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Technical Report Three

Mechanical Systems Existing Conditions Evaluation

WESTINGHOUSE ELECTRIC CO. NUCLEAR ENGINEERING HEADQUARTERS CAMPUS

Pittsburgh, PA

Daniel P. Aughenbaugh
Mechanical
Dr. Bahnfleth – Advisor

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Executive Summary

Westinghouse Nuclear Engineering Headquarters is comprised of three buildings. The central building, Building 1, is the topic of this report. Building 1 is largely open office with conference rooms, computation laboratories, a Data Center, Fitness Center and cafeteria. The concentration of computer equipment is relatively high compared to a typical low-rise office building.

Of primary importance to the client are adequate thermal comfort and air quality. Both of these variables will allow the occupants to be more productive in the workplace. Also of importance is the cost of operation for the facility in the long-term.

The primary system for Building 1 is a Variable Air Volume (VAV) system supplemented by Computer Room Cooling Units (CRAC Units) where the sensible load is too great for the VAV to handle—specifically in the Data Center. A VAV system was chosen because of its low maintenance costs, easy manageability, and efficiency. The system is supplied by chiller water from three centrifugal chillers and electric re-heat/gas-fired burners from the VAV boxes and AHUs. The system runs on an occupancy schedule that can be overridden to accommodate atypical loading.

The energy sources that are being used for the system are Natural Gas for the AHU pre-heating and Electricity for the Chillers and Re-heat. No information on initial cost has been available for this report, however with a fairly typical system; the expected cost should be similar or slightly higher than a typical system for a low-rise office building. The initial cost may be slightly higher because the building is designed for 40% OA.

When considering the Leadership in Energy and Environmental Design (LEED) Rating System, Building 1 was designed to be Certified. Most of the credits pursued pertained to material and resource usage, however several points were gain relative to the building's mechanical system.

The system has been found to adequately condition the building. All thermal loads are adequately met, all ventilation requirements are met and Indoor Air Quality is sufficient. However other systems, if investigated, may produce better economic performances. These alternative systems were likely not chosen because of the higher initial costs associated with non-conventional systems.

System Description

Introduction

Westinghouse Nuclear Engineering Headquarters is a complex of three buildings of approximately 845,000 square feet, and is being delivered is a Design-Bid-Build project. The complex contains office space with conference rooms as well as a data center, cafeteria and fitness center for employees. With the higher density of computing loads, the receptacle load of the complex will be higher than a typical office building.

For the purpose of this analysis, only Building 1 has been investigated because it contains the largest variety of occupancy types including the cafeteria, atrium/lobby, data center and fitness center along with a largest amount of office space and conference rooms.

Design Objectives and Requirements

The purpose for any HVAC system is to properly ventilate the building for the specified occupancy while maintaining a comfortable temperature and humidity level for the occupants. The mechanical system for Building 1 is designed to do exactly this. However, since every building is unique, every mechanical system is unique and are designed accordingly to accommodate these unique characteristics.

In the case of Westinghouse's Building 1 of their Nuclear Engineering Complex, the program is largely open office space with conference rooms and computer laboratories. The building also houses a data center, fitness center and cafeteria. This particular program consequently has a relative high concentration of computing equipment. This increase in internal heat load actually benefits the mechanical system because of need for heating for this particular building.

Several similar buildings have had problems maintaining a healthy indoor environment from low relative humidity and poor air filtration. Thus, the owners of the building gave higher priority to a healthier and more productive indoor environment for the workers.

The existing mechanical system was designed with low maintenance as a major influence. A system was designed that provided low maintenance costs, easy manageability, and efficiency. For the owner, this means lower energy bills and less operational costs over the lifetime of the mechanical system.

Equipment Summary

The primary system for Building 1 is a Variable Air Volume system. The system is supported by CRAC (Computer Room Cooling) Units in spaces with higher thermal loads that the VAV system cannot accommodate—specifically the Data Center, and a few computing laboratories. The VAV system was implemented because of it is practicality and lower first costs. VAV systems are widely used in similar buildings and have proven to be adequate systems.

The VAV and CRAC systems are supplied chilled water from the chiller plant located in the Basement of Building 1. The chiller plant includes three chillers with three cooling towers located in the mechanical penthouse. The Air Handling Units provide heating through Gas-fired Burners. Tables 1 through 4 display summaries for the AHUs, Chillers, Cooling Towers, and CRAC units. Table 5 provides a summary of the Domestic Hot Water Heaters.

