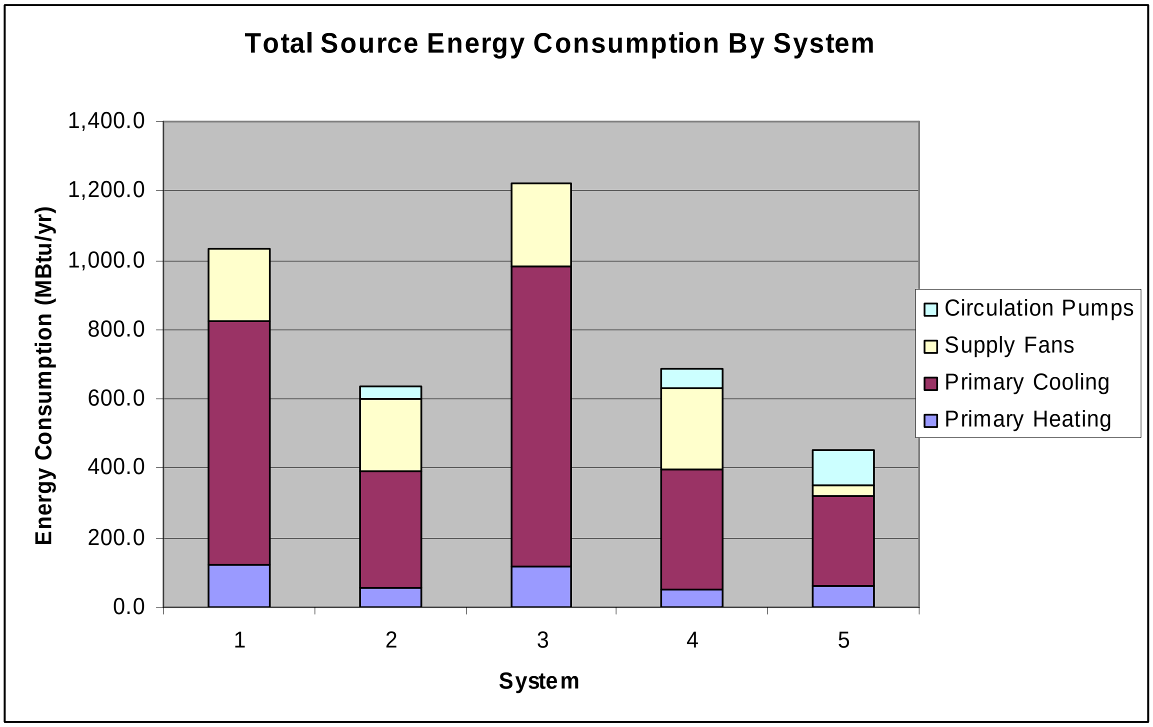


Chart 2.5B. Total Source Energy Consumption by System.

The amount of piping due to the radiant panels is the main reason for this increased piping energy. In general, the high energy consumption is due to the large amount of cooling needed in the summer. During the winter, the chiller can use the economizer cycle to provide free cooling. In general, using a central chilled water plant saves on energy consumption. If the decision of what system should be used was solely based on energy consumption it would be easy—the DOAS/Radiant system would be chosen, however, most of the time first cost is the deciding factor for owners. For full energy consumption results, see Appendix B.

Energy usage is directly related to energy cost. Table 2.5A shows the energy cost per year in US dollars for each system. These costs are based on energy rates from PECO—Philadelphia Electric Company and Philadelphia Water Department (See Appendix B). Rates as well as more detailed yearly cost information can be found in Appendix B. It is not surprising that electricity is the most costly of the energy sources. By choosing a central chilled and hot water plant, savings compared to the all electric systems can be from $287,603 to $634,504 per year. For heating, the DOAS/Radiant system was the highest in cost which should be expected since low temperature air is supplied directly to the space unlike the DOAS/VAV system where it was mixed beforehand. Still, the radiant system holds for the lowest yearly operating cost while all electric systems are highest in operating cost.

	1	**2**	**3**	**4**	**5**
Electric	$1,697,433	$1,463,243	$1,793,130	$1,495,847	$1,180,379
Gas	$0	$37,455	$0	$34,661	$41,100
Water	$152,379	$140,887	$170,704	$145,723	$107,851
Total	**$1,849,812**	**$1,641,585**	**$1,963,834**	**$1,676,231**	**$1,329,330**

Table 2.5A. Yearly Operating Cost Based on Energy Consumption.

2.5.3 First Cost

The first cost and yearly energy consumption cost usually go hand in hand. Saving money on energy in the future may cause an owner to spend a bit more up front on first cost. A number of sources were used to find the first cost of the different systems analyzed in this report. Quotes from the actual first cost of the existing system were modified to provide first cost for the alternative systems. RS Means was used to find cost of equipment that was not used in the existing system and some online resources were used to compliment RS Means. Results are summarized in Table 2.5B. With the use of DOAS/Radiant, the chiller size is reduced by more than 300 tons from the DX original system. This causes great reductions in chiller cost and when only considering the alternatives with a water cooled chiller, the option of the dedicated outdoor air system and radiant panels is lest costly than the alternatives with VAV as an airside system. The systems using packaged DX units are the least expensive, but their energy use is very high. In this case, for a savings in energy use and a slightly higher first cost, the DOAS/Radiant system should be chosen.

	VAV		DOAS/VAV		DOAS/Radiant
	DX-Electric	CHW-HW	DX-Electric	CHW-HW	CHW-HW
Required Chiller Size [tons]	1150	1150	1236	1236	840
Condenser Water Flow	4000	3500	4300	3750	2500
Chilled Water Flow		2500		2800	2000
Hot Water Flow		2250		2250	2250
AHU	$700,000	$1,050,000	$660,000	$911,000	$81,000
Chiller		$460,000		$495,000	$340,000
Pump		$38,000		$42,000	$30,000
CT/Fan	$120,000	$105,000	$130,000	$115,000	$75,000
Pump	$60,000	$52,000	$65,000	$55,000	$38,000
Boiler		$38,000		$38,000	$38,000
Pump		$34,000		$34,000	$34,000
Resistance Heaters	$50,000		$50,000		
VAV boxes	$310,000	$390,000	$340,000	$430,000	
Radiant Panels					$2,750,000
Pumps					$30,000
Piping					$40,000
Baseboard Heaters					$120,000
CDW/CHW/HW Piping (Primary)	$290,000	$195,000	$320,000	$250,000	$144,000
Ductwork (Mains)	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$500,000
Totals	$3,530,000	$4,362,000	$3,565,000	$4,370,000	$4,220,000

Table 2.5B. First Cost of Base and Alternative Mechanical Systems.

2.5.4 Emissions

Exelon Corporation, the parent company of PECO, generates electricity primarily with the use of nuclear power. Some coal, oil, natural gas, and hydro power also help to generate the electricity provided by Exelon Corporation. The emissions based on the electricity consumed for each system can be calculated by knowing the percentages of the different resources used to make electricity. Using nuclear power as a primary source for producing electricity helps save on emissions greatly as it does not produce any pollutants. Keeping the use of coal to produce electricity to a minimum helps too since it produces the most NOx. Exelon Corporation's 2004 quantities were used to find the amount of particulates, SO2, NOx, and CO2 produced by electricity consumed by each system summarized in Table 2.5D. (The detailed result of these calculations can be found in Appendix B.) It is not surprising that the amount of emissions is proportional to the amount of electricity consumed and therefore System 3 produces the most emissions.

Coal	6.0%
Oil	4.0%
Nat. Gas	1.0%
Nuclear	88.0%
Hydro/Wind	1.0%
All	100.0%

Table 2.5C. Generation Fuel Mix.

System	lbm Pollutant			
	Particulates	SO2	NOx	CO2
1	20808.1	244101.2	143723.3	44685834.0
2	17974.1	210855.6	124148.8	38599804.1
3	**21969.9**	**257730.3**	**151747.9**	**47180815.2**
4	18322.5	214942.7	126555.2	39348004.3
5	14400.1	168929.1	99463.1	30924628.5

Table 2.5D. System Emissions due to Electricity Consumption.

NOx is also produced from the burning of natural gas in a boiler. Since a boiler was used as the heating source in the central hot water plant, NOx calculations can be done based on the NOx emissions for the boiler. The NOx emission from the boiler is 0.144lbm/year per 1 MMBtu, which is quite small compared to the amount given off by the use of electricity.

2.5.5 Lost Rentable Space

The School District of Philadelphia occupies the entire building and therefore any space saved from an alternative system is theirs to use. The alternative systems using VAV as an airside system (Systems 2-4) will require the same mechanical room space that the existing system requires because the amount of air handling units were not reduced. In fact, Systems 3 and 4 with the DOAS, will require more mechanical room space for the new air handling units. The DOAS/Radiant system, System 5, will require the least amount of mechanical room space. For the two DOAS air handling units, one can be placed on the fifth floor and one can be placed on the third floor, North wing. Small pump rooms will be required on each floor for circulation of the cool water in the radiant panels but these rooms will not need nearly as much space as the air handling units do. There will be two 100 GPM pumps in the same location as the air handling units. These require no more than 100 SF of space which is about 1/12 of what the AHUs require.

2.5.6 Integration

The SDPAH is located in an existing building. This calls for special attention to the ability to construct the system. The structural integrity of the building must be checked. Constructing a chiller and boiler on the roof transfers more load to the structural members, the columns, beams, girders. The members must be checked to make sure they are strong enough to transfer the load to the ground. The existing building at 440 North Broad poses an advantage to a typical speculative office building in that it was originally built as a printing facility with floor live loads of 125 PSF. Integration of the structural system will be further investigated in the Breadth section of this paper (3.0).

Constructing the system is another issue that must be addressed. Placing chillers on the roof would require a crane. The location of this equipment is important to the surrounding community. Will it cause disturbances in everyday life of downtown Philadelphia? Also, moving material around within the building is an important concern. The freight elevators will be a great assistance in moving material vertically from floor to floor. These topics too will be discussed in the Breadth section of this paper.

2.5.7 Recommendation

Although the existing system is not expensive and can be easily installed, the DOAS/Radiant with water cooled chiller and waterside economizer provides a great savings in yearly operating cost and would be recommended to an owner if he or she desired a central water plant. At around 1.3 million dollars to operate yearly, the DOAS/Radiant system offers a payback period of about 1 year, 4 months relative to the existing system. Comparatively to the VAV with central chilled water and hot water, the pay back would be 6 months. In either case, the energy savings is worth the first cost.

A possible consideration for further investigation is using air cooled chillers with and without an airside economizer. Air cooled chillers are smaller than water cooled, usually available up to about 400 tons so they would have to be used in parallel. The air cooled chillers are typically more expensive than water cooled, but save first cost without having to buy a cooling tower.

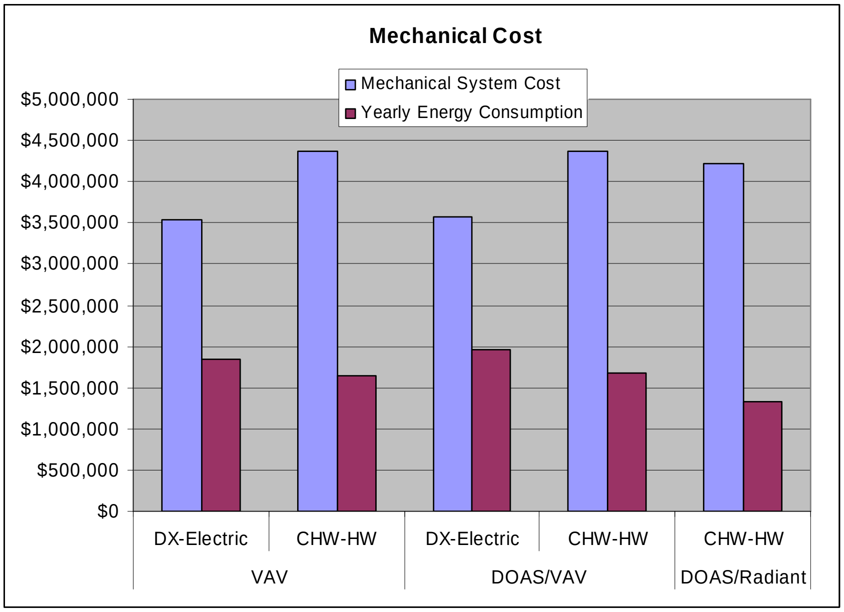


Chart 2.5C. Mechanical System First Cost/Yearly Operating Cost.

	VAV		DOAS/VAV		DOAS/Radiant
	DX-Electric	CHW-HW	DX-Electric	CHW-HW	CHW-HW
Mechanical System Cost	$3,530,000	$4,362,000	$3,565,000	$4,370,000	$4,220,000
Yearly Energy Consumption	$1,849,812	$1,641,585	$1,963,834	$1,676,231	$1,329,330

Table 2.5E. Cost Summary.

3.0 Breadth Work — Integration of Structural System and Constructability

3.1 Overview

The Philadelphia School District chose to relocate in an existing building instead of building a new facility. A concern with moving into an existing building is constructing the new building systems within it. All building systems must be integrated with the existing structure. The first topic to be explored is structural compatibility. The weight of the system to be constructed should be checked against what the existing structural system can withstand. Modifications may be needed in order to fit the new equipment in the building or on the roof.

The second topic to be discussed is constructability. Since 440 North Broad is an existing building there are boundaries as to how equipment can be moved inside the building and once inside, how it can be moved around within the building. Heavy equipment like cranes may need to be positioned and the surrounding areas must be considered when locating the crane.

The mechanical system recommendation was to install a DOAS/Radiant system with a water cooled centrifugal chiller and a gas-fired boiler. This requires placing a chiller and a cooling tower on the roof. The structural system will be checked and a constructability study will be completed.

3.2 Structural Analysis

The existing structural system consists of 5 inch slab on deck with steel columns and girders. The existing mechanical system required a cooling tower at 44,000 pounds (lbs) to be placed on the roof. The designers used column extensions for one central bay and built a new exterior concrete slab about 4 feet above the roof. The cooling tower sits on another slab which lies on top of the addition floor. The mechanical system recommendation requires two new rooftop packaged chillers in addition to the existing cooling tower. Because the existing design using column extensions works for the cooling tower, the same design will be modeled for the chillers. The original building was a printing facility which had floors designed for 125 PSF. Because the building is now being used as office space the live load will be assumed to be 80 PSF so that corridors can be placed at any location. A dead load of 75 will be assumed due to a 5" normal weight concrete slab and MEP loads on the floor.

This structural analysis will include modeling the bay that will be affected by the mechanical equipment in SAP2000 and in RAM, two structural modeling programs. The reason for using two different programs will be explained further on. It is required of the structural system to be able to take the load of the new rooftop chillers each weighing 70,000 lbs. They will take up a total area of 15 by 8 square feet. A typical bay in the School District of Philadelphia Administration Headquarters is 25 feet by 25 feet. The proposal is to build another floor above a central bay away from the cooling tower, Figure 3.2A. Like mentioned before, this is not what the cooling tower lies on—it is another slab which is on top of the new floor. The top slab is 24 by 18 feet, red in Figure 3.2B and was modeled in SAP so that the reactions can be found and placed on the model in RAM. This was done by placing pins at each point labeled 1-8 in Figure 3.2B and by placing a distributed load over the area of the slab.

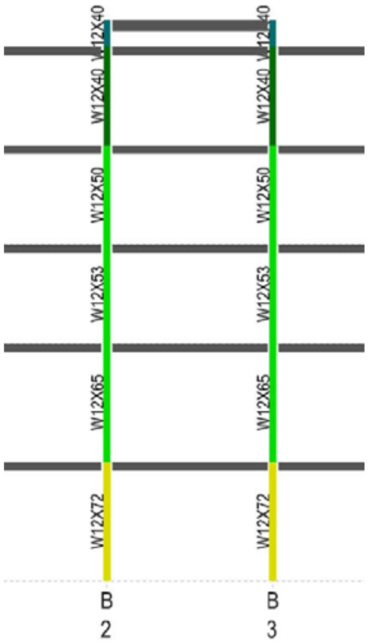


Figure 3.2A. Column Section with New Floor

Distributed Load = 70,000 lbs x 2 ÷ (24' x 18') = 324 PSF

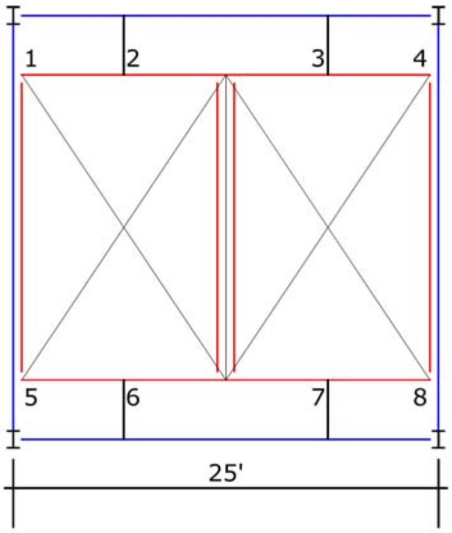


Figure 3.2B. New Mechanical Floor Above Roof.

This gave the reaction of 1 KIP at points 2, 3, 6, and 7 and 136.2 KIPS at points 1, 4, 5, and 8. The deflection can be seen on the next page. The 136.2 KIP loads were converted to a line load acting from points 1 to 5 and from points 4 to 8.

Line Load = 136.2 KIP x 2 ÷ 18' = 15.13 KIP per LF

This would be worst case scenario at full load design. These reactions were then put on the RAM model, Figure 3.2C. The model was ran using the dead and live loads assumed per floor and these point and line loads.

The output can be seen on the next page. If the beams and the columns on the top and bottom floors of the existing building are the same size or larger than the ones given in the RAM model, then the same design for the existing cooling tower can be used to design a new floor for a chiller for the DOAS/Radiant system. The existing column extensions for the cooling tower are W12x40 and the first floor columns are W12x72. The existing beams are HSS20x12x12 and HSS12x6x1/2. The beams were set in the RAM program and it was allowed to calculate the column sizes. The results from RAM show that the column sizes needed for this structural renovation coincide with what is in the building currently. The framing plan also coincides with the W16s currently in the building. See Appendix C for the beam design calculations

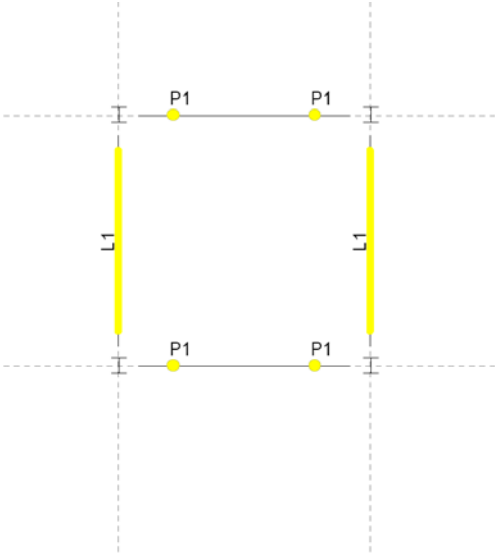


Figure 3.2C. Loads on Beams.

3.2.1 SAP Results

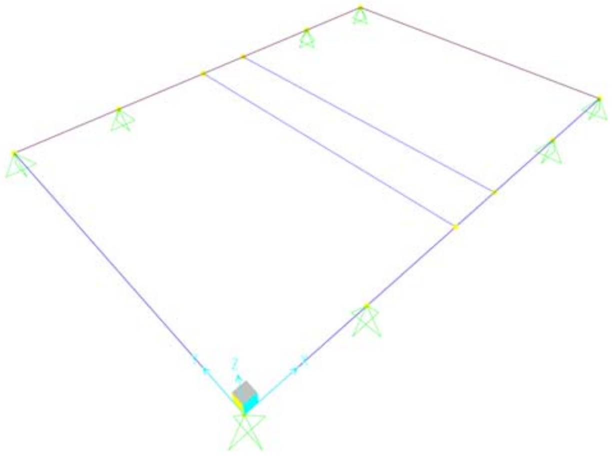


Figure 3.2D. Top Slab without Deflection.

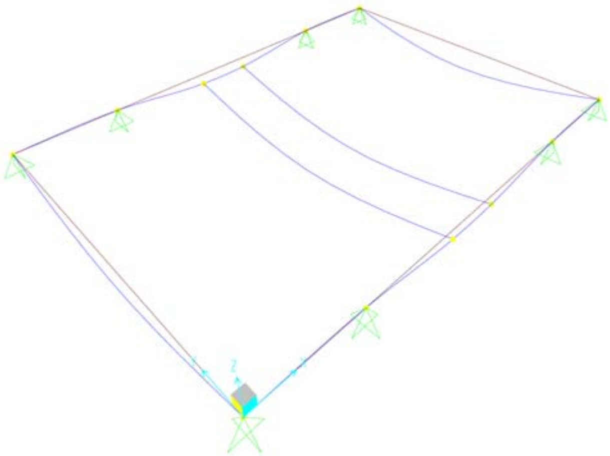


Figure 3.2E. Top Slab with Deflection.

3.2.2 RAM Results

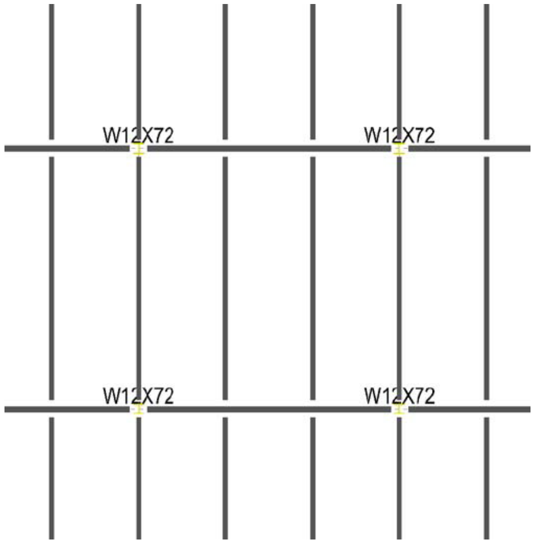


Figure 3.2F. First Floor Columns.