Table 1. Air Handling Unit Summary

Air Handling Units					
Unit	System Air Flow Rates		OA Percentage	Coil Capacities, MBH	
	Min OA	System Supply		Heating	Cooling
AHU-1	22,200	71100	31	2500	3089.4
AHU-2	31,775	63000	50	2500	3084.3
AHU-3	24550	74000	33	2500	3130.8
AHU-4	36350	72500	50	2500	4003.2
AHU-5	800	8000	10	125 kW	280.2
AHU-6	500	5000	10	-	113.7

Table 2. Chiller Summary

Chiller Units				
Unit	Capacity	NPLV kW/Ton	Evaporator	Condenser
			EWT/LWT (°F)	EWT/LWT (°F)
CH-1	450	0.505	58/44	85/94
CH-2	450	0.505	58/44	85/94
CH-3	450	0.505	58/44	85/94

Table 3. Cooling Tower Summary

Cooling Tower Units					
Unit	Water Flow Rate (GPM)		Air Flow Rate (CFM)	Sump Heater (kW)	Fan Motor (HP)
	Min	Max			
CT-1	675	1350	112250	16	25
CT-2	675	1350	112250	16	25
CT-3	675	1350	112250	16	25

Table 4. CRAC Unit Summary

CRAC Unit		
Unit	Cooling Capacity	EER
CRAC-1	128000 BTU/hr	8.4
CRAC-2	255000 BTU/hr	8.6
CRAC-3	199000 BTU/hr	7.6

Table 5. Domestic Water Heater Summary

Domestic Hot Water Heater Units (Gas)				
Unit	Delivery Temp °F	Recovery		Heat Rate (BTU)
		GPH	ΔT	
DWH-1	140	327	100	285,000
DWH-2	140	327	100	285,000

Design Factors

No information was available on any major design factors for this report. However, several obvious factors can be attributed to the design of the mechanical system. The building's location is near Pittsburgh, PA which typically requires more heating days than cooling days. The site is located on top of a hill with no wind obstructions which could lead to significant heat loss during the winter as well as effect the pressurization of the building. And the building's façade design includes 40% glazing which leads to a considerable heat loss during the winter as well as increase solar gain during the summer. The building's north-south orientation is also not preferable for effective solar gain.

Design Conditions

The outdoor conditions for the energy model are approximated as Pittsburgh, PA and are listed in Table 2 below.

Table 7. ASHRAE Design Conditions

ASHRAE Design Conditions		
Heating Design Temperature	Cooling Design Temperature	
DBT	DBT	WBT
2 °F	86°F	70°F

Design Ventilation Requirements

To verify that the building air handling system is providing the required ventilation air for the occupancies, an ASHRAE 62.1 Analysis was performed on two of the four Air Handling Units. For this analysis all diffuser rates and the total area for each zone was tabulated to determine if the design outdoor air ventilation rates matched or exceeded the minimum rates required by ASHRAE 62.1.

The conclusion of the investigation found that the design rates are 52,254 CFM for AHU1 and 45,411 CFM for AHU2. However, the design documents specify that AHU1 and AHU2 are sized for 71,100 CFM and 63,000 CFM, respectively. With an extra 20,000 CFM for each unit, these units will be running at part load for much of their operation. Oversizing is typical for all systems but this seems to be far too much. The oversizing may be for future expansion of unoccupied spaces.

On average, the outdoor air fraction was found to be about 75% which is much higher than the 50% OA of the design documents. This difference was very likely caused by the critical rooms being inaccurately calculated as rooms with larger occupancy densities. The amount of outdoor air supplied is crucial when used in a VAV system because this fraction will be supplied to all spaces and so some of the spaces will be receiving more ventilation air than is required. When more outdoor air is supplied than required, more energy must be spent to condition that air. For this reason, it is important to ensure that most of the spaces have about the same requirements for outdoor air.

Design Thermal Loads

The heating and cooling loads of the building were simulated using Trane Trace. The simulation showed that Building 1 required more heating than a typical office building. This is a result of the building's location, façade design, and its microclimate. The computing equipment load on the building offsets this load by a margin, but not enough to significantly reduce the size of the HVAC system.

As seen in Table 3, below, the computed values for the system match similarly to the figures of the design documents. The computed values are all slightly higher than their design document counterparts, but are within 10-20%. The peak loads for the building as computed are 16,000 MBtuh heating and 1,083 Tons cooling.

Table 8. Load and Ventilation Comparisons

Load and Ventilation Comparisons						
Systems	Cooling (FT²/TON)		Supply (CFM/FT²)		Ventilation (CFM/FT²)	
	Computed	DD	Computed	DD	Computed	DD
Main AHU(s)	443.42	414.80	0.696	0.623	0.219	0.255
Equipment Room AHU(s)	306	304.65	1.77	1.25	1.77	0.125

System Operation

Air side:

For the VAV system, a supply fan runs anytime an AHU is commanded to run. The supply fan VFD speed is modulated to maintain the duct static pressure setpoint. The return fan runs whenever the supply fan runs. The return fan VFD is modulated in unison with the supply fan VFD. The two fans are set to produce a positive pressure in the building.