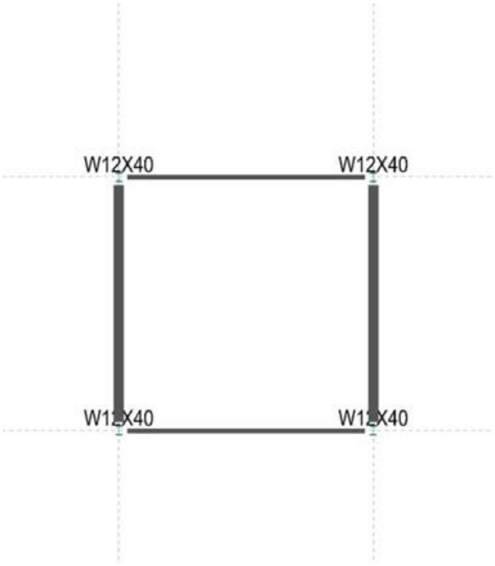


Figure 3.2G. New Floor Columns.

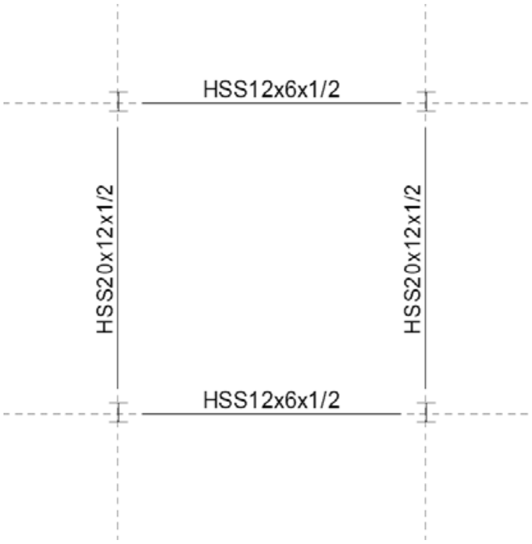


Figure 3.2H. New Floor Beams.

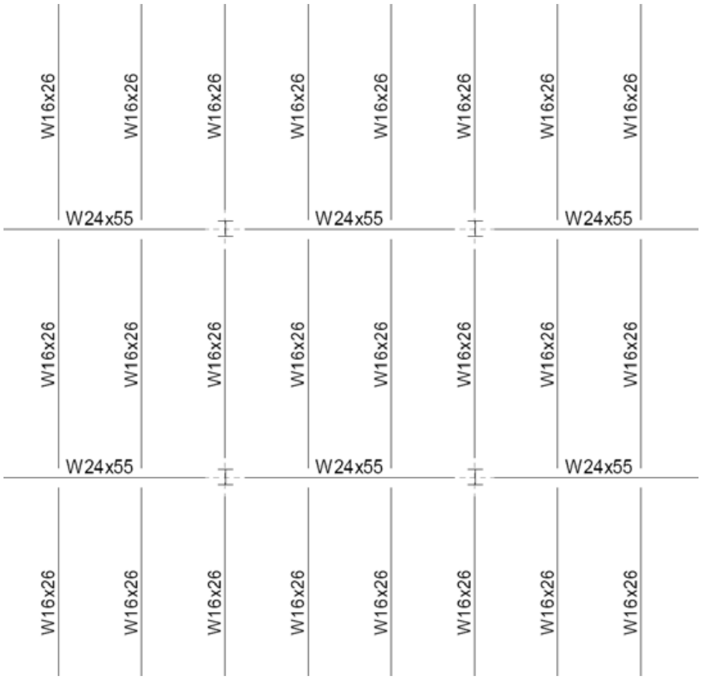


Figure 3.2I. Frame Plan

3.3 Constructability

This constructability study will include a sequence schedule and a site analysis. The sequence schedule will compare installing the VAV system compared to installing the DOAS/Radiant system. The site analysis will give locations of construction equipment and how it affects the surrounding neighborhood.

3.3.1 Sequence Schedule

The sequence schedule is appropriate for installing both the VAV and the DOAS/Radiant system. The expansive areas within the SDPAH accommodate having large lay down areas—areas where construction crews can keep material until it is time for them to install or build it. The spaces within the building are similar which allows for an even distribution of equipment and material.

Each sequence in this schedule includes the construction for five different activities. The first activity is the construction of interior walls. The second set of activities includes the construction of the ceiling plenum. This is done by constructing the systems that are highest in the plenum first. The plumbing piping usually requires a fall for a certain length so this goes into the plenum first. The ductwork takes up a lot of space and is installed next. The sprinklers are installed after the ductwork but before the electrical equipment and lighting is installed last. The sequences will be laid out by wing of each floor.

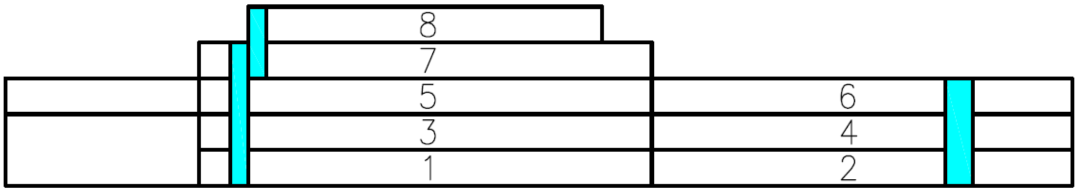


Figure 3.3A. Sequence Numbering.

The first crew will move into space 1 and build the interior walls When they are finished they will move to space 2 (Part a, Figure 3.3B) and the plumbing crew will come in to space 1 to install plumbing lines. The ductwork crew will begin installation after the plumbers and so on and so forth. This is described visually in Figure 3.3B.

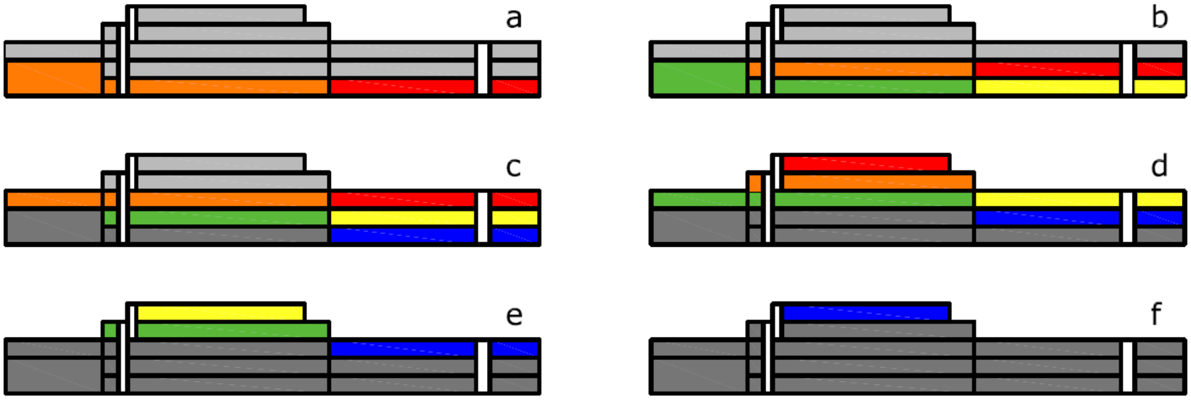


Figure 3.3B. Sequences Started and Finished.

For the VAV system, the ductwork will be assumed to take the longest time to install. From The weight of the galvanized steel ductwork was estimated to be 8 pounds per square foot at 0.2 inches thick. The estimate of the area of ductwork per sequence was taken from the mechanical construction documents and it was found that ductwork would take 35 days to install.

Installation of Ductwork		
Weight of Ductwork	500000	lbs
Total Daily Output	14250	lbs
Duration to Install	35	days

Figure 3.3C. VAV Critical Activity

Installation of Radiant Panels		
Length of Pipe	80000	ft
Total Daily Output	5250	lbs
Duration to Install	15	days

Figure 3.3D. Critical Activity

For the DOAS installation, each sequence will include the same activities as are included in the VAV installation, but with the addition of installing the radiant panels. The radiant panel installation will be included in the ductwork activity. The amount of ductwork included with the DOAS is minimal compared to that included in the VAV application. An assumption will be made that installing the radiant panels will take longer than the other activities—15 days. These activities were modeled using a scheduling program called Primavera. The ductwork and the radiant panels are on the critical path, meaning that if the crews installing this equipment falls behind schedule, it affects the activities after them as well (sprinklers and electrical), putting the whole project behind schedule. The VAV system was found to take 256 days, approximately 8 and ½ months. The radiant panel system was found to take 110 days to install the whole project, approximately 3 and 2/3 months.

3.3.2 Site Analysis

The existing site has many opportunities for easy construction. There are several freight elevators that can be used to move material from floor to floor within the building. Page 10 includes a table of all elevators located within the building. There are loading docks on the 15th Street side of the building where material can be brought into the building. There is a parking lot for Turner's construction office where a crane can be located (the red box). The crane would be necessary to move the chillers and cooling towers onto the roof of the building. The only issues with construction could be getting material into Philadelphia. The downtown location of the building and the tight streets that are around it could make it difficult for delivery trucks to get through. But once on site, construction crews have many paths they can use in order to move the system's equipment throughout the building.

Figure 3.3E. Site Analysis.

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McQuiston, Faye, Parker, Jerald, Spitler, Jeffrey. Heating, Ventilation, and Air Conditioning Analysis and Design. 5th Edition. John Wiley&Sons. 2000.

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The mechanical faculty—especially my advisor, Jae-Weon Jeong—for all their help with this project.

Mike Rush from Cannon Design for answering all of my questions regarding the Administration building’s mechanical system.

Bill Harrington from Turner Construction for giving me a tour of the semi-finished Administration building.

My ipod. ☺

Appendices

Included in this section are

Appendix A

Building Overview

Appendix B

Alternative Mechanical Designs

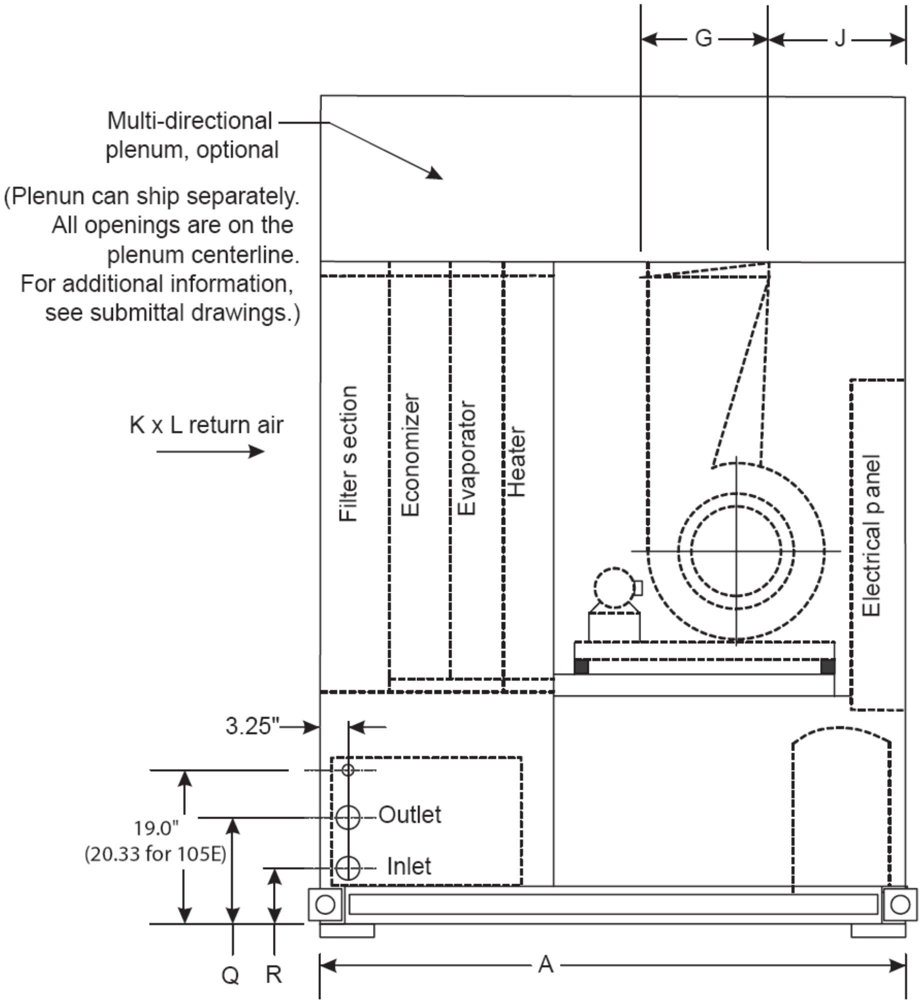
Appendix C

Integration of Structural System and Constructability

Appendix A—Building Overview

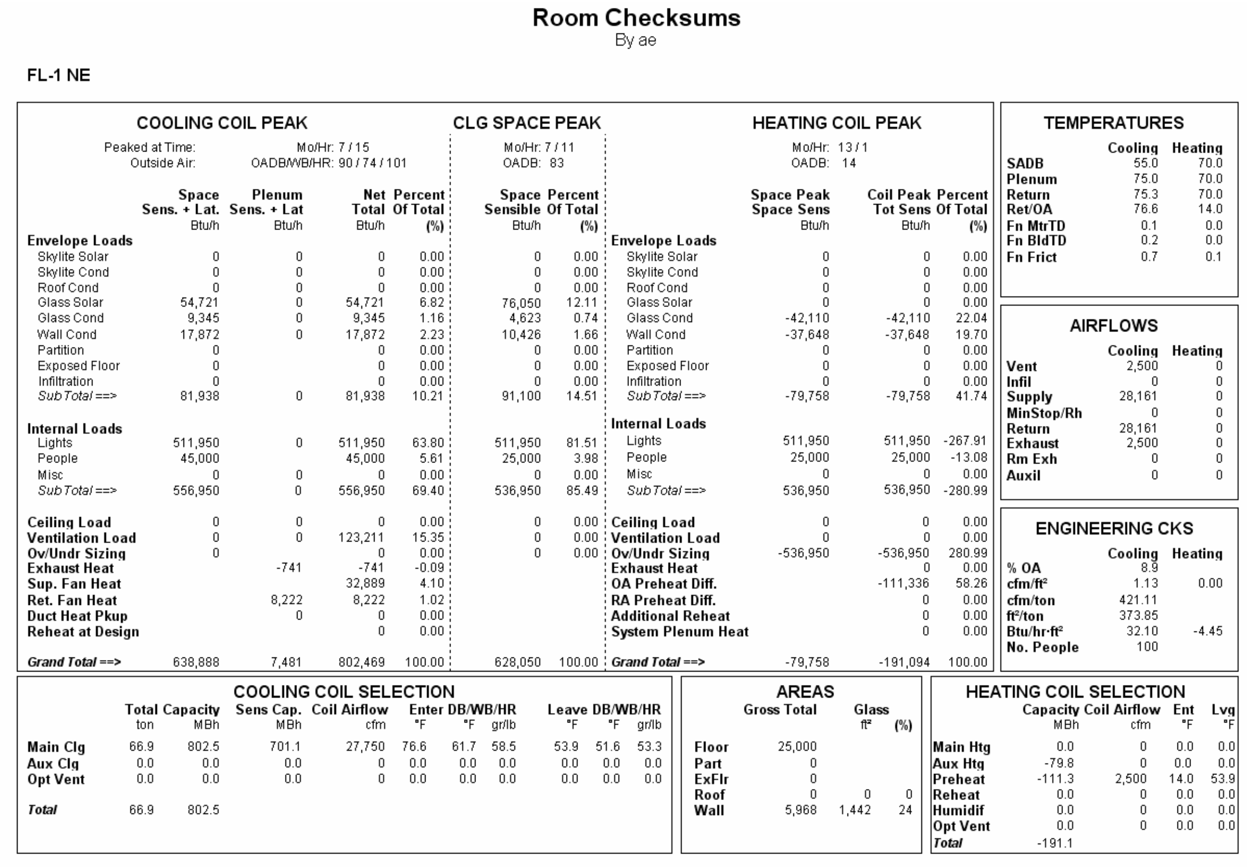
1. McQuay Self-Contained Packaged DX Air Handling Unit with Economizer Coil.
2. Sample Space and Coil Loads for Space FL-1 NE System 1—VAV-DX/Electric.

1. McQuay Self-Contained Packaged DX Air Handling Unit with Economizer Coil.



Appendix 2. Sample Space and Coil Loads for Space FL-1 NE System 1—VAV-DX/Electric.

The internal loads of the heating coil show a positive value which means the space needs cooling even in the winter. The envelope heating loads are negative which means the parallel fan powered box will be activated to supply warm are to that space.



Room Checksums

By ae

FL-1 NE

COOLING COIL PEAK — Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 90 / 74 / 101

CLG SPACE PEAK — Mo/Hr: 7 / 11; OADB: 83

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0.00	0	0.00
Skylite Cond	0	0	0	0.00	0	0.00
Roof Cond	0	0	0	0.00	0	0.00
Glass Solar	54,721	0	54,721	6.82	76,050	12.11
Glass Cond	9,345	0	9,345	1.16	4,623	0.74
Wall Cond	17,872	0	17,872	2.23	10,426	1.66
Partition	0		0	0.00	0	0.00
Exposed Floor	0		0	0.00	0	0.00
Infiltration	0		0	0.00	0	0.00
Sub Total ==>	81,938	0	81,938	10.21	91,100	14.51
Internal Loads						
Lights	511,950	0	511,950	63.80	511,950	81.51
People	45,000		45,000	5.61	25,000	3.98
Misc	0	0	0	0.00	0	0.00
Sub Total ==>	556,950	0	556,950	69.40	536,950	85.49
Ceiling Load	0	0	0	0.00	0	0.00
Ventilation Load	0	0	123,211	15.35	0	0.00
Ov/Undr Sizing	0		0	0.00	0	0.00
Exhaust Heat		-741	-741	-0.09		
Sup. Fan Heat			32,889	4.10		
Ret. Fan Heat		8,222	8,222	1.02		
Duct Heat Pkup		0	0	0.00		
Reheat at Design			0	0.00		
Grand Total ==>	638,888	7,481	802,469	100.00	628,050	100.00

HEATING COIL PEAK — Mo/Hr: 13 / 1; OADB: 14

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	0	0.00
Glass Solar	0	0	0.00
Glass Cond	-42,110	-42,110	22.04
Wall Cond	-37,648	-37,648	19.70
Partition	0	0	0.00
Exposed Floor	0	0	0.00
Infiltration	0	0	0.00
Sub Total ==>	-79,758	-79,758	41.74
Internal Loads			
Lights	511,950	511,950	-267.91
People	25,000	25,000	-13.08
Misc	0	0	0.00
Sub Total ==>	536,950	536,950	-280.99
Ceiling Load	0	0	0.00
Ventilation Load	0	0	0.00
Ov/Undr Sizing	-536,950	-536,950	280.99
Exhaust Heat		0	0.00
OA Preheat Diff.		-111,336	58.26
RA Preheat Diff.		0	0.00
Additional Reheat		0	0.00
System Plenum Heat		0	0.00
Grand Total ==>	-79,758	-191,094	100.00

TEMPERATURES

	Cooling	Heating
SADB	55.0	70.0
Plenum	75.0	70.0
Return	75.3	70.0
Ret/OA	76.6	14.0
Fn MtrTD	0.1	0.0
Fn BldTD	0.2	0.0
Fn Frict	0.7	0.1

AIRFLOWS

	Cooling	Heating
Vent	2,500	0
Infil	0	0
Supply	28,161	0
MinStop/Rh	0	0
Return	28,161	0
Exhaust	2,500	0
Rm Exh	0	0
Auxil	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	8.9	
cfm/ft²	1.13	0.00
cfm/ton	421.11	
ft²/ton	373.85	
Btu/hr·ft²	32.10	-4.45
No. People	100	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter DB/WB/HR °F	Enter DB/WB/HR gr/lb	Leave DB/WB/HR °F	Leave DB/WB/HR °F	Leave DB/WB/HR gr/lb
Main Clg	66.9	802.5	701.1	27,750	76.6	61.7	58.5	53.9	51.6	53.3
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	66.9	802.5								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	25,000		
Part	0		
ExFlr	0		
Roof	0	0	0
Wall	5,968	1,442	24

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	0.0	0	0.0	0.0
Aux Htg	-79.8	0	0.0	0.0
Preheat	-111.3	2,500	14.0	53.9
Reheat	0.0	0	0.0	0.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-191.1			

Appendix B—Alternative Mechanical Designs

1. DOAS Analysis.
2. Supply Air Requirements for VAV System.
3. Mixed Air Conditions.
4. McQuay Air Handling Unit Example Selection Procedure.
5. Mixed Air Dry and Wet Bulb Temperatures.
6. SEMCO Air Handling Unit Example Selection Procedure.
7. Radiant Panel Optimization.
8. System Calcs.
9. Energy Consumption per System.
10. Energy Rates.
11. Yearly Operating Cost.
12. Emissions Generated per System.
13. Floor 4 Systems Analysis Energy Consumption Results.
14. Chilled Water Distribution Schematic—DOAS/Radiant, System 5.

1. DOAS Analysis.

The following figures and tables show the difference in required cooling capacity for the three difference configurations of a DOAS air handling unit.

1. With Enthalpy Wheel and Sensible Wheel.
2. With Enthalpy Wheel.
3. Without Heat Recovery.

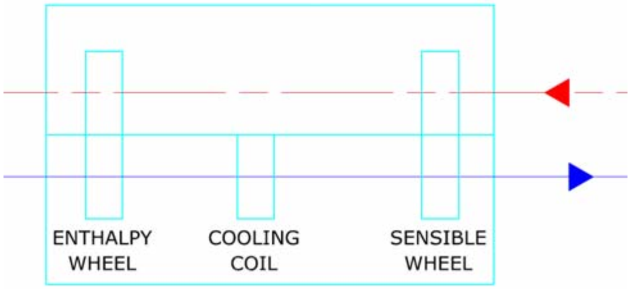


Figure D1. DOAS AHU with Enthalpy Wheel and Sensible Wheel.

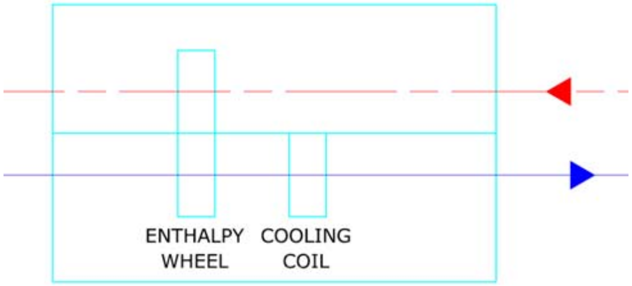


Figure D2. DOAS AHU with Enthalpy Wheel.

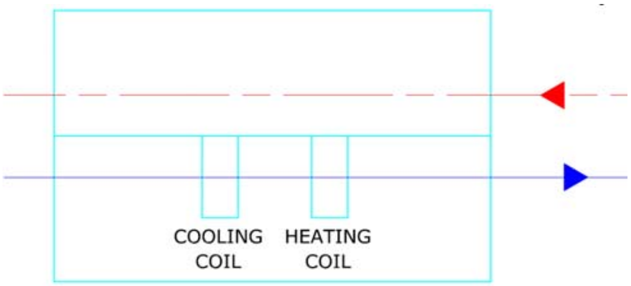
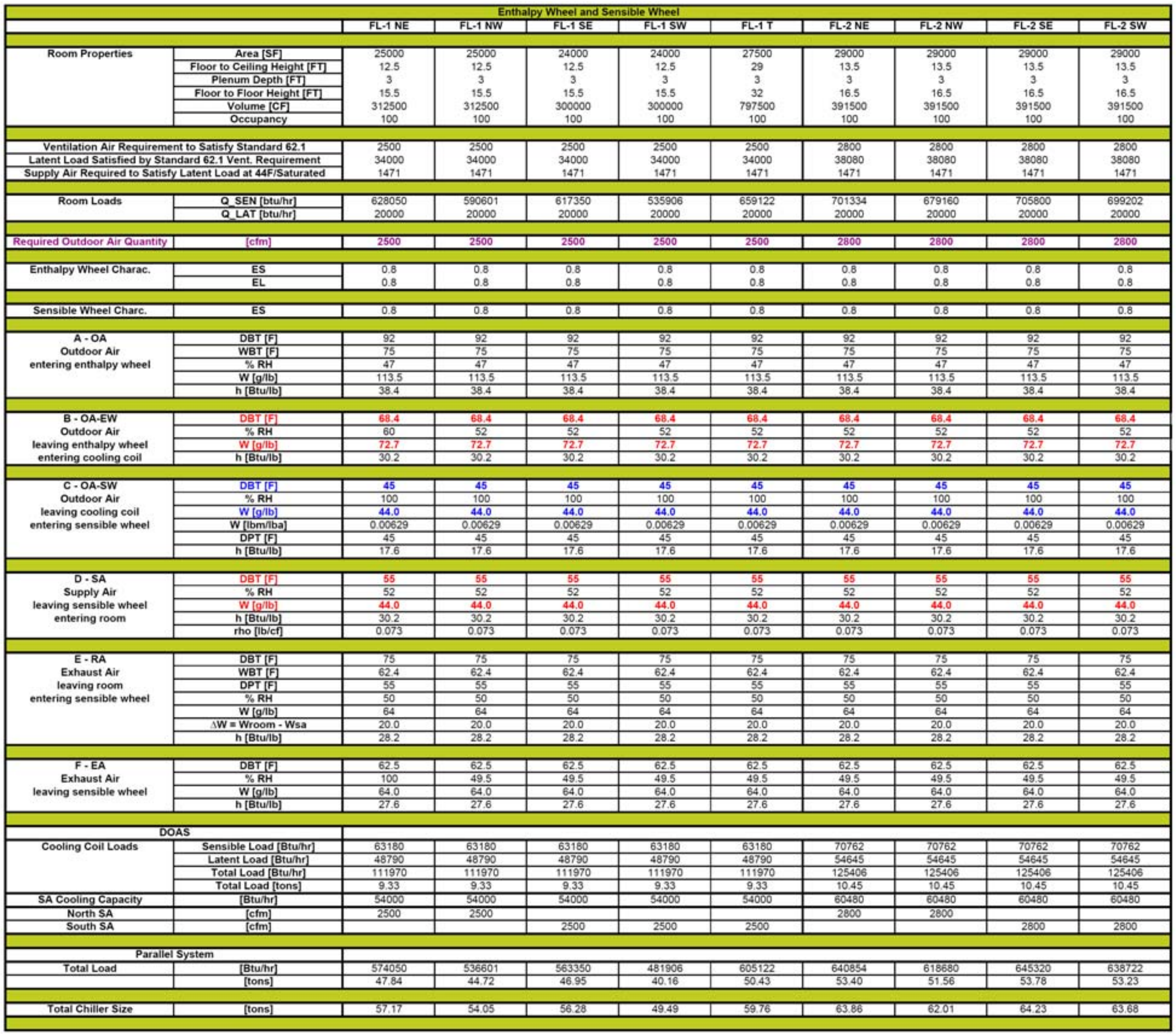


Figure D3. DOAS AHU without Heat Recovery.

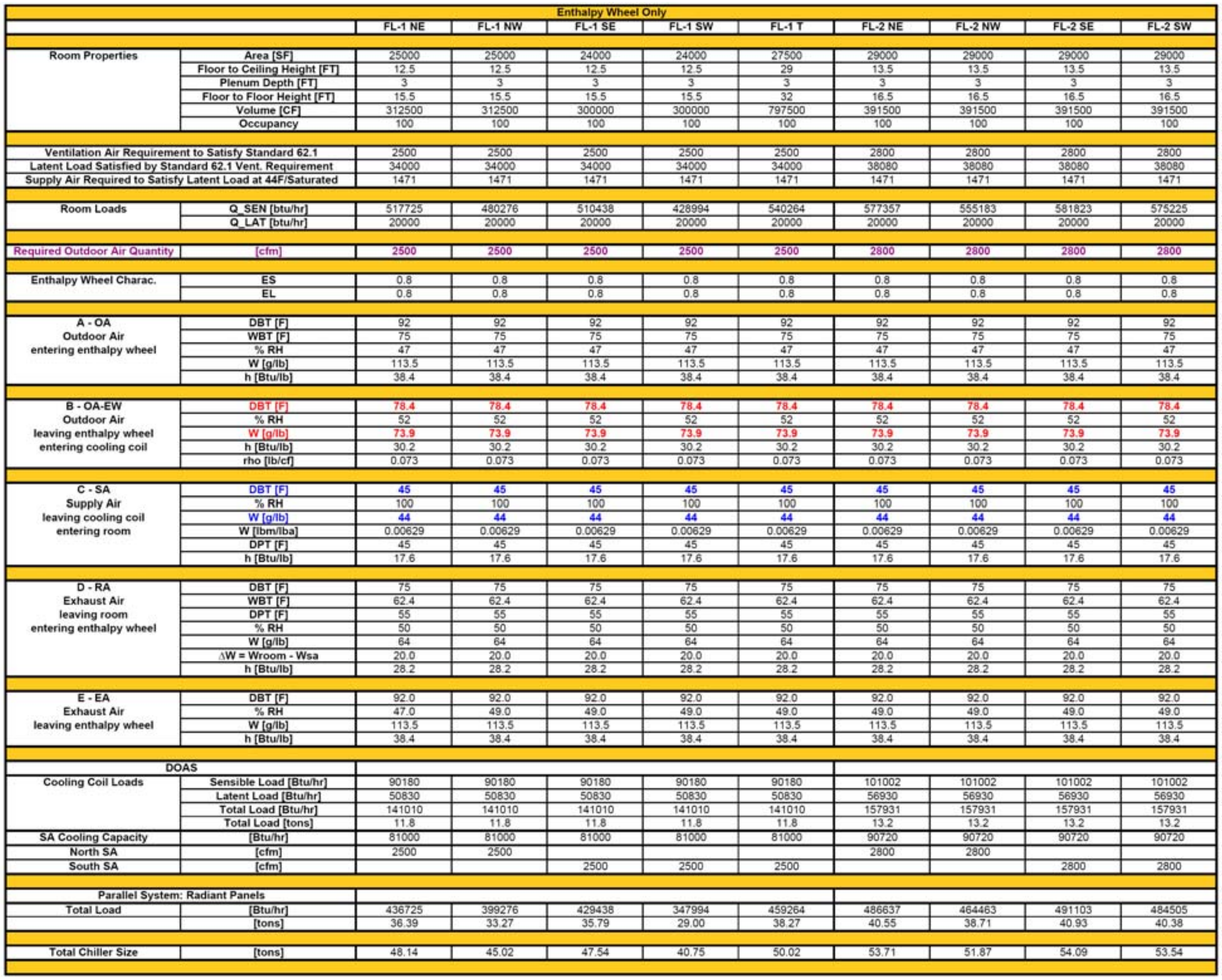
With Enthalpy Wheel and Sensible Wheel.



Enthalpy Wheel and Sensible Wheel

		FL-1 NE	FL-1 NW	FL-1 SE	FL-1 SW	FL-1 T	FL-2 NE	FL-2 NW	FL-2 SE	FL-2 SW
Room Properties	Area [SF]	25000	25000	24000	24000	27500	29000	29000	29000	29000
	Floor to Ceiling Height [FT]	12.5	12.5	12.5	12.5	29	13.5	13.5	13.5	13.5
	Plenum Depth [FT]	3	3	3	3	3	3	3	3	3
	Floor to Floor Height [FT]	15.5	15.5	15.5	15.5	32	16.5	16.5	16.5	16.5
	Volume [CF]	312500	312500	300000	300000	797500	391500	391500	391500	391500
	Occupancy	100	100	100	100	100	100	100	100	100
Ventilation Air Requirement to Satisfy Standard 62.1		2500	2500	2500	2500	2500	2800	2800	2800	2800
Latent Load Satisfied by Standard 62.1 Vent. Requirement		34000	34000	34000	34000	34000	38080	38080	38080	38080
Supply Air Required to Satisfy Latent Load at 44F/Saturated		1471	1471	1471	1471	1471	1471	1471	1471	1471
Room Loads	Q_SEN [btu/hr]	628050	590601	617350	535906	659122	701334	679160	705800	699202
	Q_LAT [btu/hr]	20000	20000	20000	20000	20000	20000	20000	20000	20000
Required Outdoor Air Quantity	[cfm]	2500	2500	2500	2500	2500	2800	2800	2800	2800
Enthalpy Wheel Charac.	ES	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	EL	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Sensible Wheel Charc.	ES	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
A - OA Outdoor Air entering enthalpy wheel	DBT [F]	92	92	92	92	92	92	92	92	92
	WBT [F]	75	75	75	75	75	75	75	75	75
	% RH	47	47	47	47	47	47	47	47	47
	W [g/lb]	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5
	h [Btu/lb]	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4
B - OA-EW Outdoor Air leaving enthalpy wheel entering cooling coil	DBT [F]	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4	68.4
	% RH	60	52	52	52	52	52	52	52	52
	W [g/lb]	72.7	72.7	72.7	72.7	72.7	72.7	72.7	72.7	72.7
	h [Btu/lb]	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2
C - OA-SW Outdoor Air leaving cooling coil entering sensible wheel	DBT [F]	45	45	45	45	45	45	45	45	45
	% RH	100	100	100	100	100	100	100	100	100
	W [g/lb]	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0
	W [lbm/lba]	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629
	DPT [F]	45	45	45	45	45	45	45	45	45
	h [Btu/lb]	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6
D - SA Supply Air leaving sensible wheel entering room	DBT [F]	55	55	55	55	55	55	55	55	55
	% RH	52	52	52	52	52	52	52	52	52
	W [g/lb]	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0
	h [Btu/lb]	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2
	rho [lb/cf]	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073
E - RA Exhaust Air leaving room entering sensible wheel	DBT [F]	75	75	75	75	75	75	75	75	75
	WBT [F]	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4
	DPT [F]	55	55	55	55	55	55	55	55	55
	% RH	50	50	50	50	50	50	50	50	50
	W [g/lb]	64	64	64	64	64	64	64	64	64
	ΔW = Wroom - Wsa	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	h [Btu/lb]	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2
F - EA Exhaust Air leaving sensible wheel	DBT [F]	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5
	% RH	100	49.5	49.5	49.5	49.5	49.5	49.5	49.5	49.5
	W [g/lb]	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0
	h [Btu/lb]	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6
DOAS										
Cooling Coil Loads	Sensible Load [Btu/hr]	63180	63180	63180	63180	63180	70762	70762	70762	70762
	Latent Load [Btu/hr]	48790	48790	48790	48790	48790	54645	54645	54645	54645
	Total Load [Btu/hr]	111970	111970	111970	111970	111970	125406	125406	125406	125406
	Total Load [tons]	9.33	9.33	9.33	9.33	9.33	10.45	10.45	10.45	10.45
SA Cooling Capacity	[Btu/hr]	54000	54000	54000	54000	54000	60480	60480	60480	60480
North SA	[cfm]	2500	2500				2800	2800		
South SA	[cfm]			2500	2500	2500			2800	2800
Parallel System										
Total Load	[Btu/hr]	574050	536601	563350	481906	605122	640854	618680	645320	638722
	[tons]	47.84	44.72	46.95	40.16	50.43	53.40	51.56	53.78	53.23
Total Chiller Size	[tons]	57.17	54.05	56.28	49.49	59.76	63.86	62.01	64.23	63.68

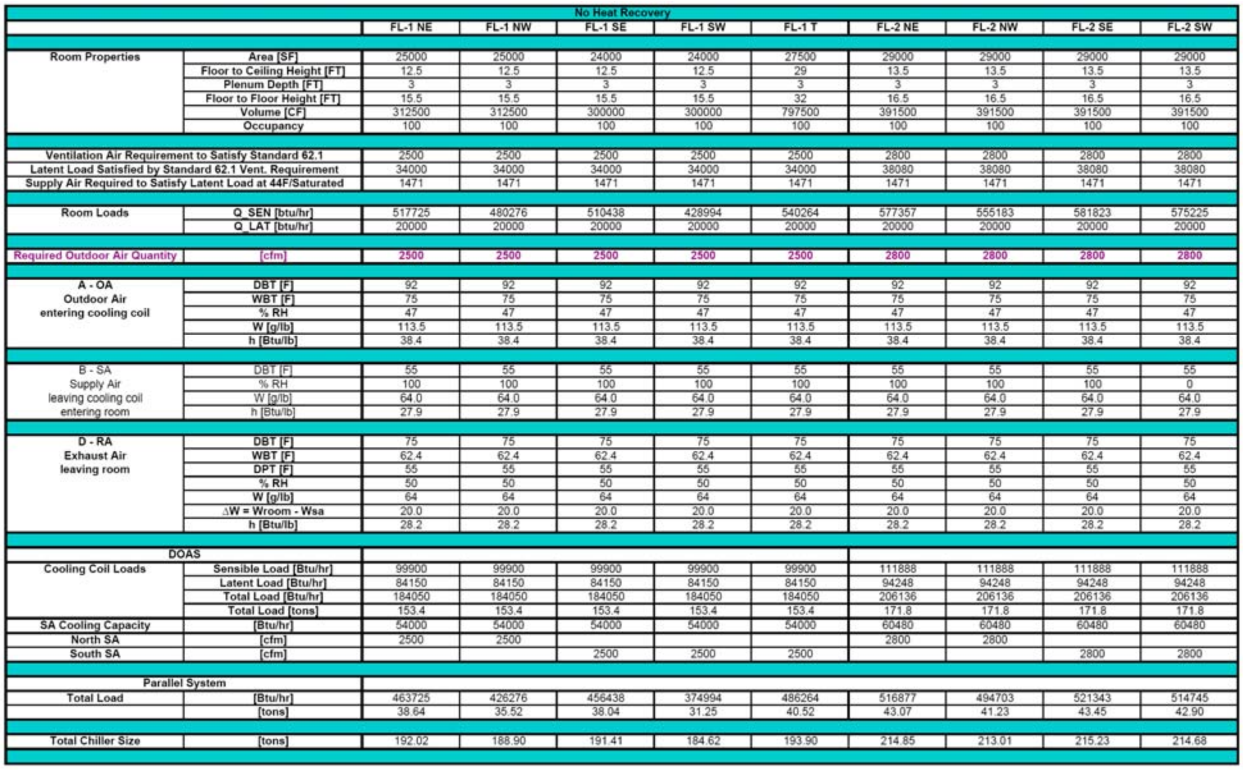
With Enthalpy Wheel.



Enthalpy Wheel Only

		FL-1 NE	FL-1 NW	FL-1 SE	FL-1 SW	FL-1 T	FL-2 NE	FL-2 NW	FL-2 SE	FL-2 SW
Room Properties	Area [SF]	25000	25000	24000	24000	27500	29000	29000	29000	29000
	Floor to Ceiling Height [FT]	12.5	12.5	12.5	12.5	29	13.5	13.5	13.5	13.5
	Plenum Depth [FT]	3	3	3	3	3	3	3	3	3
	Floor to Floor Height [FT]	15.5	15.5	15.5	15.5	32	16.5	16.5	16.5	16.5
	Volume [CF]	312500	312500	300000	300000	797500	391500	391500	391500	391500
	Occupancy	100	100	100	100	100	100	100	100	100
Ventilation Air Requirement to Satisfy Standard 62.1		2500	2500	2500	2500	2500	2800	2800	2800	2800
Latent Load Satisfied by Standard 62.1 Vent. Requirement		34000	34000	34000	34000	34000	38080	38080	38080	38080
Supply Air Required to Satisfy Latent Load at 44F/Saturated		1471	1471	1471	1471	1471	1471	1471	1471	1471
Room Loads	Q_SEN [btu/hr]	517725	480276	510438	428994	540264	577357	555183	581823	575225
	Q_LAT [btu/hr]	20000	20000	20000	20000	20000	20000	20000	20000	20000
Required Outdoor Air Quantity	[cfm]	2500	2500	2500	2500	2500	2800	2800	2800	2800
Enthalpy Wheel Charac.	ES	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	EL	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
A - OA Outdoor Air entering enthalpy wheel	DBT [F]	92	92	92	92	92	92	92	92	92
	WBT [F]	75	75	75	75	75	75	75	75	75
	% RH	47	47	47	47	47	47	47	47	47
	W [g/lb]	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5
	h [Btu/lb]	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4
B - OA-EW Outdoor Air leaving enthalpy wheel entering cooling coil	DBT [F]	78.4	78.4	78.4	78.4	78.4	78.4	78.4	78.4	78.4
	% RH	52	52	52	52	52	52	52	52	52
	W [g/lb]	73.9	73.9	73.9	73.9	73.9	73.9	73.9	73.9	73.9
	h [Btu/lb]	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2
	rho [lb/cf]	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073
C - SA Supply Air leaving cooling coil entering room	DBT [F]	45	45	45	45	45	45	45	45	45
	% RH	100	100	100	100	100	100	100	100	100
	W [g/lb]	44	44	44	44	44	44	44	44	44
	W [lbm/lba]	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629
	DPT [F]	45	45	45	45	45	45	45	45	45
	h [Btu/lb]	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6
D - RA Exhaust Air leaving room entering enthalpy wheel	DBT [F]	75	75	75	75	75	75	75	75	75
	WBT [F]	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4
	DPT [F]	55	55	55	55	55	55	55	55	55
	% RH	50	50	50	50	50	50	50	50	50
	W [g/lb]	64	64	64	64	64	64	64	64	64
	ΔW = Wroom - Wsa	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	h [Btu/lb]	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2
E - EA Exhaust Air leaving enthalpy wheel	DBT [F]	92.0	92.0	92.0	92.0	92.0	92.0	92.0	92.0	92.0
	% RH	47.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0
	W [g/lb]	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5
	h [Btu/lb]	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4
DOAS										
Cooling Coil Loads	Sensible Load [Btu/hr]	90180	90180	90180	90180	90180	101002	101002	101002	101002
	Latent Load [Btu/hr]	50830	50830	50830	50830	50830	56930	56930	56930	56930
	Total Load [Btu/hr]	141010	141010	141010	141010	141010	157931	157931	157931	157931
	Total Load [tons]	11.8	11.8	11.8	11.8	11.8	13.2	13.2	13.2	13.2
SA Cooling Capacity	[Btu/hr]	81000	81000	81000	81000	81000	90720	90720	90720	90720
North SA	[cfm]	2500	2500				2800	2800		
South SA	[cfm]			2500	2500	2500			2800	2800
Parallel System: Radiant Panels										
Total Load	[Btu/hr]	436725	399276	429438	347994	459264	486637	464463	491103	484505
	[tons]	36.39	33.27	35.79	29.00	38.27	40.55	38.71	40.93	40.38
Total Chiller Size	[tons]	48.14	45.02	47.54	40.75	50.02	53.71	51.87	54.09	53.54

Without Heat Recovery.