The cooling coil valve is modulated open whenever the outside air is greater than 60°F and the economizer is disabled or fully open and the supply fan is on and the heat coil is off. The gas pre-heating is enabled whenever the outside air is less than 55°F and the supply fan is on and the cooling coil is off (unless minimum OA requirements cause the mixed air temperature to fall below setpoint). Economizer mode is initiated when the outside air is less than 65°F and the enthalpy is less than 22 Btu/lb. The OA dampers are at a minimum of 20% open whenever the building is occupied. Minimum outside air is controlled by CO_2 sensors in the return air.

Fan Coil Boxes (FCB's) run according to an occupancy schedule and run at a minimum when not in occupancy mode. The FCB's maintain the cooling and heating setpoints within their zones. Variable Air Volume Boxes (VAV's) will modulate flow of supply air such that when cooling is required the VAV Box will increase airflow to the zone. When the space is within range of the setpoint or requires heating, the VAV Box will supply the minimum amount of airflow to the zone.

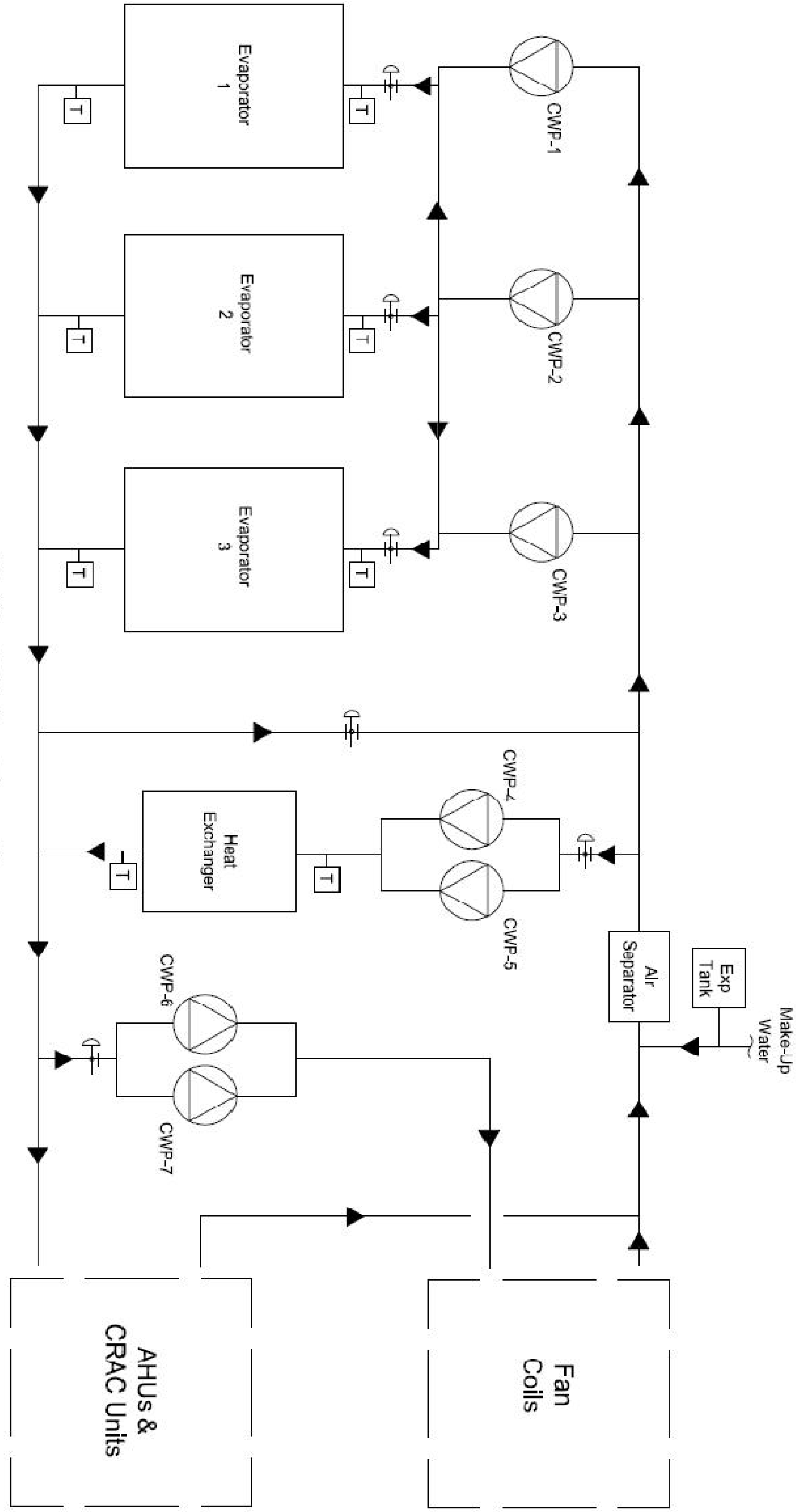
Water side:

The chilled water system shall be enabled to run whenever the cooling set point has been reached and whenever the outside air temperature is greater than 54°F. Each chiller runs from its own internal controls. The three equal sized chillers are staged to run in parallel to meet the cooling demand. The second chiller will stage on when the building load is 400 Tons and the third will stage on at 800 Tons. The three variable speed chilled water pumps operate in a lead/lag fashion. The condenser water pumps operate in the same manner. The chilled water isolation valves open whenever a chiller is called to run or called to run for freeze protection. The isolation valves open prior to the chillers being enabled and close after it is disabled. The condenser water isolation valves work the same.

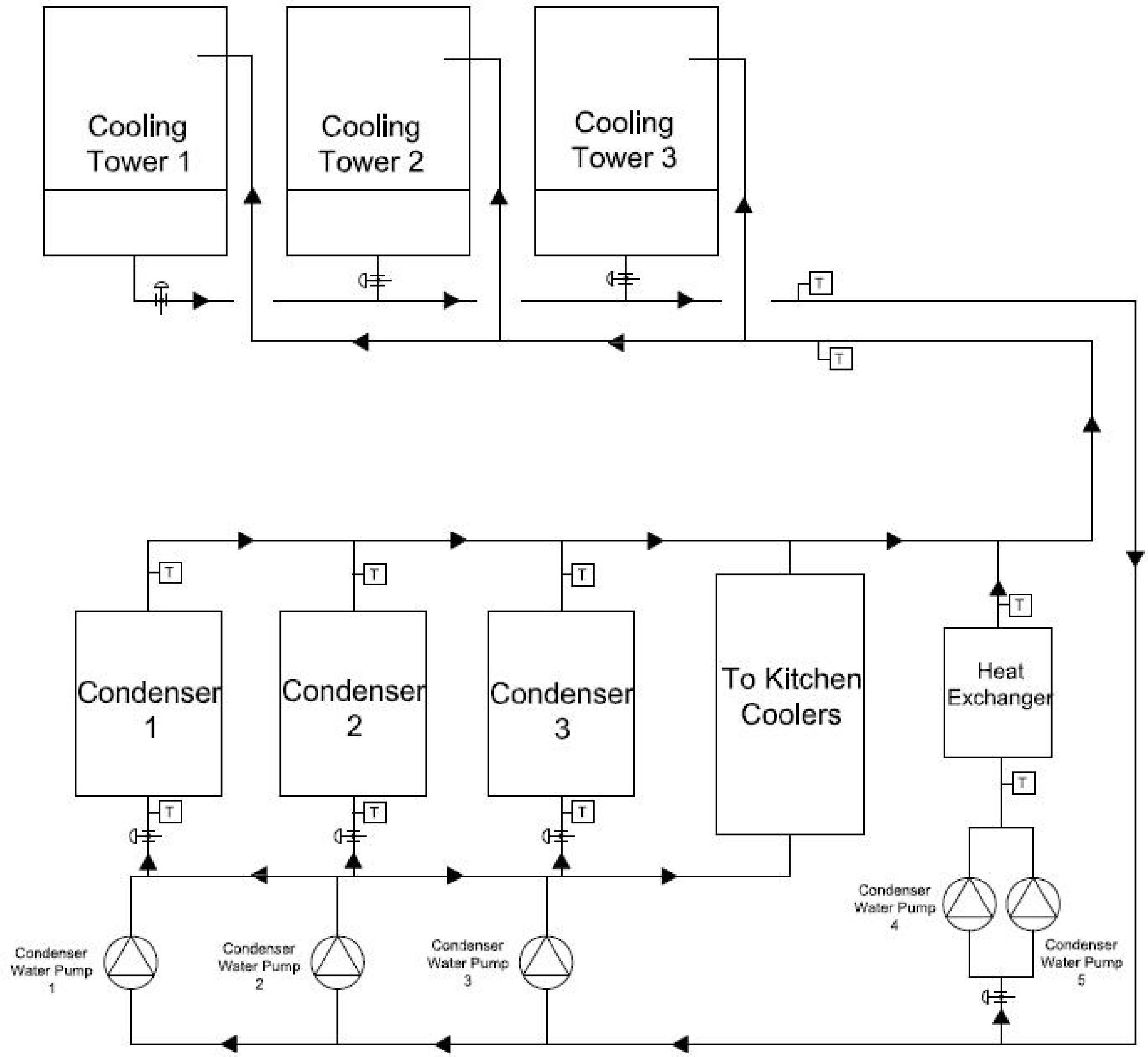
The cooling towers run whenever a chiller runs or when the free cooling heat exchanger runs. The cooling tower VFD fans maintain a setpoint of 82°F for the rising condenser water supply temperatures.