No Heat Recovery

		FL-1 NE	FL-1 NW	FL-1 SE	FL-1 SW	FL-1 T	FL-2 NE	FL-2 NW	FL-2 SE	FL-2 SW
Room Properties	Area [SF]	25000	25000	24000	24000	27500	29000	29000	29000	29000
	Floor to Ceiling Height [FT]	12.5	12.5	12.5	12.5	29	13.5	13.5	13.5	13.5
	Plenum Depth [FT]	3	3	3	3	3	3	3	3	3
	Floor to Floor Height [FT]	15.5	15.5	15.5	15.5	32	16.5	16.5	16.5	16.5
	Volume [CF]	312500	312500	300000	300000	797500	391500	391500	391500	391500
	Occupancy	100	100	100	100	100	100	100	100	100
Ventilation Air Requirement to Satisfy Standard 62.1		2500	2500	2500	2500	2500	2800	2800	2800	2800
Latent Load Satisfied by Standard 62.1 Vent. Requirement		34000	34000	34000	34000	34000	38080	38080	38080	38080
Supply Air Required to Satisfy Latent Load at 44F/Saturated		1471	1471	1471	1471	1471	1471	1471	1471	1471
Room Loads	Q_SEN [btu/hr]	517725	480276	510438	428994	540264	577357	555183	581823	575225
	Q_LAT [btu/hr]	20000	20000	20000	20000	20000	20000	20000	20000	20000
Required Outdoor Air Quantity	[cfm]	2500	2500	2500	2500	2500	2800	2800	2800	2800
A - OA Outdoor Air entering cooling coil	DBT [F]	92	92	92	92	92	92	92	92	92
	WBT [F]	75	75	75	75	75	75	75	75	75
	% RH	47	47	47	47	47	47	47	47	47
	W [g/lb]	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5
	h [Btu/lb]	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4
B - SA Supply Air leaving cooling coil entering room	DBT [F]	55	55	55	55	55	55	55	55	55
	% RH	100	100	100	100	100	100	100	100	0
	W [g/lb]	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0
	h [Btu/lb]	27.9	27.9	27.9	27.9	27.9	27.9	27.9	27.9	27.9
D - RA Exhaust Air leaving room	DBT [F]	75	75	75	75	75	75	75	75	75
	WBT [F]	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4
	DPT [F]	55	55	55	55	55	55	55	55	55
	% RH	50	50	50	50	50	50	50	50	50
	W [g/lb]	64	64	64	64	64	64	64	64	64
	∆W = Wroom - Wsa	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	h [Btu/lb]	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2
DOAS										
Cooling Coil Loads	Sensible Load [Btu/hr]	99900	99900	99900	99900	99900	111888	111888	111888	111888
	Latent Load [Btu/hr]	84150	84150	84150	84150	84150	94248	94248	94248	94248
	Total Load [Btu/hr]	184050	184050	184050	184050	184050	206136	206136	206136	206136
	Total Load [tons]	153.4	153.4	153.4	153.4	153.4	171.8	171.8	171.8	171.8
SA Cooling Capacity	[Btu/hr]	54000	54000	54000	54000	54000	60480	60480	60480	60480
North SA	[cfm]	2500	2500				2800	2800		
South SA	[cfm]			2500	2500	2500			2800	2800
Parallel System										
Total Load	[Btu/hr]	463725	426276	456438	374994	486264	516877	494703	521343	514745
	[tons]	38.64	35.52	38.04	31.25	40.52	43.07	41.23	43.45	42.90
Total Chiller Size	[tons]	192.02	188.90	191.41	184.62	193.90	214.85	213.01	215.23	214.68

2. Supply Air Requirements for VAV System.

Based on the calculation procedure in the body of this report, the following airflows were found.

			Std. 62.1	Summer							Winter				
			Vent. Air	Supply Air				Outdoor Air	Supply Air	Return Air	Supply Air		Outdoor Air	Supply Air	Return Air
	Occupancy	Floor Area	CFM	Sensible Load	CFM	Latent Load	CFM	CFM	CFM	CFM	Sensible Load	CFM	CFM	CFM	CFM
FLOOR 1															
FL-1 NE	100	25000	2500	628050	29076	20000	2451	2500	31576	29076	454693	28067	2500	30567	28067
FL-1 NW	100	25000	2500	590601	27343	20000	2451	2500	29843	27343	468519	28921	2500	31421	28921
FL-1 SE	100	24000	2500	617350	28581	20000	2451	2500	31081	28581	462339	28539	2500	31039	28539
FL-1 SW	100	24000	2500	535906	24810	20000	2451	2500	27310	24810	490562	30282	2500	32782	30282
FL-1 T	100	27500	2700	659122	30515	20000	2451	2700	33215	30515	467564	28862	2700	31562	28862
FLOOR 2															
FL-2 NE	100	29000	2800	701334	32469	20000	2451	2800	35269	32469	539666	33313	2800	36113	33313
FL-2 NW	100	29000	2800	679160	31443	20000	2451	2800	34243	31443	551052	34016	2800	36816	34016
FL-2 SE	100	29000	2800	705800	32676	20000	2451	2800	35476	32676	566174	34949	2800	37749	34949
FL-2 SW	100	29000	2800	699202	32370	20000	2451	2800	35170	32370	571899	35302	2800	38102	35302
FLOOR 3															
FL-3 NE	100	29000	2800	711863	32957	20000	2451	2800	35757	32957	372900	23019	2800	25819	23019
FL-3 NW	100	29000	2800	742208	34361	20000	2451	2800	37161	34361	373045	23027	2800	25827	23027
FL-3 SE	100	29000	2800	704972	32638	20000	2451	2800	35438	32638	522584	32258	2800	35058	32258
FL-3 SW	100	29000	2800	716604	33176	20000	2451	2800	35976	33176	524713	32390	2800	35190	32390
FL-3 T	100	28000	2800	666900	30875	20000	2451	2800	33675	30875	371753	22948	2800	25748	22948
FLOOR 5															
FL-5 E	100	19250	2500	497134	23015	20000	2451	2500	25515	23015	224206	13840	2500	16340	13840
FL-5 W	100	19250	2500	514744	23831	20000	2451	2500	26331	23831	225693	13932	2500	16432	13932

3. Mixed Air Conditions.

For the DOAS/VAV application, the outdoor air is mixed with the VAV supply air after both are conditioned separately. The temperature of the mixed air had to be calculated to check if it is within an acceptable range. Supplying air between 54F and 56F is acceptable.

	VAV Supply Air		DOAS Supply Air		Mixed Supply Air	
	Quantity	Dry Bulb T	Quantity	Dry Bulb Te	Quantity	Dry Bulb
Space	CFM	F	CFM	F	CFM	F
			FLOOR 1			
FL-1 NE	25200	55	2500	45	27700	54.10
FL-1 NW	25200	55	2500	45	27700	54.10
FL-1 SE	23750	55	2500	45	26250	54.05
FL-1 SW	23750	55	2500	45	26250	54.05
FL-1 T	27300	55	2500	45	29800	54.16
			FLOOR 2			
FL-2 NE	28500	55	2800	45	31300	54.11
FL-2 NW	28500	55	2800	45	31300	54.11
FL-2 SE	29000	55	2800	45	31800	54.12
FL-2 SW	29000	55	2800	45	31800	54.12
			FLOOR 3			
FL-3 NE	30000	55	2800	45	32800	54.15
FL-3 NW	30000	55	2800	45	32800	54.15
FL-3 SE	29450	55	2800	45	32250	54.13
FL-3 SW	29450	55	2800	45	32250	54.13
FL-3 T	27200	55	2800	45	30000	54.07
			FLOOR 5			
FL-5 E	20700	55	2500	45	23200	53.92
FL-5 W	20700	55	2500	45	23200	53.92

Table E1. DOAS/VAV Summer Mixed Air Conditions.

	VAV Supply Air		DOAS Supply Air		Mixed Supply Air	
	Quantity	Dry Bulb T	Quantity	Dry Bulb Te	Quantity	Dry Bulb
Space	CFM	F	CFM	F	CFM	F
FLOOR 1						
FL-1 NE	25200	55	1950	58.2	27150	55.23
FL-1 NW	25200	55	1950	58.2	27150	55.23
FL-1 SE	23750	55	1890	58.2	25640	55.24
FL-1 SW	23750	55	1890	58.2	25640	55.24
FL-1 T	27300	55	2150	58.2	29450	55.23
FLOOR 2						
FL-2 NE	28500	55	2080	58.2	30580	55.22
FL-2 NW	28500	55	2075	58.2	30575	55.22
FL-2 SE	29000	55	2080	58.2	31080	55.21
FL-2 SW	29000	55	2075	58.2	31075	55.21
FLOOR 3						
FL-3 NE	30000	55	2190	58.2	32190	55.22
FL-3 NW	30000	55	2190	58.2	32190	55.22
FL-3 SE	29450	55	2190	58.2	31640	55.22
FL-3 SW	29450	55	2190	58.2	31640	55.22
FL-3 T	27200	55	2080	58.2	29280	55.23
FLOOR 5						
FL-5 E	20700	55	1605	58.2	22305	55.23
FL-5 W	20700	55	1605	58.2	22305	55.23

Table E2. DOAS/VAV Winter Mixed Air Conditions.

4. McQuay Air Handling Unit Example Selection Procedure.

This example is for the FL-1 NE VAV air handling unit in the DOAS/VAV system.

1. Find Maximum Face Area

Supply Air Quantity = 25200CFM
Maximum Face Area = Supply Air Quantity/Maximum Face Velocity
= 25200CFM/500FPM = 50.4SF
*Check SWP080 with Face Area of 51.1SF

2. Find CFM Correction Factor

CFM Correction Factor = Supply Air Quantity/Nominal CFM
= 25200CFM/30660CFM = 0.82

3A. DX Coil Selection

DX Cooling Capacity Correction Factors
Total Heat = 0.968+((0.82-0.8)*100)*0.0006 = 0.969
Sensible Heat = 0.9+((0.82-0.8)*100)*0.005 = 0.911
Capacity Required by Space = 562.370MBH [Thousand Btu/h]
Total Capacity Required by Coil = 562.370/0.969 = 580.36MBH
Total Sensible Capacity Required by Coil =562.370/0.911 =617.31MBH
Total Capacity Available from SWP080F = 907MBH
Sensible Capacity Available from SWP080F = 708MBH
*Both are capacities are greater than what is required, SWP080F is ok!
SWP080F: 80F EDB, 67F EWB, 85F EWT, 56.8 LDB, 56.7 LWB, 214GPM

3B. Cooling Coil Selection

For the chilled water application, the chilled water coils were selected using Carrier's Air Handling Unit Builder. A typical coil was sized for each unit based on the average supply air quantity (32750CFM), total and sensible cooling capacity (668Mbh/648Mbh). A 4 row, 8 fin per inch coil was chosen with 45F EWT, 55F LWT, 782 SMbh, 691 TMbh, 5.6' P.D., and 156GPM.

4. Find Condenser Flow Rate

Condenser Flow Rate = 214GPM*Total Heat Correction Factor

= 214GPM*0.969 = 207GPM

5. Economizer Coil Selection

Economizer Cooling Capacity Correction Factors

Total Heat = 0.92+((0.82-0.8)*100)*0.004 = 0.929

Sensible Heat = 0.87+((0.82-0.8)*100)*0.006 = 0.883

Capacity Required by Space = 562.370MBH

Total Capacity Required by Coil = 562.370*0.929 = 494MBH

Total Sensible Capacity Required by Coil = 562.370*0.883 = 469MBH

Economizer Flow Rate = Condenser Flow Rate = 207GPM

Total Capacity Available from SWP080F = 592MBH

Sensible Capacity Available from SWP080F = 558MBH

*Both are capacities are greater than what is required, SWP080F is ok!

SWP080F: 55F EWT, 80F EDB, 67F EWB, 61.8F LDB, 60.5F LWB, 61.0F LWT

6A. Electric Heating Coil Capacity

68KW, 232MBH

6B. Hot Water Coil Capacity

1058MBH, 155.8F LWT, 100.0F LDB, 90GPM

7A. Fan/Motor Selection with Electric Heating Coil

Internal Static Pressure [ISP]

Filter: 0.251625 inches water gage [in wg]

Economizer: 0.413250 in wg

DX coil: 0.778750 in wg

Discharge Plenum: 0.461000 in wg

ISP = 0.251625 + 0.413250 + 0.778750 + 0.461000 = 1.904625 in wg

External Static Pressure [ESP]

Supply Duct: 1.00 in wg

EXP = 1.00 in wg

Total Static Pressure = ISP + ESP = 2.904625 in wg

*A 25HP airfoil fan is chosen

7B. Fan/Motor Selection with Hot Water Coil

Internal Static Pressure [ISP]

Filter:	0.251625 inches water gage [in wg]
Economizer:	0.413250 in wg
Cooling Coil:	0.778750 in wg
HW coil:	0.147750 in wg
Discharge Plenum:	0.461000 in wg

ISP = 0.251625 + 0.413250 + 0.778750 + 0.147750 + 0.461000

= 2.052375 in wg

External Static Pressure [ESP]

Supply Duct: 1.00 in wg

EXP = 1.00 in wg

Total Static Pressure = ISP + ESP = 3.052375 in wg

*A 25HP airfoil fan is chosen

8. Unit Size and Weight

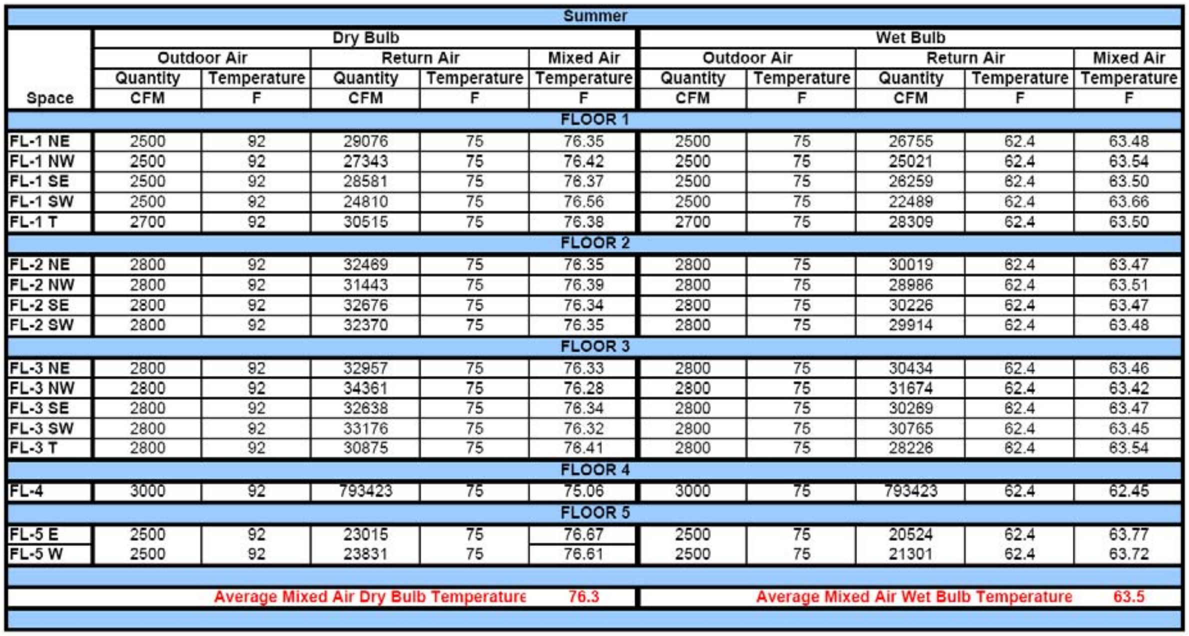
Size: 144L x 84W x 88H (in inches)

Weight:

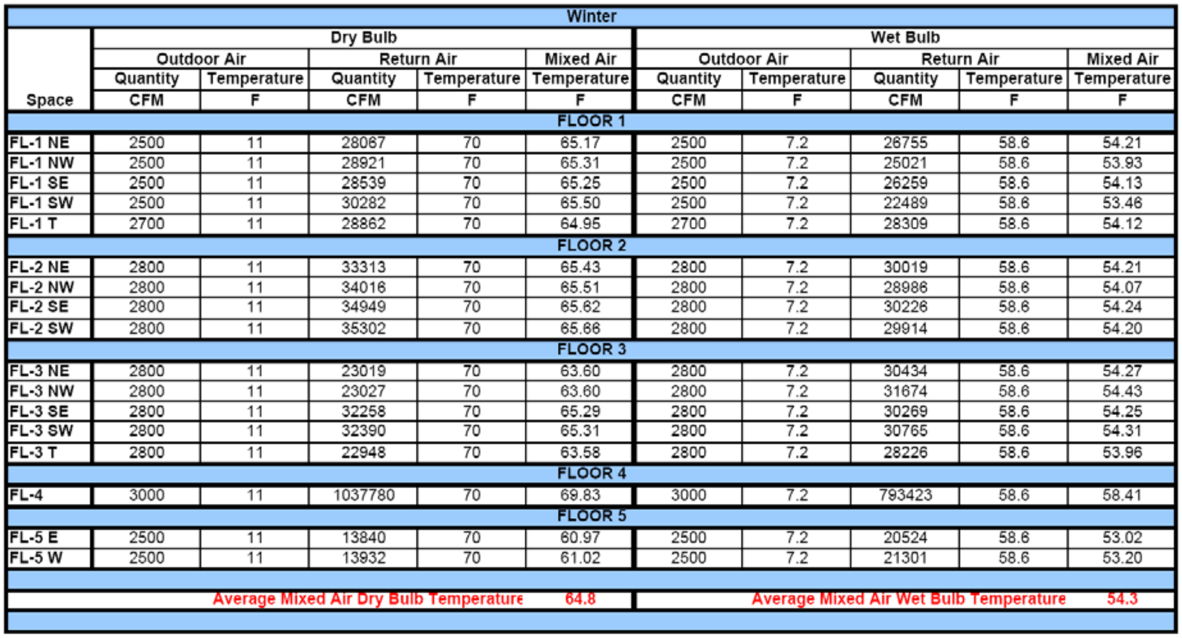
Basic Unit:	4021 lbs
Filter:	96 lbs
Evaporator Coil:	755 lbs
Economizer Coil:	723 lbs
Economizer Water Weight:	203 lbs
Electric Heating Coil:	40 lbs
Supply Fan Motor:	366 lbs
Discharge Plenum:	1003 lbs
Compressor/Condenser:	1684 lbs
Variable Frequency Drive:	100 lbs
*Total	8991 lbs

5. Mixed Air Dry and Wet Bulb Temperatures.

When using Carrier's Air Handling Unit Builder, the entering air dry and wet bulb temperatures are required to size a cooling coil. This table shows the mixed air conditions entering the VAV unit for conditioning.



Summer										
	Dry Bulb					Wet Bulb				
	Outdoor Air		Return Air		Mixed Air	Outdoor Air		Return Air		Mixed Air
	Quantity	Temperature	Quantity	Temperature	Temperature	Quantity	Temperature	Quantity	Temperature	Temperature
Space	CFM	F	CFM	F	F	CFM	F	CFM	F	F
FLOOR 1										
FL-1 NE	2500	92	29076	75	76.35	2500	75	26755	62.4	63.48
FL-1 NW	2500	92	27343	75	76.42	2500	75	25021	62.4	63.54
FL-1 SE	2500	92	28581	75	76.37	2500	75	26259	62.4	63.50
FL-1 SW	2500	92	24810	75	76.56	2500	75	22489	62.4	63.66
FL-1 T	2700	92	30515	75	76.38	2700	75	28309	62.4	63.50
FLOOR 2										
FL-2 NE	2800	92	32469	75	76.35	2800	75	30019	62.4	63.47
FL-2 NW	2800	92	31443	75	76.39	2800	75	28986	62.4	63.51
FL-2 SE	2800	92	32676	75	76.34	2800	75	30226	62.4	63.47
FL-2 SW	2800	92	32370	75	76.35	2800	75	29914	62.4	63.48
FLOOR 3										
FL-3 NE	2800	92	32957	75	76.33	2800	75	30434	62.4	63.46
FL-3 NW	2800	92	34361	75	76.28	2800	75	31674	62.4	63.42
FL-3 SE	2800	92	32638	75	76.34	2800	75	30269	62.4	63.47
FL-3 SW	2800	92	33176	75	76.32	2800	75	30765	62.4	63.45
FL-3 T	2800	92	30875	75	76.41	2800	75	28226	62.4	63.54
FLOOR 4										
FL-4	3000	92	793423	75	75.06	3000	75	793423	62.4	62.45
FLOOR 5										
FL-5 E	2500	92	23015	75	76.67	2500	75	20524	62.4	63.77
FL-5 W	2500	92	23831	75	76.61	2500	75	21301	62.4	63.72
		Average Mixed Air Dry Bulb Temperature			76.3		Average Mixed Air Wet Bulb Temperature			63.5



Winter										
	Dry Bulb					Wet Bulb				
	Outdoor Air		Return Air		Mixed Air	Outdoor Air		Return Air		Mixed Air
	Quantity	Temperature	Quantity	Temperature	Temperature	Quantity	Temperature	Quantity	Temperature	Temperature
Space	CFM	F	CFM	F	F	CFM	F	CFM	F	F
FLOOR 1										
FL-1 NE	2500	11	28067	70	65.17	2500	7.2	26755	58.6	54.21
FL-1 NW	2500	11	28921	70	65.31	2500	7.2	25021	58.6	53.93
FL-1 SE	2500	11	28539	70	65.25	2500	7.2	26259	58.6	54.13
FL-1 SW	2500	11	30282	70	65.50	2500	7.2	22489	58.6	53.46
FL-1 T	2700	11	28862	70	64.95	2700	7.2	28309	58.6	54.12
FLOOR 2										
FL-2 NE	2800	11	33313	70	65.43	2800	7.2	30019	58.6	54.21
FL-2 NW	2800	11	34016	70	65.51	2800	7.2	28986	58.6	54.07
FL-2 SE	2800	11	34949	70	65.62	2800	7.2	30226	58.6	54.24
FL-2 SW	2800	11	35302	70	65.66	2800	7.2	29914	58.6	54.20
FLOOR 3										
FL-3 NE	2800	11	23019	70	63.60	2800	7.2	30434	58.6	54.27
FL-3 NW	2800	11	23027	70	63.60	2800	7.2	31674	58.6	54.43
FL-3 SE	2800	11	32258	70	65.29	2800	7.2	30269	58.6	54.25
FL-3 SW	2800	11	32390	70	65.31	2800	7.2	30765	58.6	54.31
FL-3 T	2800	11	22948	70	63.58	2800	7.2	28226	58.6	53.96
FLOOR 4										
FL-4	3000	11	1037780	70	69.83	3000	7.2	793423	58.6	58.41
FLOOR 5										
FL-5 E	2500	11	13840	70	60.97	2500	7.2	20524	58.6	53.02
FL-5 W	2500	11	13932	70	61.02	2500	7.2	21301	58.6	53.20
		Average Mixed Air Dry Bulb Temperature			64.8		Average Mixed Air Wet Bulb Temperature			54.3

6. SEMCO Air Handling Unit Example Selection Procedure.

This example is for the North DOAS air handling unit.