Mechanical System Schematic Drawings

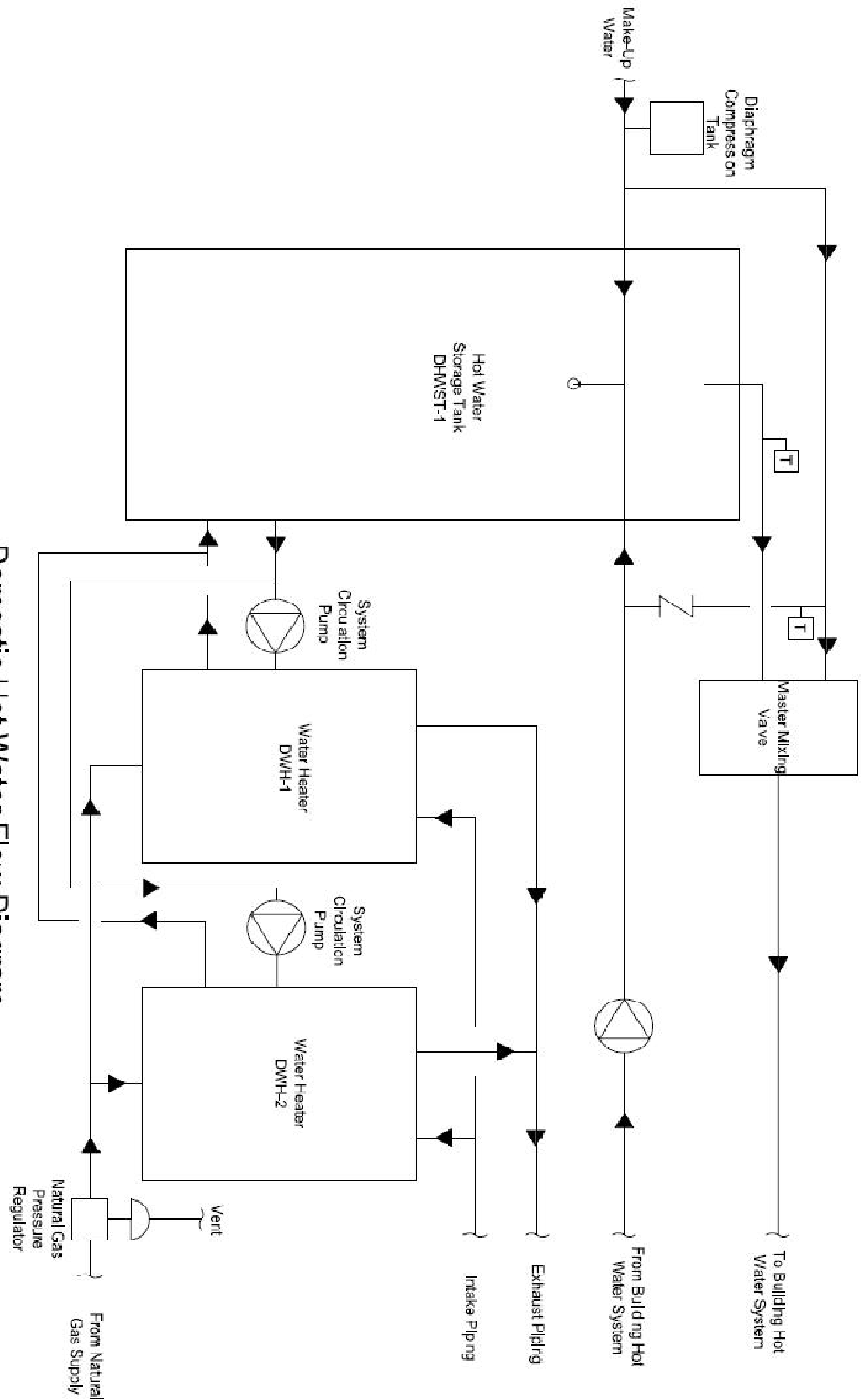
Schematic Flow Diagrams of the Chilled Water Loop, Condenser Water Loop, and Domestic Hot Water Loop are located on the next three pages.



Chilled Water Flow Diagram



Condenser Water Flow Diagram



Domestic Hot Water Flow Diagram

Mechanical System Area Usage

The total area lost due to the mechanical system is tabulated below. The Basement contains the mechanical room. The Penthouse contains the four main Air Handling Units along with the associated ductwork. All figures include duct shaft area as well as mechanical room area. The total lost area due to the Mechanical system is estimated to be around 28,962 SF.

Table 9. Mechanical Area

Lost Usable Area	
Floor	Area Used (SF)
Basement	7163
1st	443
2nd	443
3rd	443
4th	443
5th	443
Penthouse	19584

Mechanical System First Cost

Information on the first cost for the mechanical system of Building 1 has not been available for this report. However, with a VAV system specified and no special equipment, i.e. enthalpy wheel, the cost of the mechanical system should be relatively normal for a building of this type.

Annual Energy Usage (Design vs. Actual)

No information on actual energy usage from an operating history was available for this report. However, information from previous Technical Reports allows for an examination of the predicted energy performance of Building 1.

The annual energy consumption was calculated using the Trane Trace model. With the exception of the gas-fired burners of the Main AHUs, the entire building is powered by delivered electrical power.

In Table 4 below, energy use for an entire year is compiled and separated into the different types of loads in the building.

Table 4. Annual Energy Consumption

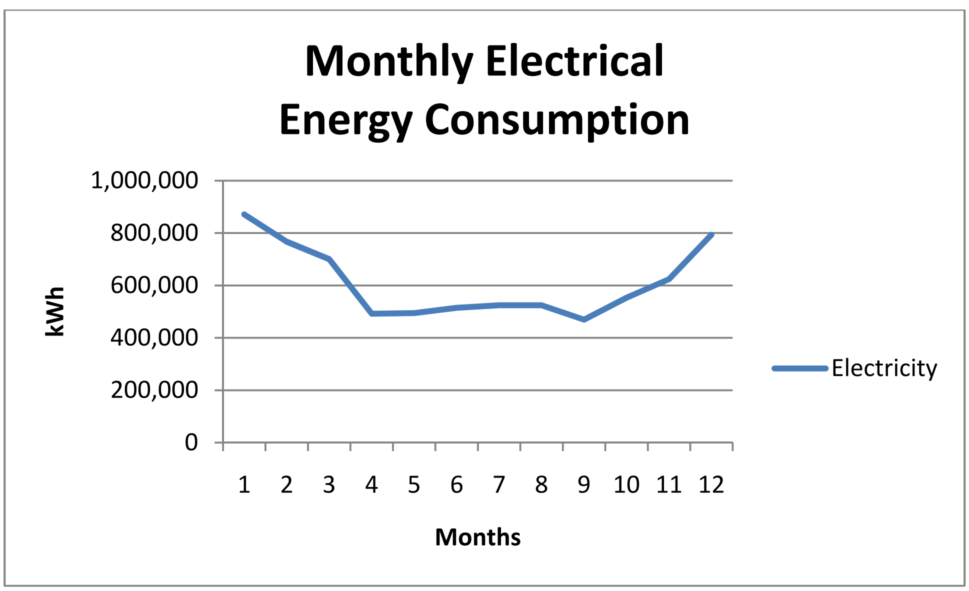
Annual Energy Consumption				
Load	Electricity (kWh)	Natural Gas (kWh)	Total Energy (kWh)	Percent of Total (%)
Heating				
Gas-Fired		49343	49343	0.7
Electric Resistance	2267004		2267004	30.8
Cooling				
Chiller	690820		690820	9.4
Cooling Tower	492072		492072	6.7
Condenser Pump	543487		543487	7.4
Auxiliary				
Supply Fans	107267		107267	1.5
Pumps	401158		401158	5.4
Lighting				
Lighting	1106314		1106314	15.0
Miscellaneous				
Receptacle	1711229		1711229	23.2
		Total	7368694	100

From this analysis, it can be determined that the largest energy load in the building is Heating. This is more than likely due to the building's location along with other factors like the amount of glazing area (40% glazing). Also, the building is oriented north-south-- not a preferable orientation for winter solar gain. It should also be noted that the building is on top of a hill with no wind obstructions around it, which may explain a higher need for heating.