1. Select Unit Based on Supply Air Quantity

Supply Air Quantity = 14400CFM

*Choose EP-24 with a minimum 11000CFM and maximum 18000CFM

2. Select Unit Configuration

In addition to the cooling/dehumidification done by the enthalpy wheel in the summer, additional cooling will be needed to obtain the required supply temperature.

In addition to the heating/humidification done by the enthalpy wheel in the winter, the outdoor air will need additional heating.

*Choose EPCH-24 with a cooling and heating coil

3. Determine Total Static Pressure for Supply Side

Internal Static Pressure [ISP]

OA Opening: 0.085 in wg
SA Opening: 0.085 in wg
Damper: 0.094 in wg
OA Filter: 0.434 in wg
Wheel: 0.569 in wg
CHW Coil: 0.564 in wg
HW Coil: 0.095 in wg
Casing: 0.300 in wg
Total: 2.226 in wg

External Static Pressure [ESP]

Supply Duct: 1.000 in wg

*Total Static Pressure = ISP + ESP = 3.226 in wg

4. Determine Total Static Pressure for Return Side

Internal Static Pressure [ISP]

EA Opening: 0.254 in wg
RA Opening: 0.254 in wg

Damper: 0.094 in wg

RA Filter: 0.534 in wg

Wheel: 0.569 in wg

Casing: 0.300 in wg

Total: 2.005 in wg

External Static Pressure [ESP]

Supply Duct: 0.500 in wg

*Total Static Pressure = ISP + ESP = 2.505 in wg

5. Determine Total Supply Air Volume

Purge/Seal Air Volume = 1735CFM

*Total Supply Air Volume = 14400CFM + 1735CFM = 16135CFM

6. Determine Motor Horsepower

Supply Motor: 13.4HP

Return Motor: 10.8HP

*Choose 15HP motors for both the supply fan and return fan

7. Base Wheel Effectiveness: 80.6%

8. Unit Size and Weight

Size: 262L x 122W x 110H (in inches)

Weight: 8450 lbs

7. Radiant Panel Optimization.

The supply water temperature had to be supplied at a higher temperature than the room dew point temperature.

Supply Water Temperature Analysis	
RA DPT [F]	55
Inlet Water Temperature [F]	56
Assumed Temp Rise [F]	10
Mean Water Temperature [F]	61.0
RA DBT - MWT [F]	14.0

Table J1. Supply Water Temperature Analysis.

A flow rate of 1GPM can have 17 panels on one circuit, will have 6.8' pressure drop per circuit, will absorb 5000Btu/hr, and will require 841GPM total flow. These results are only for floors 1 and 2.

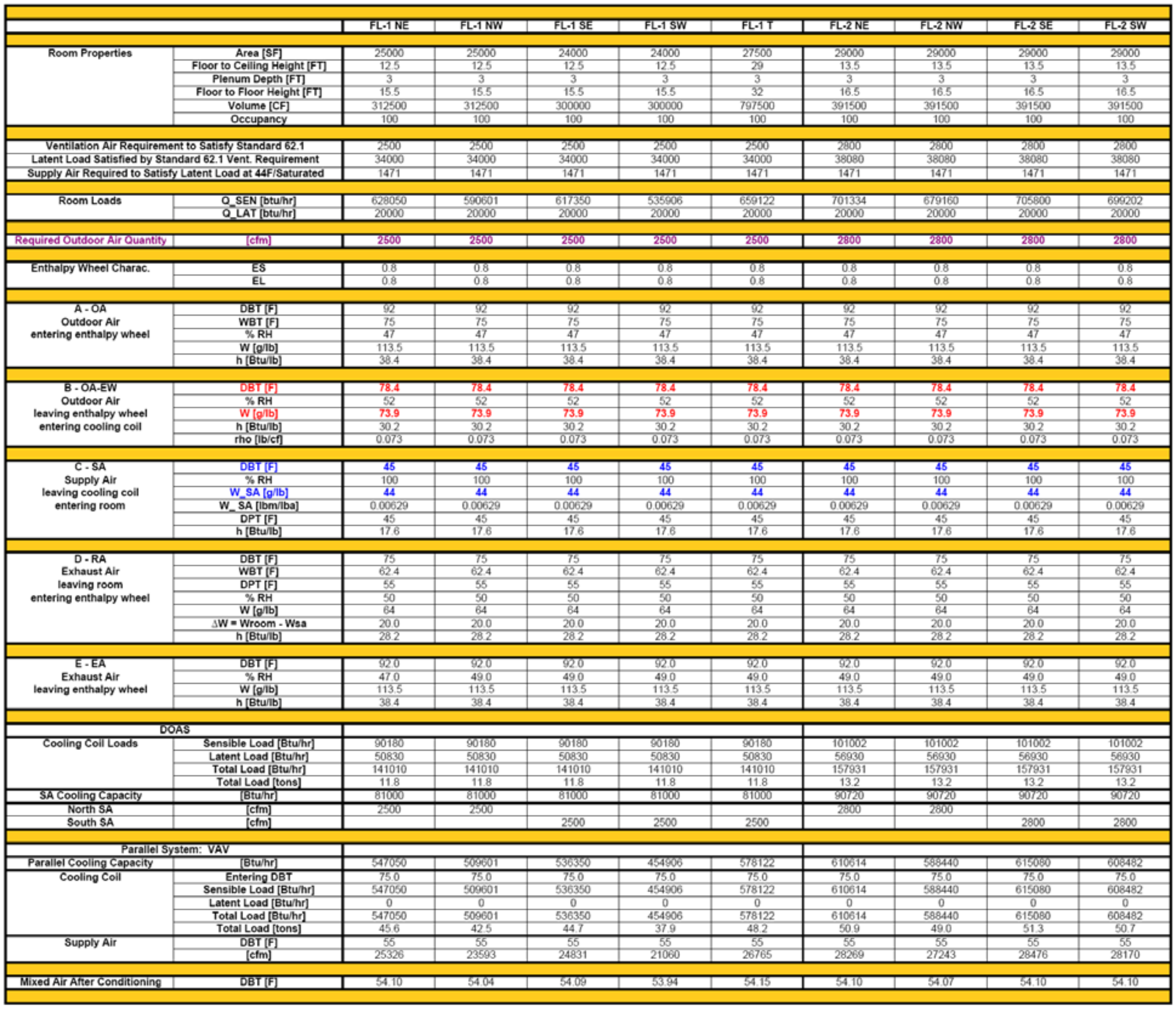
Max Pressure Drop per 2'x4'	Flow Rate	Absorption Capacity f. Flow Rate	# Panels	Pressure Drop per Circuit	# Circuits	Total Flow
5 pass	**gpm**	**Btu/hr**		**ft. wg.**		**gpm**
0.1	0.5	2500	8	0.8	1786	893
0.4	**1**	**5000**	**17**	**6.8**	**841**	**841**
1.4	2	10000	35	49.0	409	818
2	2.5	12500	44	88.0	325	813
2.8	3	15000	53	148.4	270	810

Table J2. Flow Optimization.

8. System Calculations.

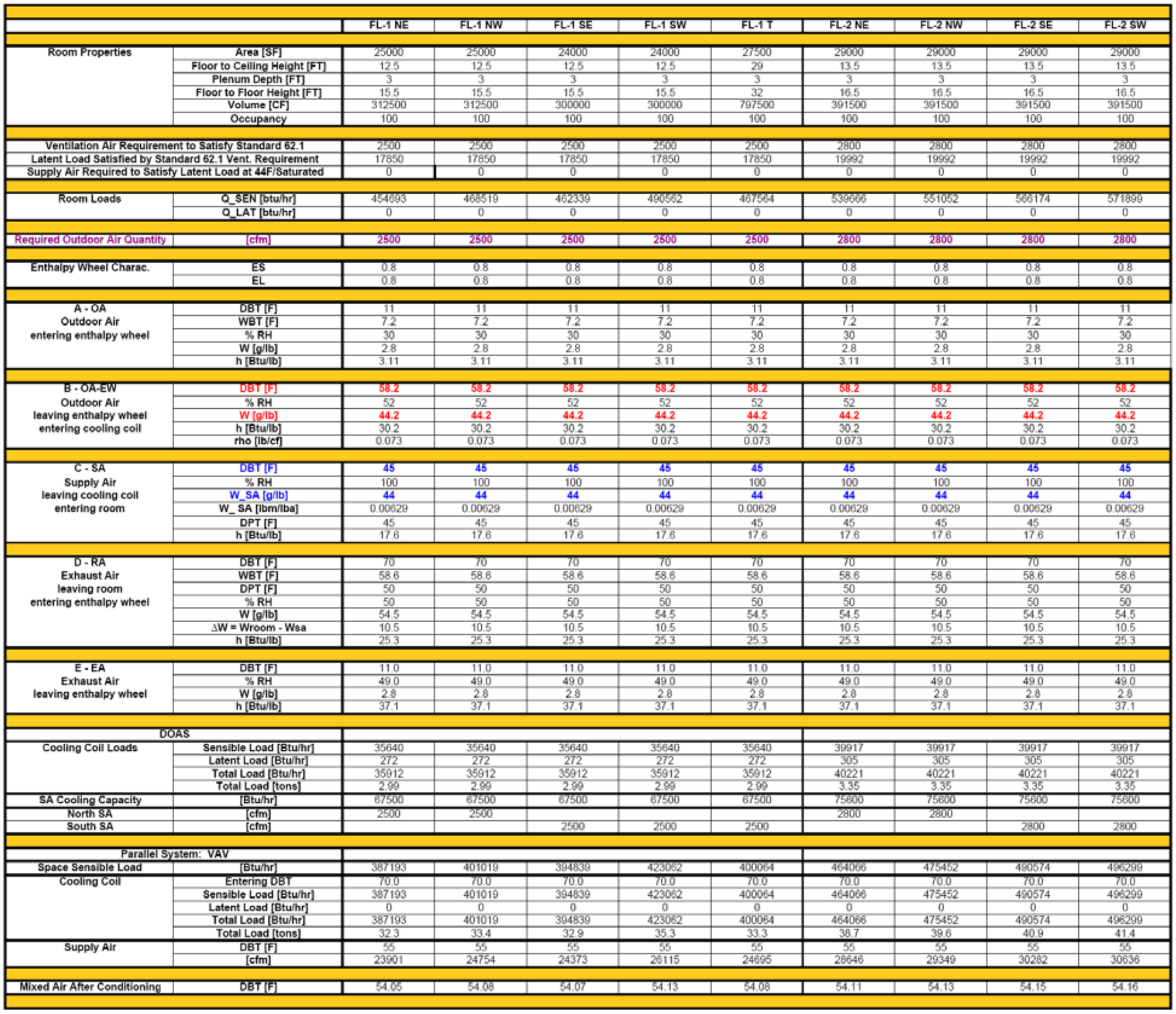
Calculations were documented for each system. The VAV only case is in Appendix E.

DOAS/VAV Summer Calcs—Floors 1 and 2



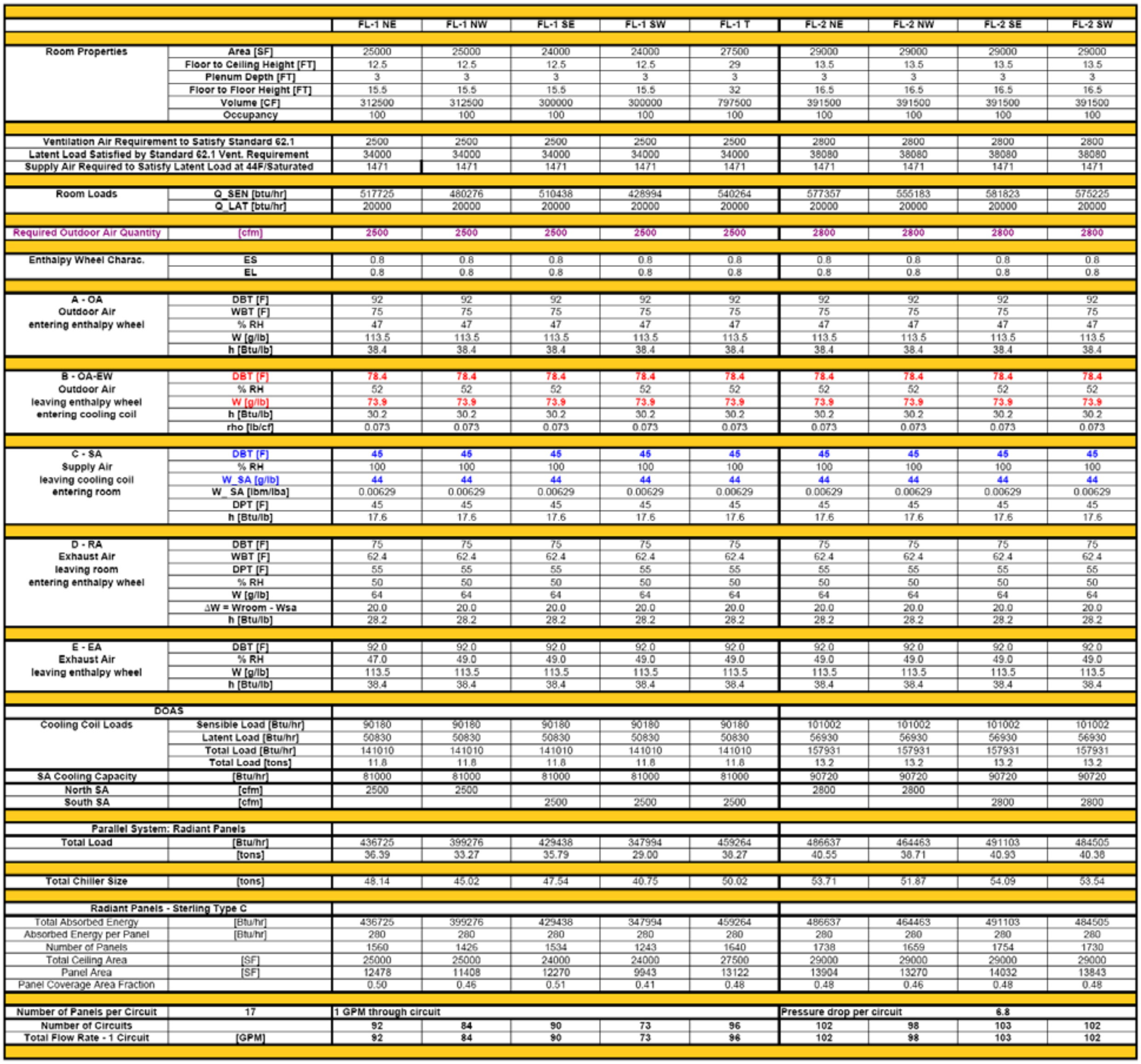
		FL-1 NE	FL-1 NW	FL-1 SE	FL-1 SW	FL-1 T	FL-2 NE	FL-2 NW	FL-2 SE	FL-2 SW
Room Properties	Area [SF]	25000	25000	24000	24000	27500	29000	29000	29000	29000
	Floor to Ceiling Height [FT]	12.5	12.5	12.5	12.5	29	13.5	13.5	13.5	13.5
	Plenum Depth [FT]	3	3	3	3	3	3	3	3	3
	Floor to Floor Height [FT]	15.5	15.5	15.5	15.5	32	16.5	16.5	16.5	16.5
	Volume [CF]	312500	312500	300000	300000	797500	391500	391500	391500	391500
	Occupancy	100	100	100	100	100	100	100	100	100
Ventilation Air Requirement to Satisfy Standard 62.1		2500	2500	2500	2500	2500	2800	2800	2800	2800
Latent Load Satisfied by Standard 62.1 Vent. Requirement		34000	34000	34000	34000	34000	38080	38080	38080	38080
Supply Air Required to Satisfy Latent Load at 44F/Saturated		1471	1471	1471	1471	1471	1471	1471	1471	1471
Room Loads	Q_SEN [btu/hr]	628050	590601	617350	535906	659122	701334	679160	705800	699202
	Q_LAT [btu/hr]	20000	20000	20000	20000	20000	20000	20000	20000	20000
Required Outdoor Air Quantity	[cfm]	2500	2500	2500	2500	2500	2800	2800	2800	2800
Enthalpy Wheel Charac.	ES	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	EL	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
A - OA Outdoor Air entering enthalpy wheel	DBT [F]	92	92	92	92	92	92	92	92	92
	WBT [F]	75	75	75	75	75	75	75	75	75
	% RH	47	47	47	47	47	47	47	47	47
	W [g/lb]	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5
	h [Btu/lb]	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4
B - OA-EW Outdoor Air leaving enthalpy wheel entering cooling coil	DBT [F]	78.4	78.4	78.4	78.4	78.4	78.4	78.4	78.4	78.4
	% RH	52	52	52	52	52	52	52	52	52
	W [g/lb]	73.9	73.9	73.9	73.9	73.9	73.9	73.9	73.9	73.9
	h [Btu/lb]	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2
	rho [lb/cf]	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073
C - SA Supply Air leaving cooling coil entering room	DBT [F]	45	45	45	45	45	45	45	45	45
	% RH	100	100	100	100	100	100	100	100	100
	W_SA [g/lb]	44	44	44	44	44	44	44	44	44
	W_ SA [lbm/lba]	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629
	DPT [F]	45	45	45	45	45	45	45	45	45
	h [Btu/lb]	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6
D - RA Exhaust Air leaving room entering enthalpy wheel	DBT [F]	75	75	75	75	75	75	75	75	75
	WBT [F]	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4
	DPT [F]	55	55	55	55	55	55	55	55	55
	% RH	50	50	50	50	50	50	50	50	50
	W [g/lb]	64	64	64	64	64	64	64	64	64
	ΔW = Wroom - Wsa	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	h [Btu/lb]	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2
E - EA Exhaust Air leaving enthalpy wheel	DBT [F]	92.0	92.0	92.0	92.0	92.0	92.0	92.0	92.0	92.0
	% RH	47.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0
	W [g/lb]	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5
	h [Btu/lb]	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4
DOAS										
Cooling Coil Loads	Sensible Load [Btu/hr]	90180	90180	90180	90180	90180	101002	101002	101002	101002
	Latent Load [Btu/hr]	50830	50830	50830	50830	50830	56930	56930	56930	56930
	Total Load [Btu/hr]	141010	141010	141010	141010	141010	157931	157931	157931	157931
	Total Load [tons]	11.8	11.8	11.8	11.8	11.8	13.2	13.2	13.2	13.2
SA Cooling Capacity	[Btu/hr]	81000	81000	81000	81000	81000	90720	90720	90720	90720
North SA	[cfm]	2500	2500				2800	2800		
South SA	[cfm]			2500	2500	2500			2800	2800
Parallel System: VAV										
Parallel Cooling Capacity	[Btu/hr]	547050	509601	536350	454906	578122	610614	588440	615080	608482
Cooling Coil	Entering DBT	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0
	Sensible Load [Btu/hr]	547050	509601	536350	454906	578122	610614	588440	615080	608482
	Latent Load [Btu/hr]	0	0	0	0	0	0	0	0	0
	Total Load [Btu/hr]	547050	509601	536350	454906	578122	610614	588440	615080	608482
	Total Load [tons]	45.6	42.5	44.7	37.9	48.2	50.9	49.0	51.3	50.7
Supply Air	DBT [F]	55	55	55	55	55	55	55	55	55
	[cfm]	25326	23593	24831	21060	26765	28269	27243	28476	28170
Mixed Air After Conditioning	DBT [F]	54.10	54.04	54.09	53.94	54.15	54.10	54.07	54.10	54.10