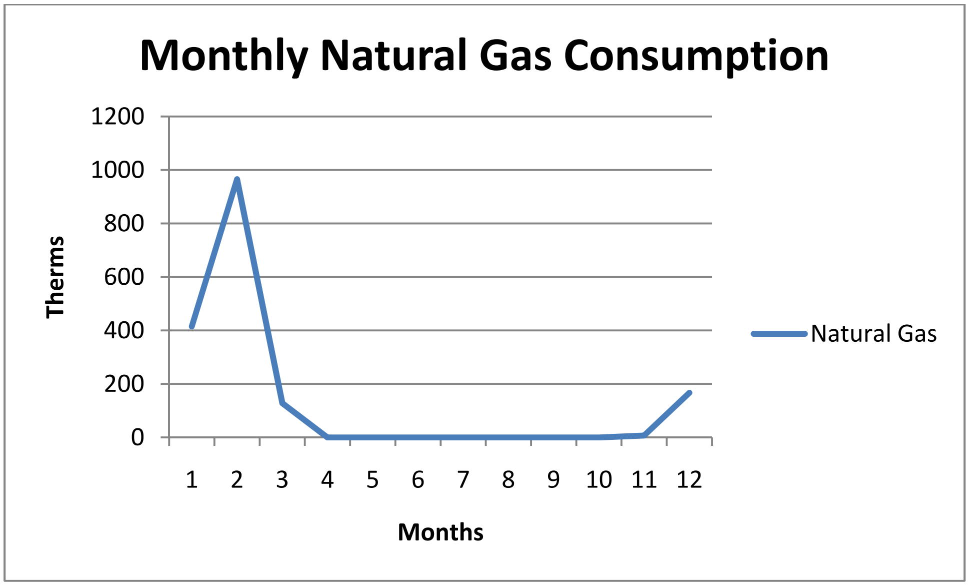
The second largest energy load in the building is the Cooling equipment. This is likely due to the higher amount of computing equipment throughout the building as well as the amount of glazing area.

As seen in Graph 1 and Graph 2 below, the energy usage throughout the year fluctuates with the seasons. The electrical load is peaked during January because of the Heating equipment. The natural gas load is peaked during February again because of Heating needed during the winter months.

Graph 1. Monthly Electrical Energy Consumption



Graph 2. Monthly Natural Gas Consumption



Energy Sources and Rates

The cost per unit of fuel is listed below in Table 5 for winter and summer months. Due to a lack of information from the project's design team, Duquesne Light and Columbia Gas rates were used. Duquesne Light and Columbia Gas were used because they are the largest utility companies in the Pittsburgh region.

Table 6. Utility Cost Information

Utility Cost Information		
Electricity (cents/kWh)		Natural Gas ($/1000FT³)
On-Peak	Off-Peak	Annual Average
7.44	5.07	5.495

Information on alternative energy sources, including district heating and cooling, has no been available for this report. However, the combination of the mechanical system of the Buildings 1, 2 & 3 was considered. The mechanical systems were separated because Westinghouse may not always the tenant in all three buildings. The separation provides other tenants with their own comfort preferences, usage and utility bills. The Trane Trace model estimated that the annual operational cost for Building 1's mechanical system is around $0.73/SF. This figure is comprised of only utility costs; no cost for maintenance has been available.

LEED-NC Evaluation

Information on the LEED-NC evaluation for Building 1's mechanical system has not been available for this report. However, information from the design documents was available and provided a general scope of what LEED points were attained. The building was designed to meet LEED Certified at a minimum under LEED-NC Version2.2. The following LEED credits, that are associated with mechanical systems, are specified in the design documents. Other LEED points are being attained for the project, however they are not listed. These other points are vastly for material and resources.

EQ Prerequisite 1: Minimum Indoor Air Quality Performance Establish minimum indoor air quality (IAQ) performance to enhance indoor air quality in buildings, thus contributing to the comfort and well-being of the occupants.

Meet the minimum requirements of Sections 4 through 7 of ASHRAE 62.1-2004, Ventilation for Acceptable Indoor Air Quality. Mechanical ventilation systems shall be designed using the Ventilation Rate Procedure or the applicable local code, whichever is more stringent. Naturally ventilated buildings shall comply with ASHRAE 62.1-2004, paragraph 5.1.

EQ Prerequisite 2: Environmental Tobacco Smoke Control

Minimize exposure of building occupants, indoor surfaces, and ventilation air distribution systems to Environmental Tobacco Smoke (ETS).

Credit EQ 3.1: Construction Indoor Air Quality Management Plan: During Construction

Reduce indoor air quality problems resulting from the construction/renovation process in order to help sustain the comfort and well-being of construction workers and building occupants.

Credit EQ 3.2: Construction Indoor Air Quality Management Plan: Before Occupancy

Reduce indoor air quality problems resulting from the construction/renovation process in order to help sustain the comfort and well-being of construction workers and building occupants. For this project, all ducts were sealed to prevent any material from entering the system.

Credit EQ 4.1: Low-Emitting Materials: Adhesives & Sealants

Reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.

Credit EQ 4.2: Low-Emitting Materials: Paints & Coatings

Reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.

Credit EQ 4.3: Low-Emitting Materials: Carpet Systems

Reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.

Credit EQ 4.4: Low-Emitting Materials: Composite Wood & Agrifiber Products

Reduce the quantity of indoor air contaminants that are odorous, irritating and/or harmful to the comfort and well-being of installers and occupants.

Credit EQ 6.2: Controllability of Systems: Thermal Comfort

Provide a high level of thermal comfort system control by individual occupants or by specific groups in multi-occupant spaces (i.e. classrooms or conference areas) to promote the productivity, comfort and well-being of building occupants. Provide individual comfort controls for 50% (minimum) of the building occupants to enable adjustments to suit individual task needs and preferences. Operable windows can be used in lieu of comfort controls for occupants of areas that are 20 feet inside of and 10 feet to either side of the operable part of the window. The areas of operable window must meet the requirements of ASHRAE 62.1-2004 paragraph 5.1 Natural Ventilation.

AND

Provide comfort system controls for all shared multi-occupant spaces to enable adjustments to suit group needs and preferences. Conditions for thermal comfort are described in ASHRAE Standard 55-2004 to include the primary factors of air temperature, radiant temperature, air speed and humidity. Comfort system control for the purposes of this credit is defined as the provision of control over at least one of these primary factors in the occupant's local environment.

Credit WE 3.1: Water Use Reduction: 20% Reduction

Maximize water efficiency within buildings to reduce the burden on municipal water supply and wastewater systems.

EA Prerequisite 1: Fundamental Commissioning of the Building Energy Systems

Verify that the building's energy related systems are installed, calibrated and perform according to the owner's project requirements, basis of design, and construction documents.

EA Prerequisite 2: Minimum Energy Performance Required
Establish the minimum level of energy efficiency for the proposed building and systems.

EA Prerequisite 3: Fundamental Refrigerant Management Reduce ozone depletion.

Zero use of CFC-based refrigerants in new base building HVAC&R systems. When reusing existing base building HVAC equipment, complete a comprehensive CFC phase-out conversion prior to project completion. Phase-out plans extending beyond the project completion date will be considered on their merits.

Credit EA 4.0: Enhanced Refrigerant Management

Reduce ozone depletion and support early compliance with the Montreal Protocol while minimizing direct contributions to global warming. No CFC refrigerants use.

Overall Evaluation

The VAV system chosen for Building 1 has been implemented in many office buildings for several decades. This conventional system has been proven to be very effective in most applications.

It is likely that a VAV system was implemented because it has a lower initial cost while still allowing a pursuit of LEED Certification. The system was also implemented for low maintenance costs, easy manageability, and relatively higher efficiency.

Operating cost for the system was estimated by the Trace model to be around $0.73/SF (not including maintenance costs). Even with maintenance costs included, the annual cost should be less the $1.4/SF listed in the Energy Information Agency's 2003

Commercial Buildings Energy Consumption Survey. The most prominent reason for this reduced cost is from the low utility costs of the Pittsburgh area which are considerably lower than the national average.

The cost of maintenance for this system should be relative low. Coupling a VAV System with a Hydronic Loop is very common and the maintenance staff should have no trouble with hardware repair and replacement.

Another cost of a system of this type is that a considerable amount of space is required for routing of ducts. The owner of the Building, Wells REIT II, is leasing the building out to Westinghouse, this lost square footage effects the payback period for the owner significantly—less rentable square footage, less revenue. By downsizing certain components through alternative strategies, the overall building cost could be decreased. Since air has a relatively small heat capacity, by conditioning the spaces through other means, i.e. chilled beams or radiant floors, the ductwork can be significantly downsized. This idea was implemented in the Data Center with the CRAC Units. These units were configured to connect to the Chilled Water loop and would condition the space by re-circulating the air instead of using return air.

With a VAV system, Indoor Air Quality can become an issue. This problem comes from the very nature of the system; that the air delivered to the rooms is a combination of ventilation and return air. If designed or installed incorrectly, modulations of supply airflow by the VAV Boxes can occur with no change in the outdoor air fraction-- resulting in a ventilation air deficiency. Also, if filters are not placed in the correct location and maintained, contaminants from inside the building can be re-circulated to all of the spaces in the building.

When designed, each of the Westinghouse Complex buildings was given chiller plants to more easily separate the leasing space into the three buildings. However, from an overall maintenance perspective, this is harder to maintain as the personnel must go from building to building. Also, each building has N+1 redundancy for its chillers, the cost of which could be reduced through a plant strategy.