DOAS/VAV Winter Calcs—Floors 1 and 2



		FL-1 NE	FL-1 NW	FL-1 SE	FL-1 SW	FL-1 T	FL-2 NE	FL-2 NW	FL-2 SE	FL-2 SW
Room Properties	Area [SF]	25000	25000	24000	24000	27500	29000	29000	29000	29000
	Floor to Ceiling Height [FT]	12.5	12.5	12.5	12.5	29	13.5	13.5	13.5	13.5
	Plenum Depth [FT]	3	3	3	3	3	3	3	3	3
	Floor to Floor Height [FT]	15.5	15.5	15.5	15.5	32	16.5	16.5	16.5	16.5
	Volume [CF]	312500	312500	300000	300000	797500	391500	391500	391500	391500
	Occupancy	100	100	100	100	100	100	100	100	100
Ventilation Air Requirement to Satisfy Standard 62.1		2500	2500	2500	2500	2500	2800	2800	2800	2800
Latent Load Satisfied by Standard 62.1 Vent. Requirement		17850	17850	17850	17850	17850	19992	19992	19992	19992
Supply Air Required to Satisfy Latent Load at 44F/Saturated		0	0	0	0	0	0	0	0	0
Room Loads	Q_SEN [btu/hr]	454693	468519	462339	490562	467564	539666	551052	566174	571899
	Q_LAT [btu/hr]	0	0	0	0	0	0	0	0	0
Required Outdoor Air Quantity	[cfm]	2500	2500	2500	2500	2500	2800	2800	2800	2800
Enthalpy Wheel Charac.	ES	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	EL	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
A - OA Outdoor Air entering enthalpy wheel	DBT [F]	11	11	11	11	11	11	11	11	11
	WBT [F]	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2
	% RH	30	30	30	30	30	30	30	30	30
	W [g/lb]	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
	h [Btu/lb]	3.11	3.11	3.11	3.11	3.11	3.11	3.11	3.11	3.11
B - OA-EW Outdoor Air leaving enthalpy wheel entering cooling coil	DBT [F]	58.2	58.2	58.2	58.2	58.2	58.2	58.2	58.2	58.2
	% RH	52	52	52	52	52	52	52	52	52
	W [g/lb]	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2	44.2
	h [Btu/lb]	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2
	rho [lb/cf]	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073
C - SA Supply Air leaving cooling coil entering room	DBT [F]	45	45	45	45	45	45	45	45	45
	% RH	100	100	100	100	100	100	100	100	100
	W_SA [g/lb]	44	44	44	44	44	44	44	44	44
	W_ SA [lbm/lba]	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629
	DPT [F]	45	45	45	45	45	45	45	45	45
	h [Btu/lb]	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6
D - RA Exhaust Air leaving room entering enthalpy wheel	DBT [F]	70	70	70	70	70	70	70	70	70
	WBT [F]	58.6	58.6	58.6	58.6	58.6	58.6	58.6	58.6	58.6
	DPT [F]	50	50	50	50	50	50	50	50	50
	% RH	50	50	50	50	50	50	50	50	50
	W [g/lb]	54.5	54.5	54.5	54.5	54.5	54.5	54.5	54.5	54.5
	∆W = Wroom - Wsa	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
	h [Btu/lb]	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3
E - EA Exhaust Air leaving enthalpy wheel	DBT [F]	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
	% RH	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0
	W [g/lb]	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
	h [Btu/lb]	37.1	37.1	37.1	37.1	37.1	37.1	37.1	37.1	37.1
DOAS										
Cooling Coil Loads	Sensible Load [Btu/hr]	35640	35640	35640	35640	35640	39917	39917	39917	39917
	Latent Load [Btu/hr]	272	272	272	272	272	305	305	305	305
	Total Load [Btu/hr]	35912	35912	35912	35912	35912	40221	40221	40221	40221
	Total Load [tons]	2.99	2.99	2.99	2.99	2.99	3.35	3.35	3.35	3.35
SA Cooling Capacity	[Btu/hr]	67500	67500	67500	67500	67500	75600	75600	75600	75600
North SA	[cfm]	2500	2500				2800	2800		
South SA	[cfm]			2500	2500	2500			2800	2800
Parallel System: VAV										
Space Sensible Load	[Btu/hr]	387193	401019	394839	423062	400064	464066	475452	490574	496299
Cooling Coil	Entering DBT	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
	Sensible Load [Btu/hr]	387193	401019	394839	423062	400064	464066	475452	490574	496299
	Latent Load [Btu/hr]	0	0	0	0	0	0	0	0	0
	Total Load [Btu/hr]	387193	401019	394839	423062	400064	464066	475452	490574	496299
	Total Load [tons]	32.3	33.4	32.9	35.3	33.3	38.7	39.6	40.9	41.4
Supply Air	DBT [F]	55	55	55	55	55	55	55	55	55
	[cfm]	23901	24754	24373	26115	24695	28646	29349	30282	30636
Mixed Air After Conditioning	DBT [F]	54.05	54.08	54.07	54.13	54.08	54.11	54.13	54.15	54.16

DOAS/Radiant Summer Calcs—Floors 1 and 2



		FL-1 NE	FL-1 NW	FL-1 SE	FL-1 SW	FL-1 T	FL-2 NE	FL-2 NW	FL-2 SE	FL-2 SW
Room Properties	Area [SF]	25000	25000	24000	24000	27500	29000	29000	29000	29000
	Floor to Ceiling Height [FT]	12.5	12.5	12.5	12.5	29	13.5	13.5	13.5	13.5
	Plenum Depth [FT]	3	3	3	3	3	3	3	3	3
	Floor to Floor Height [FT]	15.5	15.5	15.5	15.5	32	16.5	16.5	16.5	16.5
	Volume [CF]	312500	312500	300000	300000	797500	391500	391500	391500	391500
	Occupancy	100	100	100	100	100	100	100	100	100
Ventilation Air Requirement to Satisfy Standard 62.1		2500	2500	2500	2500	2500	2800	2800	2800	2800
Latent Load Satisfied by Standard 62.1 Vent. Requirement		34000	34000	34000	34000	34000	38080	38080	38080	38080
Supply Air Required to Satisfy Latent Load at 44F/Saturated		1471	1471	1471	1471	1471	1471	1471	1471	1471
Room Loads	Q_SEN [btu/hr]	517725	480276	510438	428994	540264	577357	555183	581823	575225
	Q_LAT [btu/hr]	20000	20000	20000	20000	20000	20000	20000	20000	20000
Required Outdoor Air Quantity	[cfm]	**2500**	**2500**	**2500**	**2500**	**2500**	**2800**	**2800**	**2800**	**2800**
Enthalpy Wheel Charac.	ES	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	EL	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
A - OA Outdoor Air entering enthalpy wheel	DBT [F]	92	92	92	92	92	92	92	92	92
	WBT [F]	75	75	75	75	75	75	75	75	75
	% RH	47	47	47	47	47	47	47	47	47
	W [g/lb]	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5
	h [Btu/lb]	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4
B - OA-EW Outdoor Air leaving enthalpy wheel entering cooling coil	DBT [F]	**78.4**	**78.4**	**78.4**	**78.4**	**78.4**	**78.4**	**78.4**	**78.4**	**78.4**
	% RH	52	52	52	52	52	52	52	52	52
	W [g/lb]	**73.9**	**73.9**	**73.9**	**73.9**	**73.9**	**73.9**	**73.9**	**73.9**	**73.9**
	h [Btu/lb]	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2
	rho [lb/cf]	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073	0.073
C - SA Supply Air leaving cooling coil entering room	DBT [F]	**45**	**45**	**45**	**45**	**45**	**45**	**45**	**45**	**45**
	% RH	100	100	100	100	100	100	100	100	100
	W_SA [g/lb]	**44**	**44**	**44**	**44**	**44**	**44**	**44**	**44**	**44**
	W_ SA [lbm/lba]	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629	0.00629
	DPT [F]	45	45	45	45	45	45	45	45	45
	h [Btu/lb]	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6
D - RA Exhaust Air leaving room entering enthalpy wheel	DBT [F]	75	75	75	75	75	75	75	75	75
	WBT [F]	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4	62.4
	DPT [F]	55	55	55	55	55	55	55	55	55
	% RH	50	50	50	50	50	50	50	50	50
	W [g/lb]	64	64	64	64	64	64	64	64	64
	ΔW = Wroom - Wsa	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
	h [Btu/lb]	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2
E - EA Exhaust Air leaving enthalpy wheel	DBT [F]	92.0	92.0	92.0	92.0	92.0	92.0	92.0	92.0	92.0
	% RH	47.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0	49.0
	W [g/lb]	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5	113.5
	h [Btu/lb]	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4	38.4
DOAS										
Cooling Coil Loads	Sensible Load [Btu/hr]	90180	90180	90180	90180	90180	101002	101002	101002	101002
	Latent Load [Btu/hr]	50830	50830	50830	50830	50830	56930	56930	56930	56930
	Total Load [Btu/hr]	141010	141010	141010	141010	141010	157931	157931	157931	157931
	Total Load [tons]	11.8	11.8	11.8	11.8	11.8	13.2	13.2	13.2	13.2
SA Cooling Capacity	[Btu/hr]	81000	81000	81000	81000	81000	90720	90720	90720	90720
North SA	[cfm]	2500	2500				2800	2800		
South SA	[cfm]			2500	2500	2500			2800	2800
Parallel System: Radiant Panels										
Total Load	[Btu/hr]	436725	399276	429438	347994	459264	486637	464463	491103	484505
	[tons]	36.39	33.27	35.79	29.00	38.27	40.55	38.71	40.93	40.38
Total Chiller Size	[tons]	48.14	45.02	47.54	40.75	50.02	53.71	51.87	54.09	53.54
Radiant Panels - Sterling Type C										
Total Absorbed Energy	[Btu/hr]	436725	399276	429438	347994	459264	486637	464463	491103	484505
Absorbed Energy per Panel	[Btu/hr]	280	280	280	280	280	280	280	280	280
Number of Panels		1560	1426	1534	1243	1640	1738	1659	1754	1730
Total Ceiling Area	[SF]	25000	25000	24000	24000	27500	29000	29000	29000	29000
Panel Area	[SF]	12478	11408	12270	9943	13122	13904	13270	14032	13843
Panel Coverage Area Fraction		0.50	0.46	0.51	0.41	0.48	0.48	0.46	0.48	0.48
Number of Panels per Circuit	17	1 GPM through circuit					Pressure drop per circuit		6.8	
Number of Circuits		92	84	90	73	96	102	98	103	102
Total Flow Rate - 1 Circuit	[GPM]	92	84	90	73	96	102	98	103	102

9. Energy Consumption per System.

Values were taken from TRACE based on the energy consumption of each modeled system.

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**

System 2

	Electric Consumption (kWh)	Gas Consumption (therms)	Water Consumption (1000 gallons)	Percent of Total Energy %	**Total Source Energy (kBtu/yr)**
Primary Heating					
Primary Heating	22539.0	49555.3		5.0	**54471.5**
Primary Cooling					
Cooling Compressor	2110947.8			7.2	**216161.6**
Tower/Cond Fans	672199.4		23481.1	2.3	**68833.4**
Condenser Pump	489990.5			1.7	**50175.1**
Other CLG Accessories	0.0			0.0	**0.0**
Cooling Subtotal	3273137.7		23481.1	11.2	**335170.1**
Auxiliary					
Supply Fans	2062866.7			7.0	**211238.0**
Circ Pumps	335646.8			1.1	**34370.3**
Base Utilities	0.0			0.0	**0.0**
Aux Subtotal	2398513.5			8.1	**245608.3**
Lighting/Equipment					
Lighting/Equipment	22285440.0			75.7	**2282034.3**
Totals	27979630.2		23481.1	100.0	**2917284.2**

System 3

	Electric Consumption	Gas Consumption	Water Consumption	Percent of Total Energy	**Total Source Energy**
	(kWh)	(therms)	(1000 gallons)	%	**(kBtu/yr)**
Primary Heating					
Primary Heating	1119320.9	0.0		3.3	**114618.7**
Primary Cooling					
Cooling Compressor	6815661.0			19.9	**697925.3**
Tower/Cond Fans	439288.9		28450.5	1.3	**44983.3**
Condenser Pump	1238664.8			3.6	**126839.6**
Other CLG Accessories	876.0			0.0	**89.7**
Cooling Subtotal	8494490.7		28450.5	24.8	**869837.9**
Auxiliary					
Supply Fans	2300449.5			6.7	**235566.6**
Circ Pumps	0.0			0.0	**0.0**
Base Utilities	0.0			0.0	**0.0**
Aux Subtotal	2300449.5			6.7	**235566.6**
Lighting/Equipment					
Lighting/Equipment	22285440.0			65.2	**2282034.3**
Totals	34199701.1		28450.5	100.0	**3502057.5**

System 4

	Electric Consumption	Gas Consumption	Water Consumption	Percent of Total Energy	**Total Source Energy**
	(kWh)	(therms)	(1000 gallons)	%	**(kBtu/yr)**
Primary Heating					
Primary Heating	22539.8	45861.2		4.6	**50583.0**
Primary Cooling					
Cooling Compressor	2238820.0			7.5	**229255.7**
Tower/Cond Fans	669206.8		24287.1	2.2	**68526.9**
Condenser Pump	478854.3			1.6	**49034.8**
Other CLG Accessories	0.0			0.0	**0.0**
Cooling Subtotal	3386881.1		24287.1	11.3	**346817.4**
Auxiliary					
Supply Fans	2300449.5			7.7	**235566.6**
Circ Pumps	526663.6			1.8	**53930.5**
Base Utilities	0.0			0.0	**0.0**
Aux Subtotal	2827113.1			9.5	**289497.1**
Lighting/Equipment					
Lighting/Equipment	22285440.0			74.6	**2282034.3**
Totals	28521974.0		24287.1	100.0	**2968931.8**

System 5

	Electric Consumption (kWh)	Gas Consumption (therms)	Water Consumption (1000 gallons)	Percent of Total Energy %	**Total Source Energy (kBtu/yr)**
Primary Heating					
Primary Heating	25561.1	54378.8		6.7	**59858.3**
Primary Cooling					
Cooling Compressor	1573273.4			6.6	**161103.6**
Tower/Cond Fans	552840.5		17975.1	2.3	**56611.0**
Condenser Pump	400901.3			1.7	**41052.4**
Other CLG Accessories	0.0			0.0	**0.0**
Cooling Subtotal	2527015.2		17975.1	10.6	**258767.0**
Auxiliary					
Supply Fans	341908.0			1.4	**35011.5**
Circ Pumps	950483.1			4.0	**97329.7**
Base Utilities	0.0			0.0	**0.0**
Aux Subtotal	1292391.1			5.4	**132341.2**
Lighting/Equipment					
Lighting/Equipment	18571200.0			77.3	**1901695.3**
Totals	22416167.4		17975.1	100.0	**2352661.8**

10. Energy Rates.

The energy rates were based on PECO rates from 03/31/06.

PECO Unbundled Rates [03/31/06]			
Fixed Distribution Service Charge		$291.43	per month
Variable Distribution Service Charge			
Demand		$1.68	per kW
1st 150 hours of billed demand		$0.0091	per kWh
2nd 150 hours of billed demand		$0.0054	per kWh
All other KWH		$0.0018	per kWh
Competitive Transition Charge			
Demand		$4.74	per kW
1st 150 hours of billed demand		$0.0262	per kWh
2nd 150 hours of billed demand		$0.0158	per kWh
All other KWH		$0.0056	per kWh
Energy and Capacity Charge			
Demand		$6.45	per kW
1st 150 hours of billed demand		$0.0494	per kWh
2nd 150 hours of billed demand		$0.0353	per kWh
All other KWH		$0.0213	per kWh
Transmission Charge			
Demand		$0.80	per kW
1st 150 hours of billed demand		$0.0043	per kWh
2nd 150 hours of billed demand		$0.0025	per kWh
All other KWH		$0.0008	per kWh
Time of Use Adjustment	Summer	Winter	
	June-Sept	Oct-May	
Off-Peak Credit	($0.0021)	($0.0021)	per kWh
On-Peak Charge	$0.0058	$0.0022	per kWh

11. Yearly Operating Cost.

The yearly operating cost for each system was based on the PECO energy rates as of 03/31/06 in the previous Appendix.

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**

System 2

	Electric On-Peak			Gas On-Peak	Water On-Peak	
	Consumption	Demand	Total	Consumption	Consumption	Monthly Total
	$	$	$	$	$	$
January	$70,434	$44,034	$114,468	$7,370	$9,124	**$130,962**
February	$63,106	$43,827	$106,933	$6,835	$8,178	**$121,946**
March	$73,480	$44,899	$118,379	$5,416	$10,522	**$134,317**
April	$73,288	$45,408	$118,696	$3,724	$11,190	**$133,610**
May	$76,817	$46,882	$123,699	$0	$12,987	**$136,686**
June	$74,919	$48,302	$123,221	$0	$14,070	**$137,291**
July	$89,712	$49,188	$138,900	$0	$15,839	**$154,739**
August	$87,629	$48,166	$135,795	$0	$14,534	**$150,329**
September	$82,904	$46,747	$129,651	$0	$12,738	**$142,389**
October	$75,501	$44,941	$120,442	$3,447	$11,465	**$135,354**
November	$72,288	$44,469	$116,757	$4,260	$10,499	**$131,516**
December	$72,232	$44,070	$116,302	$6,403	$9,741	**$132,446**
Totals	**$912,310**	**$550,933**	**$1,463,243**	**$37,455**	**$140,887**	**$1,641,585**

System 3						
	Electric On-Peak			Gas On-Peak	Water On-Peak	
	Consumption	Demand	Total	Consumption	Consumption	Monthly Total
	$	$	$	$	$	$
January	$93,530	$55,620	$149,150	$0	$13,604	**$162,754**
February	$84,803	$55,443	$140,246	$0	$12,349	**$152,595**
March	$92,406	$54,953	$147,359	$0	$13,943	**$161,302**
April	$88,657	$54,074	$142,731	$0	$13,744	**$156,475**
May	$89,231	$54,625	$143,856	$0	$14,392	**$158,248**
June	$100,015	$57,870	$157,885	$0	$15,382	**$173,267**
July	$106,010	$58,478	$164,488	$0	$16,861	**$181,349**
August	$102,984	$57,604	$160,588	$0	$15,656	**$176,244**
September	$96,515	$55,628	$152,143	$0	$14,003	**$166,146**
October	$90,754	$53,967	$144,721	$0	$13,927	**$158,648**
November	$88,173	$54,362	$142,535	$0	$13,284	**$155,819**
December	$92,564	$54,864	$147,428	$0	$13,559	**$160,987**
Totals	**$1,125,642**	**$667,488**	**$1,793,130**	**$0**	**$170,704**	**$1,963,834**

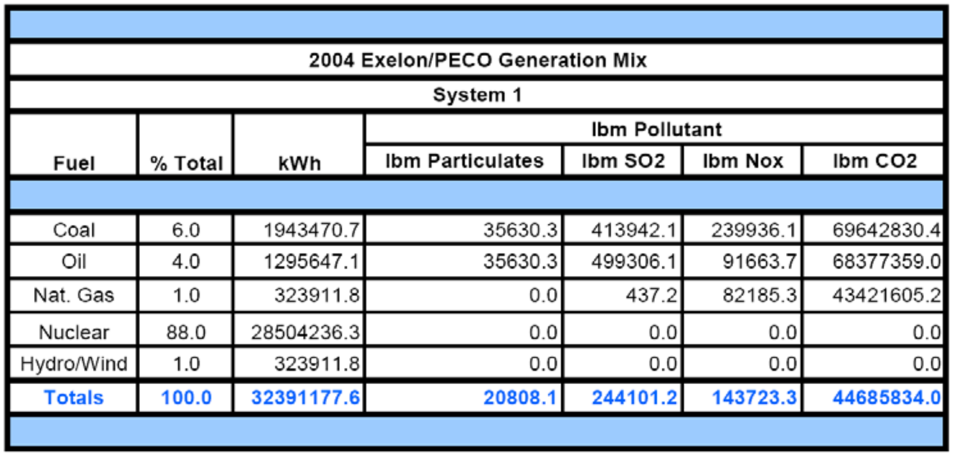
System 4						
	Electric On-Peak			Gas On-Peak	Water On-Peak	
	Consumption	Demand	Total	Consumption	Consumption	Monthly Total
	$	$	$	$	$	$
January	$73,309	$45,078	$118,387	$6,820	$11,164	**$136,371**
February	$65,663	$45,486	$111,149	$6,325	$10,025	**$127,499**
March	$76,189	$45,706	$121,895	$5,012	$11,932	**$138,839**
April	$74,867	$46,006	$120,873	$3,447	$11,920	**$136,240**
May	$77,522	$46,553	$124,075	$0	$12,461	**$136,536**
June	$85,105	$48,031	$133,136	$0	$13,215	**$146,351**
July	$89,110	$48,754	$137,864	$0	$14,395	**$152,259**
August	$87,687	$47,876	$135,563	$0	$13,438	**$149,001**
September	$83,567	$46,869	$130,436	$0	$12,104	**$142,540**
October	$77,090	$45,536	$122,626	$3,190	$12,085	**$137,901**
November	$74,226	$45,274	$119,500	$3,942	$11,501	**$134,943**
December	$75,197	$45,146	$120,343	$5,925	$11,483	**$137,751**
Totals	**$939,532**	**$556,315**	**$1,495,847**	**$34,661**	**$145,723**	**$1,676,231**

System 5

	Electric On-Peak			Gas On-Peak	Water On-Peak	
	Consumption	Demand	Total	Consumption	Consumption	Monthly Total
	$	$	$	$	$	$
January	$55,989	$34,508	$90,497	$7,311	$7,259	**$105,067**
February	$50,195	$34,931	$85,126	$8,133	$6,529	**$99,788**
March	$58,837	$35,940	$94,777	$5,944	$8,278	**$108,999**
April	$58,690	$36,353	$95,043	$3,587	$8,731	**$107,361**
May	$62,114	$37,777	$99,891	$680	$10,059	**$110,630**
June	$68,219	$38,763	$106,982	$77	$10,489	**$117,548**
July	$71,862	$39,692	$111,554	$0	$11,548	**$123,102**
August	$70,235	$38,586	$108,821	$52	$10,641	**$119,514**
September	$66,870	$37,627	$104,497	$518	$9,621	**$114,636**
October	$60,517	$36,141	$96,658	$3,132	$8,863	**$108,653**
November	$57,863	$35,755	$93,618	$4,338	$8,169	**$106,125**
December	$57,626	$35,289	$92,915	$7,328	$7,664	**$107,907**
Totals	**$739,017**	**$441,362**	**$1,180,379**	**$41,100**	**$107,851**	**$1,329,330**

12. Emissions Generated per System.

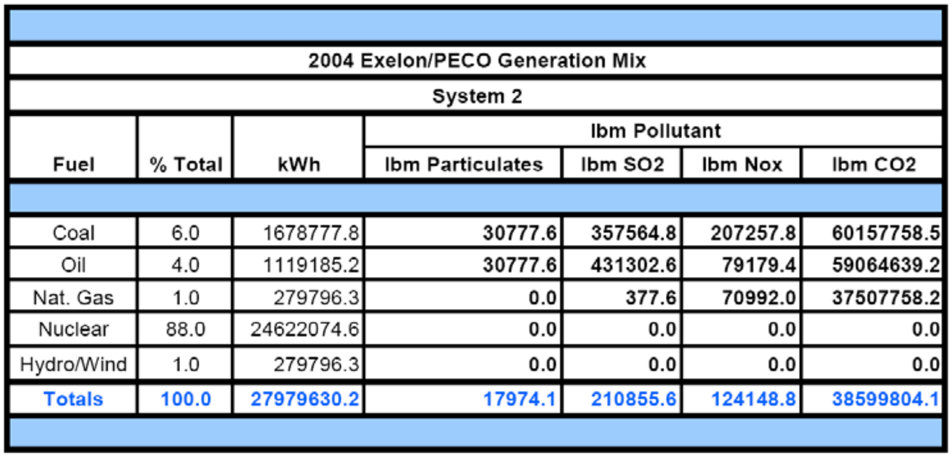
These emission rates were calculated based on Exelon's 2004 generation fuel mix.



2004 Exelon/PECO Generation Mix

System 1

Fuel	% Total	kWh	lbm Pollutant			
			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**



2004 Exelon/PECO Generation Mix

System 2

Fuel	% Total	kWh	lbm Pollutant			
			lbm Particulates	lbm SO2	lbm Nox	lbm CO2
Coal	6.0	1678777.8	**30777.6**	**357564.8**	**207257.8**	**60157758.5**
Oil	4.0	1119185.2	**30777.6**	**431302.6**	**79179.4**	**59064639.2**
Nat. Gas	1.0	279796.3	**0.0**	**377.6**	**70992.0**	**37507758.2**
Nuclear	88.0	24622074.6	**0.0**	**0.0**	**0.0**	**0.0**
Hydro/Wind	1.0	279796.3	**0.0**	**0.0**	**0.0**	**0.0**
Totals	**100.0**	**27979630.2**	**17974.1**	**210855.6**	**124148.8**	**38599804.1**

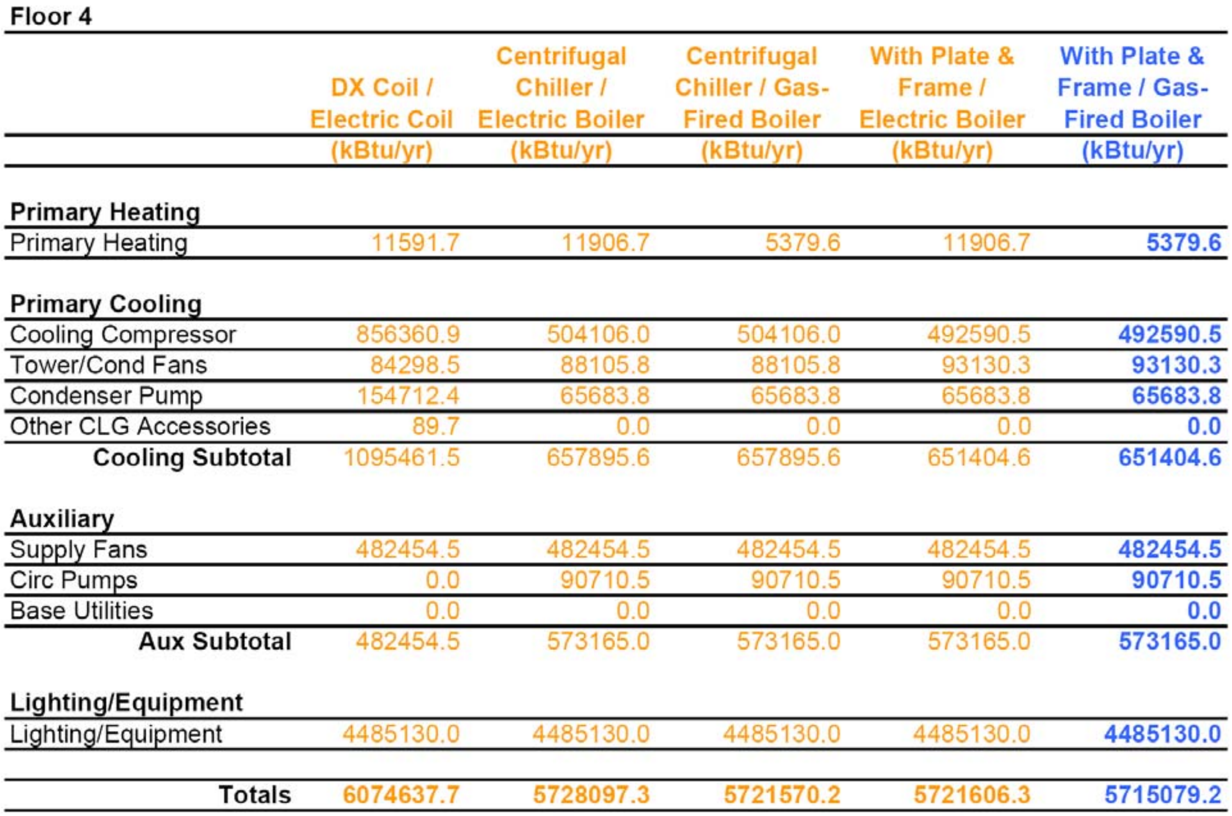
System 3						
			lbm Pollutant			
Fuel	% Total	kWh	lbm Particulates	lbm SO2	lbm Nox	lbm CO2
Coal	6.0	2051982.1	37619.7	437054.0	253332.7	73531256.3
Oil	4.0	1367988.0	37619.7	527184.2	96781.6	72195128.8
Nat. Gas	1.0	341997.0	0.0	461.6	86774.0	45845999.7
Nuclear	88.0	30095737.0	0.0	0.0	0.0	0.0
Hydro/Wind	1.0	341997.0	0.0	0.0	0.0	0.0
Totals	**100.0**	**34199701.1**	**21969.9**	**257730.3**	**151747.9**	**47180815.2**

2004 Exelon/PECO Generation Mix						
System 4						
			lbm Pollutant			
Fuel	% Total	kWh	lbm Particulates	lbm SO2	lbm Nox	lbm CO2
Coal	6.0	1711318.4	31374.2	364495.7	211275.2	61323827.8
Oil	4.0	1140879.0	31374.2	439662.8	80714.2	60209520.0
Nat. Gas	1.0	285219.7	0.0	384.9	72368.1	38234790.7
Nuclear	88.0	25099337.1	0.0	0.0	0.0	0.0
Hydro/Wind	1.0	285219.7	0.0	0.0	0.0	0.0
Totals	**100.0**	**28521974.0**	**18322.5**	**214942.7**	**126555.2**	**39348004.3**

2004 Exelon/PECO Generation Mix						
System 5						
			lbm Pollutant			
Fuel	% Total	kWh	lbm Particulates	lbm SO2	lbm Nox	lbm CO2
Coal	6.0	1344970.0	24657.8	286466.7	166046.7	48196004.6
Oil	4.0	896646.7	24657.8	345542.5	63435.4	47320240.8
Nat. Gas	1.0	224161.7	0.0	302.5	56876.0	30049724.7
Nuclear	88.0	19726227.3	0.0	0.0	0.0	0.0
Hydro/Wind	1.0	224161.7	0.0	0.0	0.0	0.0
Totals	**100.0**	**22416167.4**	**14400.1**	**168929.1**	**99463.1**	**30924628.5**

13. Floor 4 Systems Analysis Energy Consumption Results.

Floor 4's energy usage using combinations of a centrifugal chiller, an economizer, and a boiler.

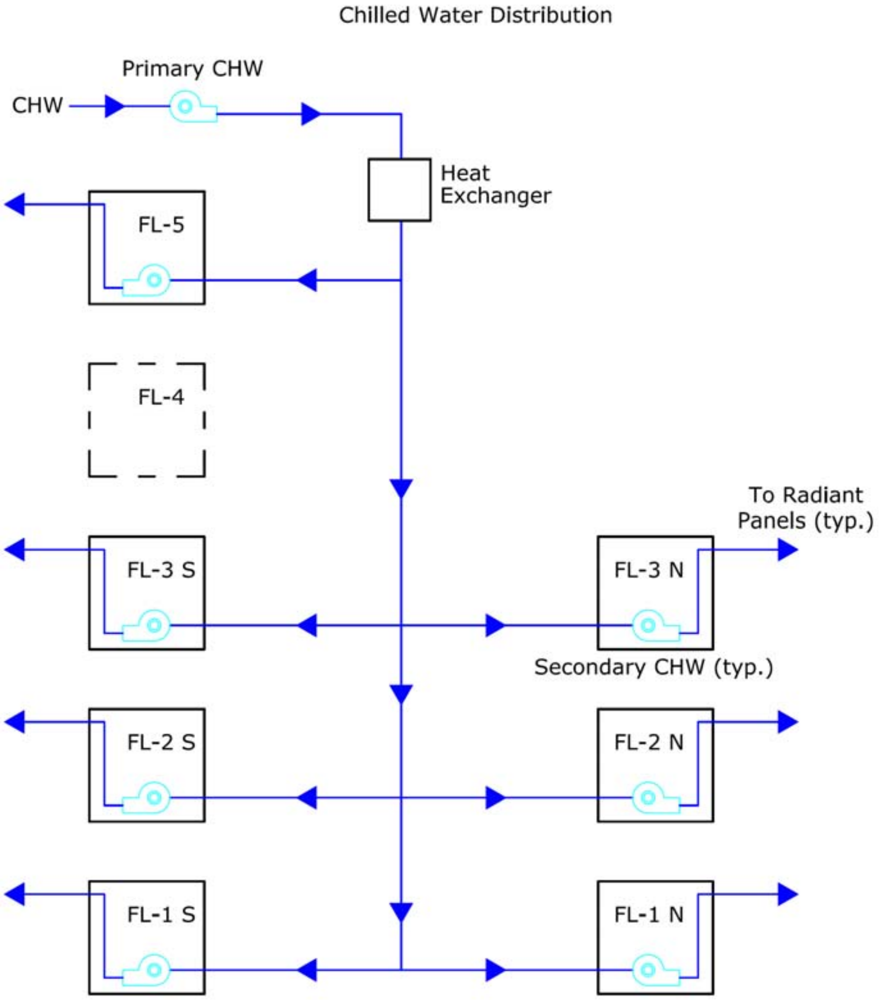


Floor 4

	DX Coil / Electric Coil (kBtu/yr)	Centrifugal Chiller / Electric Boiler (kBtu/yr)	Centrifugal Chiller / Gas-Fired Boiler (kBtu/yr)	With Plate & Frame / Electric Boiler (kBtu/yr)	With Plate & Frame / Gas-Fired Boiler (kBtu/yr)
Primary Heating					
Primary Heating	11591.7	11906.7	5379.6	11906.7	5379.6
Primary Cooling					
Cooling Compressor	856360.9	504106.0	504106.0	492590.5	492590.5
Tower/Cond Fans	84298.5	88105.8	88105.8	93130.3	93130.3
Condenser Pump	154712.4	65683.8	65683.8	65683.8	65683.8
Other CLG Accessories	89.7	0.0	0.0	0.0	0.0
Cooling Subtotal	1095461.5	657895.6	657895.6	651404.6	651404.6
Auxiliary					
Supply Fans	482454.5	482454.5	482454.5	482454.5	482454.5
Circ Pumps	0.0	90710.5	90710.5	90710.5	90710.5
Base Utilities	0.0	0.0	0.0	0.0	0.0
Aux Subtotal	482454.5	573165.0	573165.0	573165.0	573165.0
Lighting/Equipment					
Lighting/Equipment	4485130.0	4485130.0	4485130.0	4485130.0	4485130.0
Totals	6074637.7	5728097.3	5721570.2	5721606.3	5715079.2

14. Chilled Water Distribution Schematic—DOAS/Radiant, System 5.

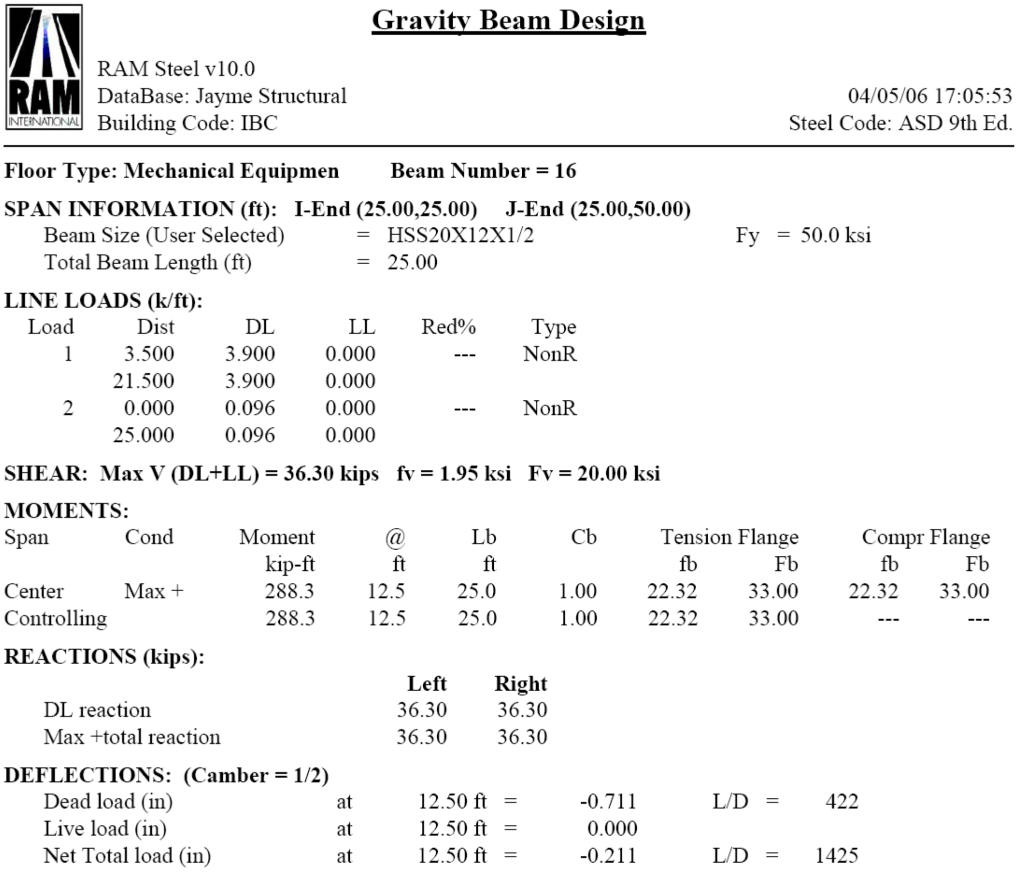
Chilled water is pumped through primary pumps directly from the chiller to secondary pumps that maintain the flow throughout the radiant panels.



Appendix C—Integration of Structural System and Constructability

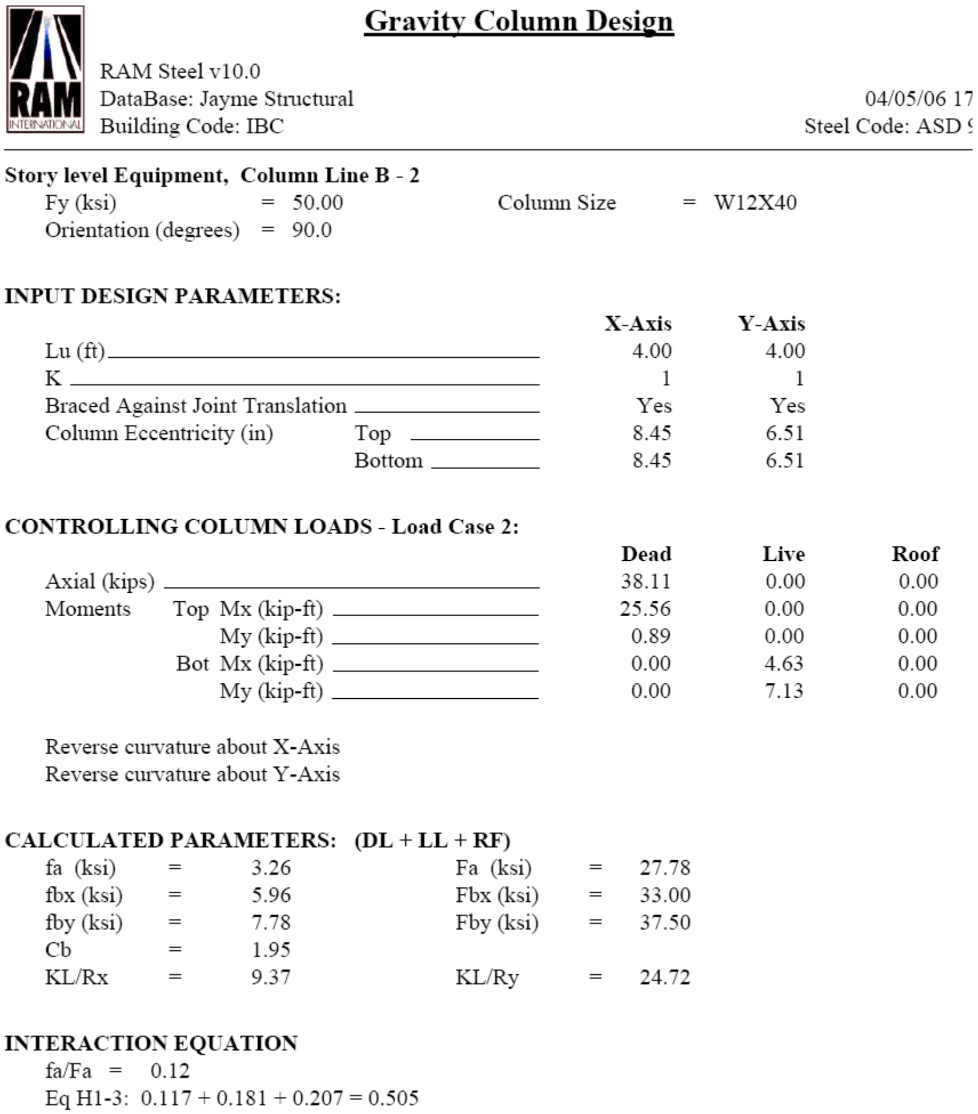
1. Gravity Beam Design.
2. Gravity Column Design.
3. Primavera Ductwork Schedule.

1. Gravity Beam Design



```
                              Gravity Beam Design

       RAM Steel v10.0
       DataBase: Jayme Structural                                  04/05/06 17:05:53
       Building Code: IBC                                     Steel Code: ASD 9th Ed.
________________________________________________________________________________________
Floor Type: Mechanical Equipmen        Beam Number = 16

SPAN INFORMATION (ft):   I-End (25.00,25.00)    J-End (25.00,50.00)
   Beam Size (User Selected)          =   HSS20X12X1/2                  Fy   = 50.0 ksi
   Total Beam Length (ft)             =   25.00

LINE LOADS (k/ft):
  Load       Dist        DL         LL       Red%      Type
     1      3.500      3.900      0.000       ---      NonR
           21.500      3.900      0.000
     2      0.000      0.096      0.000       ---      NonR
           25.000      0.096      0.000

SHEAR:  Max V (DL+LL) = 36.30 kips   fv = 1.95 ksi   Fv = 20.00 ksi

MOMENTS:
Span         Cond          Moment      @       Lb       Cb       Tension Flange       Compr Flange
                           kip-ft     ft       ft                   fb       Fb         fb       Fb
Center       Max +          288.3    12.5     25.0     1.00      22.32    33.00      22.32    33.00
Controlling                 288.3    12.5     25.0     1.00      22.32    33.00        ---      ---

REACTIONS (kips):
                                              Left      Right
   DL reaction                               36.30      36.30
   Max +total reaction                       36.30      36.30

DEFLECTIONS:  (Camber = 1/2)
   Dead load (in)                at       12.50 ft  =      -0.711       L/D  =     422
   Live load (in)                at       12.50 ft  =       0.000
   Net Total load (in)           at       12.50 ft  =      -0.211       L/D  =    1425
```

2.0 Gravity Column Design



Gravity Column Design

RAM Steel v10.0
DataBase: Jayme Structural
Building Code: IBC

04/05/06 17
Steel Code: ASD

Story level Equipment, Column Line B - 2

Fy (ksi) = 50.00
Column Size = W12X40
Orientation (degrees) = 90.0

INPUT DESIGN PARAMETERS:

		X-Axis	Y-Axis
Lu (ft)		4.00	4.00
K		1	1
Braced Against Joint Translation		Yes	Yes
Column Eccentricity (in)	Top	8.45	6.51
	Bottom	8.45	6.51

CONTROLLING COLUMN LOADS - Load Case 2:

			Dead	Live	Roof
Axial (kips)			38.11	0.00	0.00
Moments	Top	Mx (kip-ft)	25.56	0.00	0.00
		My (kip-ft)	0.89	0.00	0.00
	Bot	Mx (kip-ft)	0.00	4.63	0.00
		My (kip-ft)	0.00	7.13	0.00

Reverse curvature about X-Axis
Reverse curvature about Y-Axis

CALCULATED PARAMETERS: (DL + LL + RF)

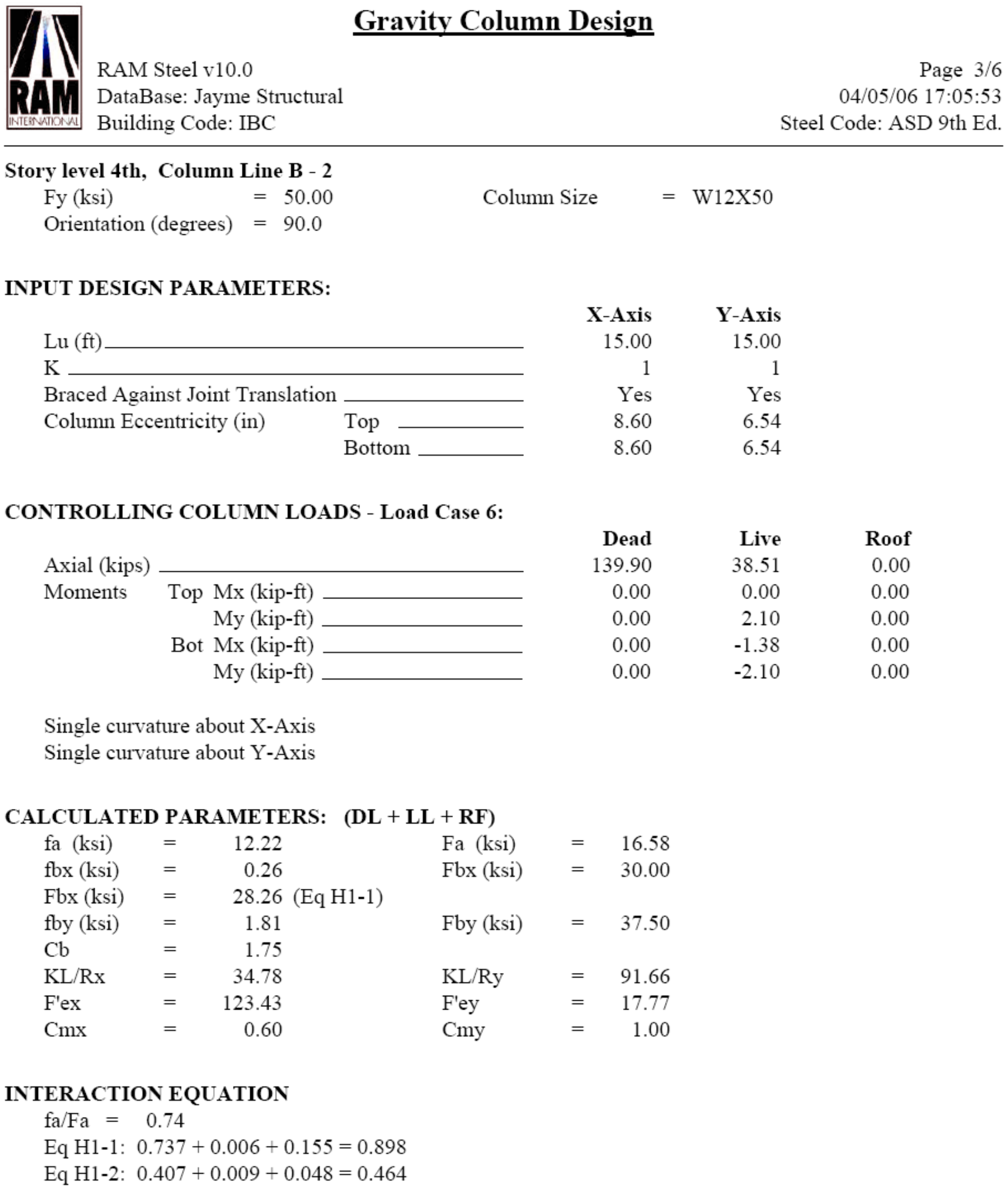
fa (ksi) = 3.26
Fa (ksi) = 27.78
fbx (ksi) = 5.96
Fbx (ksi) = 33.00
fby (ksi) = 7.78
Fby (ksi) = 37.50
Cb = 1.95
KL/Rx = 9.37
KL/Ry = 24.72

INTERACTION EQUATION

fa/Fa = 0.12
Eq H1-3: 0.117 + 0.181 + 0.207 = 0.505

Gravity Column Design

```
RAM Steel v10.0                                                    Page  2/6
DataBase: Jayme Structural                                 04/05/06 17:05:53
Building Code: IBC                                      Steel Code: ASD 9th Ed.

Story level 5th,  Column Line B - 2
     Fy (ksi)                =   50.00              Column Size      =   W12X40
     Orientation (degrees)   =   90.0

INPUT DESIGN PARAMETERS:
                                                          X-Axis       Y-Axis
     Lu (ft)_____________________________________________  15.00        15.00
     K __________________________________________________      1            1
     Braced Against Joint Translation ___________________    Yes          Yes
     Column Eccentricity (in)          Top ______________   8.45         6.51
                                       Bottom ___________   8.45         6.51

CONTROLLING COLUMN LOADS - Load Case 2:
                                                           Dead         Live         Roof
     Axial (kips) _______________________________________  88.93        27.50         0.00
     Moments       Top  Mx (kip-ft) _____________________   0.00         0.00         0.00
                        My (kip-ft) _____________________   0.00         0.00         0.00
                   Bot  Mx (kip-ft) _____________________   0.00         1.61         0.00
                        My (kip-ft) _____________________   0.00         2.48         0.00

     Single curvature about X-Axis
     Single curvature about Y-Axis

CALCULATED PARAMETERS:   (DL + LL + RF)
     fa  (ksi)     =         9.95                Fa  (ksi)     =    16.35
     fbx (ksi)     =         0.38                Fbx (ksi)     =    30.00
     Fbx (ksi)     =        23.11  (Eq H1-1)
     fby (ksi)     =         2.71                Fby (ksi)     =    37.50
     Cb            =         1.75
     KL/Rx         =        35.14                KL/Ry         =    92.71
     F'ex          =       120.94                F'ey          =    17.37
     Cmx           =         0.60                Cmy           =     0.60

INTERACTION EQUATION
     fa/Fa   =    0.61
     Eq H1-1:  0.609 + 0.011 + 0.102 = 0.721
     Eq H1-2:  0.332 + 0.013 + 0.072 = 0.417
```



```
                          Gravity Column Design

RAM Steel v10.0                                                  Page  3/6
DataBase: Jayme Structural                               04/05/06 17:05:53
Building Code: IBC                                   Steel Code: ASD 9th Ed.
---------------------------------------------------------------------------
Story level 4th,  Column Line B - 2
     Fy (ksi)                =   50.00              Column Size        =   W12X50
     Orientation (degrees)   =   90.0

INPUT DESIGN PARAMETERS:
                                                          X-Axis      Y-Axis
     Lu (ft)_____________________________________          15.00       15.00
     K __________________________________________              1           1
     Braced Against Joint Translation ___________            Yes         Yes
     Column Eccentricity (in)       Top _________           8.60        6.54
                                    Bottom ______           8.60        6.54

CONTROLLING COLUMN LOADS - Load Case 6:
                                                          Dead        Live        Roof
     Axial (kips) _______________________________        139.90       38.51        0.00
     Moments       Top  Mx (kip-ft) _____________          0.00        0.00        0.00
                        My (kip-ft) _____________          0.00        2.10        0.00
                   Bot  Mx (kip-ft) _____________          0.00       -1.38        0.00
                        My (kip-ft) _____________          0.00       -2.10        0.00

     Single curvature about X-Axis
     Single curvature about Y-Axis

CALCULATED PARAMETERS:   (DL + LL + RF)
     fa  (ksi)     =         12.22                Fa  (ksi)     =     16.58
     fbx (ksi)     =          0.26                Fbx (ksi)     =     30.00
     Fbx (ksi)     =         28.26  (Eq H1-1)
     fby (ksi)     =          1.81                Fby (ksi)     =     37.50
     Cb            =          1.75
     KL/Rx         =         34.78                KL/Ry         =     91.66
     F'ex          =        123.43                F'ey          =     17.77
     Cmx           =          0.60                Cmy           =      1.00

INTERACTION EQUATION
     fa/Fa  =    0.74
     Eq H1-1:  0.737 + 0.006 + 0.155 = 0.898
     Eq H1-2:  0.407 + 0.009 + 0.048 = 0.464
```

Gravity Column Design

```
RAM Steel v10.0                                                    Page  4/6
DataBase: Jayme Structural                                 04/05/06 17:05:53
Building Code: IBC                                    Steel Code: ASD 9th Ed.
_____________________________________________________________________________
Story level 3rd,  Column Line B - 2
   Fy (ksi)               =   50.00              Column Size      =   W12X53
   Orientation (degrees)  =   90.0

INPUT DESIGN PARAMETERS:
                                                   X-Axis      Y-Axis
   Lu (ft)_________________________________         15.00       15.00
   K ______________________________________             1           1
   Braced Against Joint Translation _______           Yes         Yes
   Column Eccentricity (in)      Top ______          8.55        7.49
                                 Bottom ___          8.55        7.49

CONTROLLING COLUMN LOADS - Load Case 6:
                                                     Dead        Live        Roof
   Axial (kips) ___________________________        190.91       56.43        0.00
   Moments        Top  Mx (kip-ft) ________          0.00        0.00        0.00
                       My (kip-ft) ________          0.00        2.20        0.00
                  Bot  Mx (kip-ft) ________          0.00       -1.37        0.00
                       My (kip-ft) ________          0.00       -2.40        0.00

   Single curvature about X-Axis
   Single curvature about Y-Axis

CALCULATED PARAMETERS:   (DL + LL + RF)
   fa  (ksi)     =       15.85            Fa  (ksi)    =    20.44
   fbx (ksi)     =        0.23            Fbx (ksi)    =    30.00
   fby (ksi)     =        1.50            Fby (ksi)    =    37.50
   Cb            =        1.75
   KL/Rx         =       34.49            KL/Ry        =    72.64
   F'ex          =      125.57            F'ey         =    28.30
   Cmx           =        0.60            Cmy          =     0.97

INTERACTION EQUATION
   fa/Fa   =     0.78
   Eq H1-1:  0.776 + 0.005 + 0.088 = 0.869
   Eq H1-2:  0.528 + 0.008 + 0.040 = 0.576
```

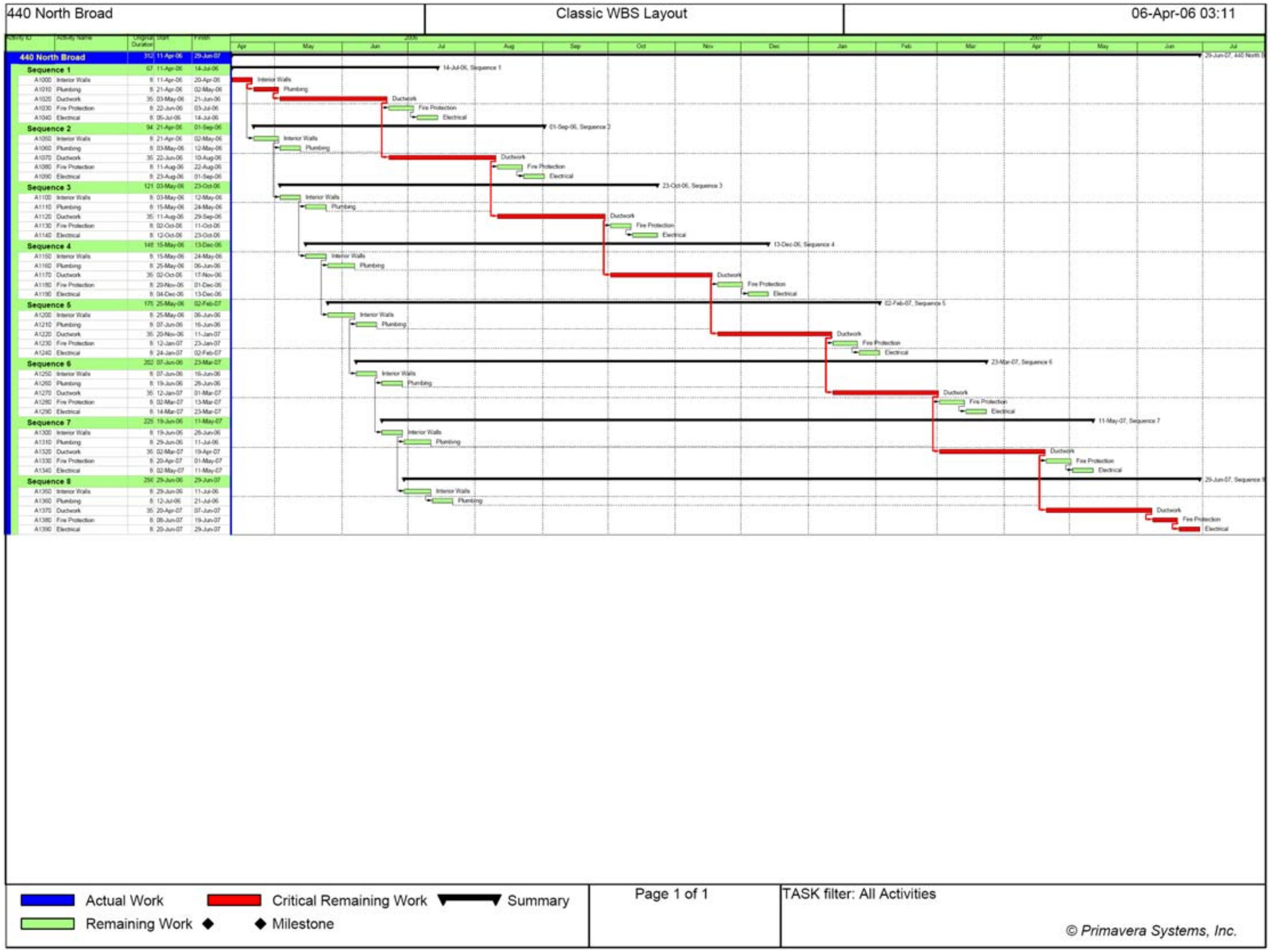
Gravity Column Design

```
RAM Steel v10.0                                                   Page  5/6
DataBase: Jayme Structural                                04/05/06 17:05:53
Building Code: IBC                                  Steel Code: ASD 9th Ed.
---------------------------------------------------------------------------
Story level 2nd,  Column Line B - 2
    Fy (ksi)                =  50.00            Column Size        =  W12X65
    Orientation (degrees)   =  90.0

INPUT DESIGN PARAMETERS:
                                                     X-Axis       Y-Axis
    Lu (ft)___________________________________        18.00        18.00
    K ________________________________________            1            1
    Braced Against Joint Translation __________          Yes          Yes
    Column Eccentricity (in)     Top __________         8.55         8.50
                                 Bottom _______         8.55         8.50

CONTROLLING COLUMN LOADS - Load Case 6:
                                                       Dead         Live         Roof
    Axial (kips) _____________________________       242.30        73.33         0.00
    Moments      Top  Mx (kip-ft) ____________         0.00         0.00         0.00
                      My (kip-ft) ____________         0.00         2.15         0.00
                 Bot  Mx (kip-ft) ____________         0.00        -1.19         0.00
                      My (kip-ft) ____________         0.00        -2.36         0.00

    Single curvature about X-Axis
    Single curvature about Y-Axis

CALCULATED PARAMETERS:   (DL + LL + RF)
    fa  (ksi)    =      16.53             Fa  (ksi)     =    20.64
    fbx (ksi)    =       0.16             Fbx (ksi)     =    30.00
    fby (ksi)    =       0.97             Fby (ksi)     =    36.22
    Cb           =       1.75
    KL/Rx        =      40.89             KL/Ry         =    71.56
    F'ex         =      89.32             F'ey          =    29.16
    Cmx          =       0.60             Cmy           =     0.96

INTERACTION EQUATION
    fa/Fa  =    0.80
    Eq H1-1:  0.801 + 0.004 + 0.060 = 0.864
    Eq H1-2:  0.551 + 0.005 + 0.027 = 0.583
```

Gravity Column Design

```
RAM Steel v10.0                                                          Page  6/6
DataBase: Jayme Structural                                       04/05/06 17:05:53
Building Code: IBC                                           Steel Code: ASD 9th Ed.
-----------------------------------------------------------------------------------
Story level 1st,  Column Line B - 2
   Fy (ksi)                 =  50.00          Column Size        =  W12X72
   Orientation (degrees)    =  90.0

INPUT DESIGN PARAMETERS:
                                                  X-Axis      Y-Axis
   Lu (ft)__________________________________       18.00       18.00
   K _______________________________________           1           1
   Braced Against Joint Translation ________         Yes         Yes
   Column Eccentricity (in)       Top ______        8.65        8.50
                                  Bottom ___        0.00        0.00

CONTROLLING COLUMN LOADS - Load Case 6:
                                                    Dead        Live        Roof
   Axial (kips) ____________________________      293.81       93.33        0.00
   Moments      Top  Mx (kip-ft) ___________        0.00        0.00        0.00
                     My (kip-ft) ___________        0.00        2.36        0.00
                Bot  Mx (kip-ft) ___________        0.00        0.00        0.00
                     My (kip-ft) ___________        0.00        0.00        0.00

   Single curvature about X-Axis
   Single curvature about Y-Axis

CALCULATED PARAMETERS:   (DL + LL + RF)
   fa  (ksi)   =     18.35              Fa  (ksi)   =    20.74
   fbx (ksi)   =      0.00              Fbx (ksi)   =    30.00
   fby (ksi)   =      0.87              Fby (ksi)   =    37.50
   Cb          =      1.00
   KL/Rx       =     40.61              KL/Ry       =    71.05
   F'ex        =     90.56              F'ey        =    29.58
   Cmx         =      0.00              Cmy         =     0.60

INTERACTION EQUATION
   fa/Fa  =    0.88
   Eq H1-1:  0.885 + 0.000 + 0.037 = 0.922
   Eq H1-2:  0.612 + 0.000 + 0.023 = 0.635
```

3. Primavera Ductwork Schedule.



440 North Broad | Classic WBS Layout | 06-Apr-06 03:11

Activity ID	Activity Name	Original Duration	Start	Finish
440 North Broad		312	11-Apr-06	29-Jun-07
Sequence 1		67	11-Apr-06	14-Jul-06
A1000	Interior Walls	8	11-Apr-06	20-Apr-06
A1010	Plumbing	8	21-Apr-06	02-May-06
A1020	Ductwork	35	03-May-06	21-Jun-06
A1030	Fire Protection	8	22-Jun-06	03-Jul-06
A1040	Electrical	8	05-Jul-06	14-Jul-06
Sequence 2		94	21-Apr-06	01-Sep-06
A1050	Interior Walls	8	21-Apr-06	02-May-06
A1060	Plumbing	8	03-May-06	12-May-06
A1070	Ductwork	35	22-Jun-06	10-Aug-06
A1080	Fire Protection	8	11-Aug-06	22-Aug-06
A1090	Electrical	8	23-Aug-06	01-Sep-06
Sequence 3		121	03-May-06	23-Oct-06
A1100	Interior Walls	8	03-May-06	12-May-06
A1110	Plumbing	8	15-May-06	24-May-06
A1120	Ductwork	35	11-Aug-06	29-Sep-06
A1130	Fire Protection	8	02-Oct-06	11-Oct-06
A1140	Electrical	8	12-Oct-06	23-Oct-06
Sequence 4		148	15-May-06	13-Dec-06
A1150	Interior Walls	8	15-May-06	24-May-06
A1160	Plumbing	8	25-May-06	06-Jun-06
A1170	Ductwork	35	02-Oct-06	17-Nov-06
A1180	Fire Protection	8	20-Nov-06	01-Dec-06
A1190	Electrical	8	04-Dec-06	13-Dec-06
Sequence 5		175	25-May-06	02-Feb-07
A1200	Interior Walls	8	25-May-06	06-Jun-06
A1210	Plumbing	8	07-Jun-06	16-Jun-06
A1220	Ductwork	35	20-Nov-06	11-Jan-07
A1230	Fire Protection	8	12-Jan-07	23-Jan-07
A1240	Electrical	8	24-Jan-07	02-Feb-07
Sequence 6		202	07-Jun-06	23-Mar-07
A1250	Interior Walls	8	07-Jun-06	16-Jun-06
A1260	Plumbing	8	19-Jun-06	28-Jun-06
A1270	Ductwork	35	12-Jan-07	01-Mar-07
A1280	Fire Protection	8	02-Mar-07	13-Mar-07
A1290	Electrical	8	14-Mar-07	23-Mar-07
Sequence 7		225	19-Jun-06	11-May-07
A1300	Interior Walls	8	19-Jun-06	28-Jun-06
A1310	Plumbing	8	29-Jun-06	11-Jul-06
A1320	Ductwork	35	02-Mar-07	19-Apr-07
A1330	Fire Protection	8	20-Apr-07	01-May-07
A1340	Electrical	8	02-May-07	11-May-07
Sequence 8		256	29-Jun-06	29-Jun-07
A1350	Interior Walls	8	29-Jun-06	11-Jul-06
A1360	Plumbing	8	12-Jul-06	21-Jul-06
A1370	Ductwork	35	20-Apr-07	07-Jun-07
A1380	Fire Protection	8	08-Jun-07	19-Jun-07
A1390	Electrical	8	20-Jun-07	29-Jun-07

🟦 Actual Work
🟩 Remaining Work
🟥 Critical Remaining Work
◆ Milestone
▼ Summary

Page 1 of 1

TASK filter: All Activities

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